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Project Title:

# New Buildings Energy Renovation Business Models incorporating dual energy services

# NOVICE

**Grant Agreement No: 745594**

**Collaborative Project**

## Lifecycle performance of building energy upgrade technologies

| | |
|---|---|
| Deliverable No. | D2.1 |
| Work package | WP2 |
| Task | Task 2.1: Building Energy Supply Technologies for retrofitting<br>Task 2.2: Building Energy Management Systems<br>Task 2.3: Building ICT technologies for DR<br>Task 2.4: Comfort standards and control techniques for DR<br>Task 2.5: Holistic Approach for dual services enabled equipment |
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| No & name | **D2.1: Lifecycle performance of building energy upgrade technologies** | | | | |
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| Author(s) | Olga Macías, Sarah Noyé, Nagore Tellado, Dimosthenis Tsagkrasoulis , Tasos Tsitsanis, Mircea Bucur, Jo Southernwood | | | | |
| Description of the related tasks and the deliverable in the DoW | Task 2.1: Building Energy Supply Technologies for retrofitting. The objective of this task is to provide a deep review of technologies and systems for the energy supply retrofitting of buildings. The task will identify, describe and categorise which technological solutions are in use or near application. In order to reach a user friendly and clear structure, concise descriptions will answer the three main questions: WHAT (short description of the technology/system/tool), WHY (description of advantages and in case disadvantages) and WHEN (conditions under which it works fine). Technical characterisation will be done for each technology and advantages and limitations will be worked out and described. | | | | |
| | Task 2.2: Building Energy Management Systems. The current task will identify the trend in BEMS development and the most popular technologies in the domain of the BEMS and how these technologies fit in the DR business. This task will analyse the BEMS interoperability with DR platforms in order to assess the requirements of BEMS in order to support the DR in buildings. The analysis will be carried out from different point of views: i) interoperability from the point of view of the required functionalities for DR business. How do BEMS support the DR business, existing barriers and drivers; ii) interoperability from the point of view of the communication interfaces. Finally, the reliability and safety of the systems will be assessed. | | | | |
| | Task 2.3: Building ICT technologies for DR. The main aim of this task is to define and evaluate ICT-based technologies that can enable the business realization of the NOVICE Integrated Energy-Contracting Model. To this end, the task will investigate, evaluate and qualify a wide range of ICT technologies spanning from typical Building Energy Management Systems to Control Boxes and individual smart devices, enabling bi-directional communication between the end-user and the ESCO/ DR Aggregator.<br>Such technologies shall enable the definition of prosumer behaviour in the built environment by combining appropriate data streams (energy, environmental, occupancy, air quality), while allowing the extraction of meaningful profiles that incorporate knowledge about occupants' visual and thermal comfort (and their boundaries) and subsequently, their flexibility to participate in human-centric EE/ DR integrated schemes. Qualified technologies need to satisfy the capability to serve highly effective and integrated energy efficiency and demand response strategies, interoperable, real time and standards-based communication with service provider systems, seamless interaction with building occupants and in-home/ building devices, non-intrusiveness and automated operation on the basis of human-centric features.<br>Task 2.3 will describe the state of the art of ICT solutions available for building level deployment (renovation) that lead to a better understanding of user preferences as well as the needed ICT developments to cover domains such as health, metabolic activity etc. that have impact on users' comfort and are not directly linked with the environmental conditions. | | | | |

| | | | |
|---|---|---|---|
| | Task 2.4: Comfort standards and control techniques for DR. Initially a review of existing comfort standards will be carried out, in order to establish the comfort objectives of building users. The control techniques should ensure the comfort conditions while reducing the energy consumption. This task will describe the evolution from traditional control techniques to control techniques based on demand forecasting. The forecasting applied to the satisfaction of comfort standards leads to the capability to predict the peak demand and to react consequently. Task 2.4 will describe how the building uses flexibility in terms of comfort conditions to shift the energy demand and help to schedule energy needs in periods in which the energy is cheaper or the integrity of the distribution grid is not compromised. This forecasting capability applied to DR strategies can enhance the typical event driven DR business to schedule based business models. | | |
| | Task 2.5: Holistic Approach for dual services enabled equipment. T2.5 is informed by the output of T2.1-2.4 Its main objective is to perform a thorough feasibility study on the building retrofit technologies that have been identified in the tasks of WP2 as able to provide both EE and DR in building renovation. Particular combinations of different types of technologies (HVAC, energy storage, BEMS and ICT) will be identified and evaluated for their effectiveness in EE and DR, including the range of DR programs which a particular technology enables the consumer to participate. An economic assessment for each technology kit will be carried out including their costing and comparison, from an investment point of view, with commonly undertaken upgrade interventions. The finding of this task will inform the work of T5.3 on the determination of the technology solution scenarios for quantifying revenue streams from EE and DR services in building renovation. | | |
| Comments | Revision of building Energy Upgrade Technologies for Efficiency and Flexibility | | |
| V | Date | Authors | Description |
| 0.1 | 13.03.2018 | TECNALIA | Version ready for revision |
| 0.2 | 15.05.2018 | TECNALIA | Revised version |
| 1.0 | 23.05.2018 | IERC | FINAL version uploaded to portal |
| 2.0 | 29.07.2019 | TECNALIA | REVISED FINAL version |

## Disclaimer

# Table of Contents

## List of Figures

## List of Tables

## List of Figures

## List of Tables

# 1 PUBLISHABLE EXECUTIVE SUMMARY

This report has been developed within the scope of the NOVICE project, and the report contains all results from WP2, entitled “Building Energy Upgrade Technologies for Efficiency and Flexibility”. The main objective of WP2 is to perform a thorough feasibility study on combinations of building retrofit technologies that can provide both EE and DR in building renovation whilst ensuring user comfort.

The NOVICE project aims to initially implement the dual EE/DR scheme for non-residential buildings. The reasoning behind this decision is that those buildings are commonly of significant size and already display particular features, such as energy management systems, which can lower the installation costs of additional technologies necessary for increased flexibility. The target buildings are therefore offices; hotels & restaurants; educational facilities, warehouse & retail and health facilities.

Two primary types of DR can be implemented in each type of building:

- **Implicit DR** (also called “price-based” DR) refers to consumers opting to be exposed to time-varying electricity prices that reflect the value and cost of electricity in different time periods. Using this information, consumers themselves can decide – or automate the decision – to shift their electricity consumption away from times of high prices and thereby reduce their energy bill.
- **Explicit DR** (also called “incentive-based” DR) refers to the scheme where the flexibility result of DR actions is sold upfront on the electricity markets, either directly from large industrial consumers or through DR service providers, such as aggregators. Consumers receive specific rewards to alter their consumption profile upon request. These requests can be triggered by high electricity demand, flexibility needs, or an anomaly in the network. Explicit DR can thus be used both for economic reasons, as well as in emergency situations, when it is necessary to reduce consumption during times when the power grid is stressed to the point of jeopardizing reliability (Eurelectic, 2015).

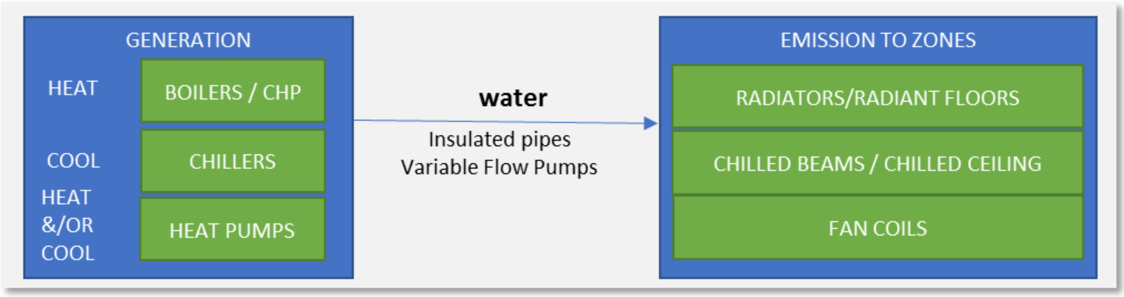
This report examines how the both implicit and explicit DR can be deployed in buildings of different types and the suitability of each strategy in different situations.

The most suitable building systems for DR are centralized electric HVAC systems and electricity generation systems with storage. Systems based on gas as an energy source are also considered here, even though they are less suited to DR because they can have a significant impact on EE and are very common in buildings across Europe.

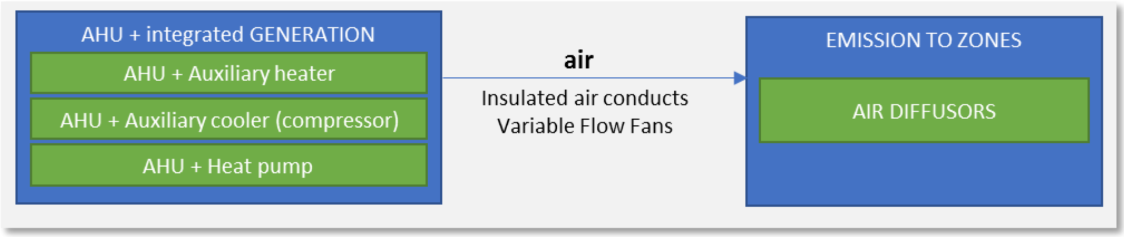
The main characteristic of a centralized system is that heat and cold generation equipment (generation sub-system) are located in a specific plant room. A fluid (e.g. water or air) is used as a means of transporting the energy (hot or cold) throughout the building to all the thermal zones. As a result, in buildings with centralized heating and cooling systems, a distribution sub-system is necessary. The characteristics of the distribution sub-system will vary depending on the fluid used (water, air, refrigerant fluid), but it will be made up of a distribution network (pipes or ducts) and by the elements necessary to generate the movement of the fluid across the network (pumps and fans). Finally, centralized systems include a diffusion sub-system to carry out the final energy delivery to thermal zones according to their specific needs, so that thermal loads are met and heating and cooling demand can be satisfied.

The HVAC systems that have been considered in this study for combined DR/EE strategies are:

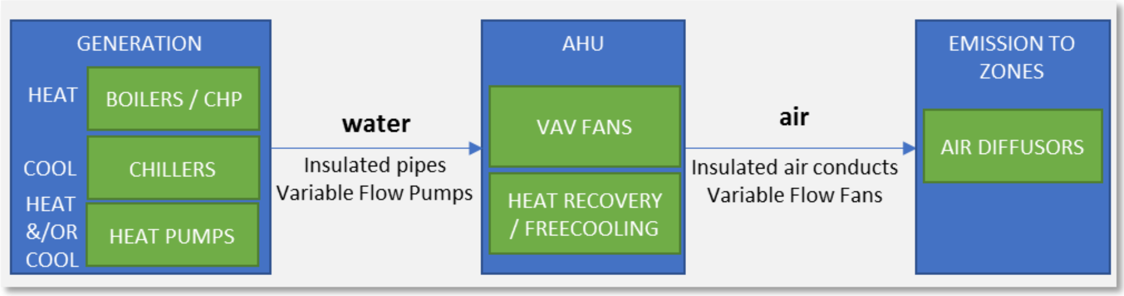
**All water systems,**



**All air systems**



**Water-air systems**



The main strategies for these systems are:

- Control in the Diffusion Subsystem or Thermal Zone
- Control at Distribution Subsystem or AHU if present.
- Control in the Diffusion Subsystem or Thermal Zone

This document describes how the systems can be controlled for implicit and explicit DR strategies.

Distributed energy resources can also play a significant role in DR. Apart from renewable solutions, electric energy storage systems present a potentially important source of load flexibility and increase the ability of each site to consume electricity only at times when lower tariffs are in operation. The electric generation and storage systems that have been considered in this study include: CHP, fuel generators, PV panels and batteries.

Thermal energy generation and storage systems are less suited to DR, but some relevant control strategies can still be implemented. Solar thermal collectors, water tanks and boreholes have been considered as part of this study as ways of collecting and storing heat.

Lighting systems also allow some level of DR. The strategies to be implemented can include more effective user controls, automatic controls based on a time schedule, or daylight or occupancy control. In this case the strategy of load shifting is not possible, as the use of the light is associated with user comfort but modern lighting systems can be dimmed by a few percent in some non-critical areas during a demand response event.

Having identified the key technologies that could be implemented as part of a combined EE/DR strategy, this report goes on to determine the ICT technologies and BEMS tools that would be required to control this equipment. The type of control system required varies depending on whether Implicit or Explicit DR strategies are being considered

Implicit DR requires the installation of a few ICT key technologies within the building. In particular this includes (i) Advanced Metering Infrastructures (AMIs), which, from the point of view of electricity suppliers, allow remote meter reading of consumer-specific usage data, such as instantaneous and interval usage; and (ii), user communication and graphical interfaces that inform consumers of the time-varying tariffs and further assist in the decision-making process regarding load control through suitable energy analytics applications. For Explicit DR, sensors and actuators are required. Sensors are located in the thermal zones to adapt the building to the real use of the building and to assure comfort conditions, but they must also be located in the HVAC equipment and energy storage and generation systems.

The ICT technologies are connected to BEMS systems via a bi-directional communication system that links to other building equipment. This allows the BEMS to use data gathered by the sensors to control equipment actuators and respond to changing conditions. With the advent of DR the BEMS are now required to support further interaction with external sources of information, for example energy suppliers and aggregators, and enable new functionalities such as load aggregation and critical DR event handling.

In order to provide practical information for the DR/EE users, so called “Technology Kits” have been developed. The kits merge together the typical systems existing in buildings with the applicable DR strategies and the required ICT and BEMS solutions for implicit or explicit DR. The kits are a graphical summary of the findings of this report and are intended to assist building owners/managers to select the most appropriate means of implementing DR strategies in their buildings.

The output of WP2, realised in this Deliverable, will serve as input in T5.3 to determine the most feasible and performant renovation scenarios.

# 2 INTRODUCTION

## 2.1 PURPOSE

The purpose of this deliverable is to report on the work performed for WP2 of the NOVICE project. The overall goal of WP2 is to **investigate commercial and non-residential building renovation technologies** that can offer both energy savings and demand response potential. The process covers all aspects including building energy systems, indoor comfort standards, Building Energy Management Systems (BEMS) and Information & Communication Technologies (ICT).

Therefore, the deliverable begins with (i) the identification and assessment of the **building retrofit technologies** focused mainly on building energy supply systems, renewable energy production and energy storage technologies that can provide both energy savings and **DR** potential. This is followed by (ii) a review of **comfort standards** and determination of the comfort bandwidths that can offer DR potential along with the appropriate control techniques that can harvest that potential. Finally the report ends with (iii) the analysis of the building **energy technologies** including **ICT** and **BEMS**, which provide both energy efficiency and flexibility with commonly used interventions.

The building retrofitting, BEMS and ICT technology solutions are identified, described and categorised in a set of technical sheets that accompany this report and include a description of the technology, their advantages and disadvantages, the conditions under which they work well, their maturity, the lifecycle cost and performance.

Results from this step will be the basis for selecting the appropriate retrofitting technologies for the demonstration sites for NOVICE.

## 2.2 CONTRIBUTION OF PARTNERS

**Tecnalia:** Identification of building HVAC technologies and energy storage and generation systems appropriate for EE/DR strategies. Support and assist in the review of comfort standards and the determination of DR potential. And finally, identification of the appropriate technology kits for EE and DR services in building renovation, assessing their life cycle cost.

**IERC:** Review comfort standards and determine the DR potential inherent in them, along with the particular control techniques.

**KiWi Power:** Identification of BEMS technologies and support and assist in the identification of ICT solutions that can offer both EE and DR and along with their technical qualification.

**Hypertech:** Identification of ICT Technologies enabling Demand Side Management and Demand Response. Support and assist in the review of comfort standards, BEMS and the selection of appropriate retrofitting kits.

**e7:** Supports the identification of building supply and ICT technologies, comfort standards and the particular control techniques that can offer both EE and DR, along with the economic assessment and comparison of the new technology kits with conventional retrofit interventions.

**Joule Assets:** Support the research and analysis of the specific requirements for entering particular markets and the specific capabilities created by different technology groups.

## 2.3 BASELINE

For the purposes of Deliverable 2.1, information was extracted primarily from the following sources:

- Deliverable 5.1 which defines the target buildings of NOVICE
- Previous European projects, mainly Enprove and Fiemser
- Scientific papers describing EE and DR retrofitting strategies for building renovation
- Online sources for identification of commercially available technologies

## 2.4 RELATIONS TO OTHER ACTIVITIES

The outputs from the activities of WP2 will be the inputs for the building energy modelling that will be carried out in WP5.

# 3 NOVICE TARGET BUILDINGS

The NOVICE project aims to initially implement the dual EE/DR scheme in non-residential buildings. The reasoning behind this is that non-domestic buildings are commonly of significant size and already display particular features, such as energy management systems, which can lower the installation costs associated with the additional technologies necessary to increase building flexibility. In addition, NOVICE focuses on moderate retrofit actions, comprising of reasonable number of energy efficiency measures, mainly concerning BEMS, DR and controls. In this section, we elaborate further on the assumption of moderate retrofitting and subsequently explore and evaluate the previously described methodologies that are suitable for the deployment of the dual EE/DR program.

A moderate building retrofit project, for the purpose of energy efficiency, commonly involves 3-5 improvements, on elements which have a bearing on energy use, and/or of renewable energy technologies (Economidou, 2011). According to the referenced report, such renovation projects can result in energy usage reductions in the range of 30-60%, at a cost level of approximately €140/m$^2$ (Economidou, 2011). Our purpose is to propose technologies that, within the same renovation scenario, can also provide DR potential. A further point of reference is that NOVICE targets predominantly the tertiary sector, including public buildings (hospitals, schools, universities), hotels, supermarkets, offices, and to a certain extent, industrial premises. The reason for this selection is that potential profits can be greater for those types of buildings, compared to the residential sector. Furthermore, tertiary buildings are more likely to already have certain equipment installed, such as a building management system, thus reducing retrofitting costs. Results from a survey, published in 2013 (Garnier, 2013), on the type Energy Performance Contracting programs offered by utilities and ESCOs, supports the aforementioned choice. As can be seen in Figure 3-1, more than half of the utilities and ESCOs surveyed offer EPC programs for public buildings. Hospitals, offices, universities, hotels and the industry had the next highest percentages.

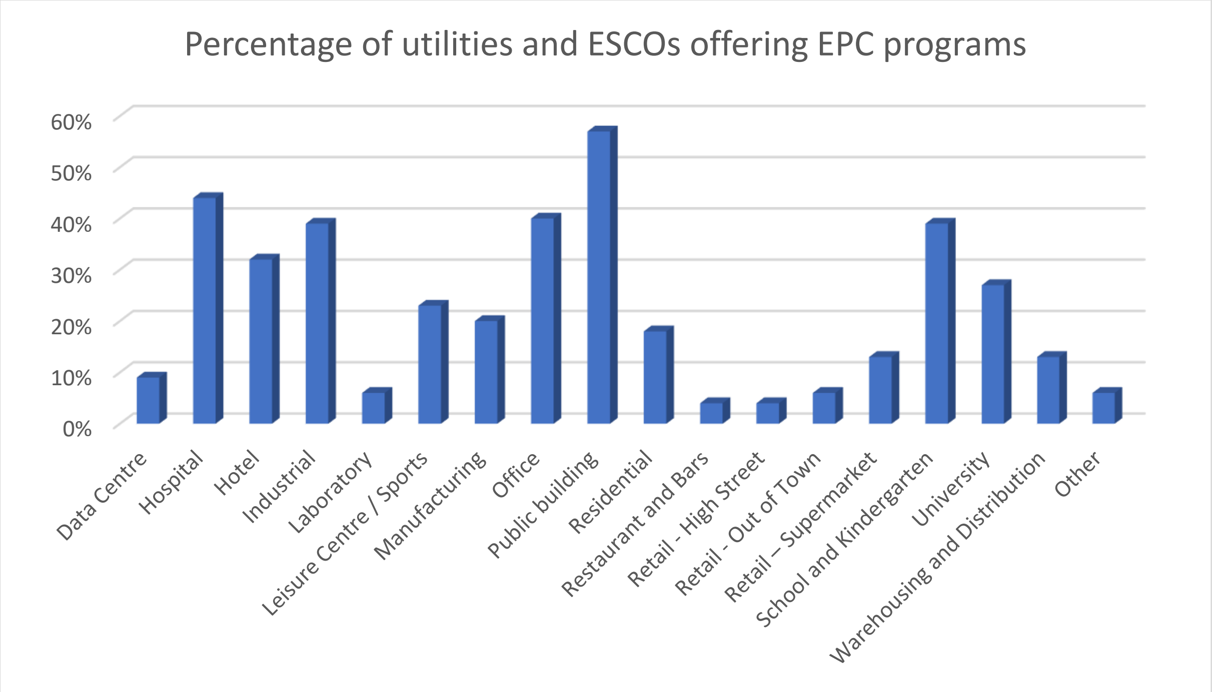


*Figure 3-1 Percentage of utilities and ESCOs offering EPC programs for different building types. source* (Garnier, 2013)

The objective of NOVICE is to introduce retrofitting technologies that will allow both an increase in the EE of buildings and the ability to participate in demand response.

The objective is to examine how best to implement those technologies in the five target building archetypes (offices; hotels & restaurants; educational facilities, warehouse & retail and health facilities) that were identified in Deliverable 5.1 as most suited to DR. Buildings that require renovation to install more efficient systems, and that have potential to participate in DR are the target buildings for the NOVICE project. Nevertheless, in some cases the existing systems will already be energy efficient so only the complements required to allow DR will be necessary. In these buildings the investment associated with EE upgrades will be avoided. In general the energy efficiency renovation measures will focus on upgrades to the energy supply systems because replacing the distribution and diffusion systems would be a too expensive to be cost-effective.

Considering those system as a starting point renovation technologies will be described in order to increase EE and allow DR.

*Table 3-1 Building Systems in the before building renovation*

| | | **BUILDING TYPES** | |
|---|---|---|---|
| | | Offices<br>Hotels & Restaurants<br>Educational facilities | Warehouse & Retail<br>Health facilities |
| HEATING | Generation: **CONVENTIONAL BOILERS:** The most common equipment of heat generation involves the combustion of fossil fuels such as gas or oil. The efficiency of these boilers is around 70%-80%. These boilers produce hot water at constant temperature (around 80 °C) and can't modulate the temperature of the generated hot water to adjust it to the energy demand and to the exterior air temperature. As a consequence, they present the lowest efficiency of all the available boiler types; Distribution: **RADIATORS:** Hot water generated in the boiler, is circulated by pumps through radiators within the building. Radiators can be individually controlled by a central temperature control system or by an individual control system. | X | X |
| | **LOCAL ELECTRICAL HEATERS:** Autonomous systems that work independently. The efficiency of these systems in terms of primary energy is low comparing with the others (convective heating). | X | |
| **COOLING** | **DIRECT EXPANSION SYSTEMS:** In a direct-expansion (DX) unitary system, the evaporator is in direct contact with the air stream, so the cooling coil of the airside loop is also the evaporator of the refrigeration loop. One of the most common reasons for selecting a DX system, especially packaged DX systems, is that, in a smaller building, it frequently has a lower installed cost than a chilled water system because it requires less field labor and has fewer materials to install. | X | X |

| | | BUILDING TYPES | |
|---|---|---|---|
| | | Offices<br>Hotels & Restaurants<br>Educational facilities | Warehouse & Retail<br>Health facilities |
| | **Centralized systems CHILLERS:** They remove heat from water via a vapor-compression or absorption refrigeration cycle. This cool water is distributed by the distribution system to diffusion units (fan coils, radiator, etc.) and to air handling unit (AHU) where the energy is used to condition the thermal zones of the building. According to the type of condenser used in the chiller, the central air-conditioning system is air-cooled (In the condenser the refrigerant flows through the tubes and rejects heat to air that is drawn across the tubes) or water-cooled system (the condenser rejects the heat of the refrigerant to water flowing through it). Air-cooled chillers are usually outside and consist of condenser coils cooled by fan-driven air. Water-cooled chillers are usually inside a building, and heat from these chillers is carried by recirculation of water to outdoor cooling towers. | | X |
| **VENTILATION** | **Mechanical ventilation system** | NO | YES |
| **LIGHTING** | **Type of luminares:** | Incandescent/ halogen/ fluorescent | Incandescent/ halogen/ fluorescent |

# 4 GENERAL CONCEPTS OF DEMAND RESPONSE

Prior to the description of the available technologies for both energy efficiency and demand response, we introduce the notions of Implicit and Explicit DR, and provide an overview of the market status in the EU.

Traditionally, electricity power systems are organized so that supply resources are made to follow demand under all circumstances. This poses significant challenges in the power generation and distribution systems, especially in times and periods of peak energy demand. The situation has been further complicated with the advent of Distributed Energy Resources (DER), which enabled consumers to enter the supply market. One potential solution with good prospects is to reverse the so far established situation, and enable electricity demand to follow the available supply.

Under that premise, Demand Response (DR) is the shifting or shedding of demand for electricity resources during times of electrical grid stress or when the price of electricity is high (see Figure 4-1). (OpenADR, 2012). It encompasses the planning, implementation and monitoring of activities, designed to encourage consumers to change their electricity usage patterns, including timing and level of electricity demand (CIGRE, 2011).

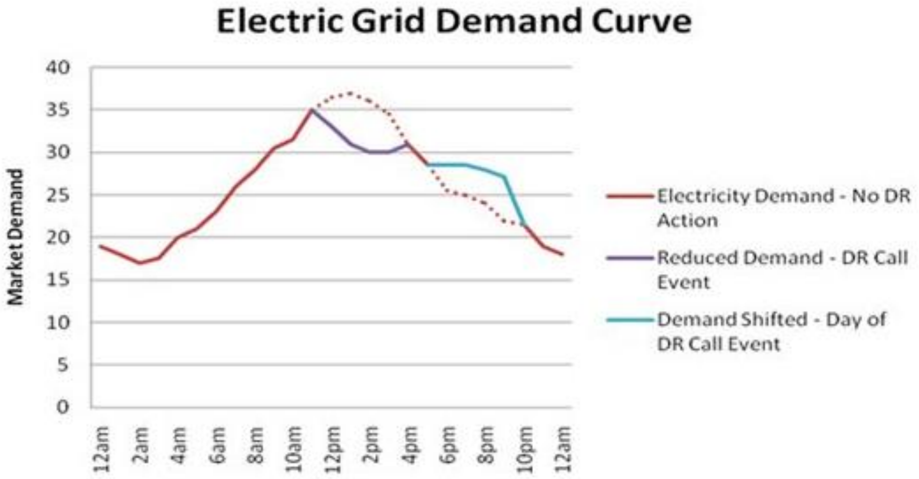


*Figure 4-1 How Demand Response Works. Load shedding and shifting allow better management and equalization between energy supply and demand. Source:* (LaMonica, 2014).

Various DR strategies can be identified. The main differentiation stems from the load control method of operation. The two primary types of DR, i.e. implicit and explicit, are described below. An illustration and examples of specific DR programs are shown in Figure 4-2.

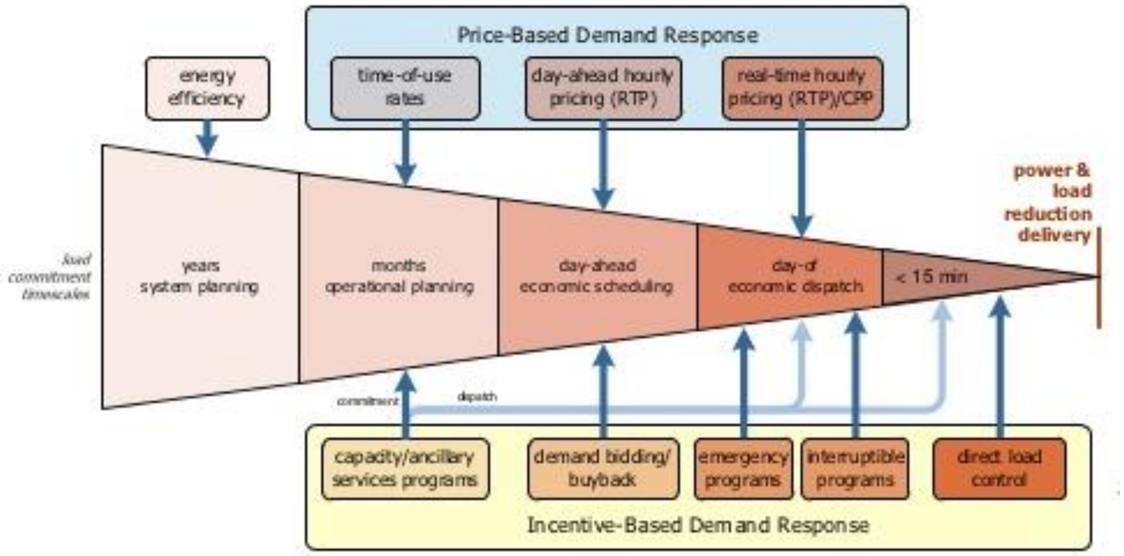


*Figure 4-2 Examples of Implicit and Explicit Demand Response Programs, along with their load commitment timescales. (Source:* DOE, 2006)

## 4.1 IMPLICIT DR

Implicit DR (also called "price-based" DR) refers to consumers opting to be exposed to time-varying electricity prices that reflect the value and cost of electricity in different time periods. Using this information, consumers themselves can decide – or automate the decision – to shift their electricity consumption away from times of high prices and thereby reduce their energy bill. To date, time-varying prices offered by electricity suppliers can range from simple day and night prices to highly dynamic tariffs based on hourly wholesale prices. Examples include time-of-use tariffs, critical peak pricing, and real-time pricing (Eurelectic, 2015).

### 4.1.1 Implicit DR schemes

The main Implicit DR programs/schemes are the following:

#### *4.1.1.1 Time-of-Use*

In Time-of-Use (ToU) tariff programs, electricity cost rates are not flat, but rather change for broad blocks of time. In principle, higher values are encountered when electricity demand is large (as reflected in wholesale prices). Prices for each time period are pre-determined and constant (Eurelectic, 2015; SMARTGRID, 2017).

#### *4.1.1.2 Real-Time Pricing*

In Real-Time Pricing (RTP), also called dynamic pricing, retail prices change continually to reflect the cost of supply in the wholesale markets. Price updates can come as hourly prices set and announced one day in advance to consumers, or real-time pricing directly tracking wholesale market prices (Eurelectic, 2015; SMARTGRID, 2017).

#### *4.1.1.3 Critical Peak Pricing*

Critical Peak Pricing (CPP) enables suppliers to invoke critical events during a specified time period, when they observe or anticipate high wholesale market prices or power system emergency conditions.

While these events last, the electricity prices can be raised by a substantial order of magnitude (Eurelectic, 2015; SMARTGRID, 2017).

#### *4.1.1.4 Critical Time Rebates*

Critical Time Rebates (CTR) operate under the same principle as CPP. Suppliers can raise critical events when they expect high electricity values and/or demand. In contrast to the CPP scheme though, the price for electricity during these periods remains the same. The customer is refunded a predetermined value for any relative reduction in consumption during these events, based on what the utility deemed the customer was expected to consume (SMARTGRID, 2017).

### 4.1.2 Stakeholders in implicit DR

The related stakeholders participating in implicit DR are listed below:

#### *4.1.2.1 Producer*

The Producer's role is to feed energy into the grid. The primary objective of the producer is to operate its assets at maximum efficiency. With regard to DR, its main role and responsibilities remain largely unchanged, although its operating conditions can be significantly affected by the flexible supply/demand, as well as the introduction of renewable energy sources.

#### *4.1.2.2 TSO/DSO*

The Transmission System Operator (TSO) and Distribution System Operator (DSO) manage the transport of the electrical power on the transmission and distribution networks respectively, from production, to high voltage transmission system and finally the consumer. They are responsible for the long-term ability of the transmission and distribution systems to meet reasonable demands for the distribution of electricity, providing system services such as voltage control and network restoration. In that respect, DR can help the TSO/DSO by providing the means for peak load shedding of the system.

#### *4.1.2.3 BRP*

The Balance Responsible Party (BRP) has the active responsibility of continuously balancing supply and demand of energy for its portfolio of producers and consumers. In principle, everyone connected to the grid must ensure that, at each time, the exact amount of energy produced is also consumed. The BRP is contracted by the retailer. The consumers' balance responsibility is transferred to the BRP, who takes over the imbalance risk. Price-based DR programs can implicitly benefit the BRP in their goal to maintain energy balance by reducing peaks in the energy demand curve.

#### *4.1.2.4 Retailer/Supplier*

The Retailer sources, supplies, and invoices energy to its customers. Sufficient energy is sourced either from own power generation units, or, most commonly from the market. In order to maintain balance, they should buy the same amount of energy for any given time period, as their customer's will consume. This obligation is often delegated to a BRP.

#### *4.1.2.5 Consumer*

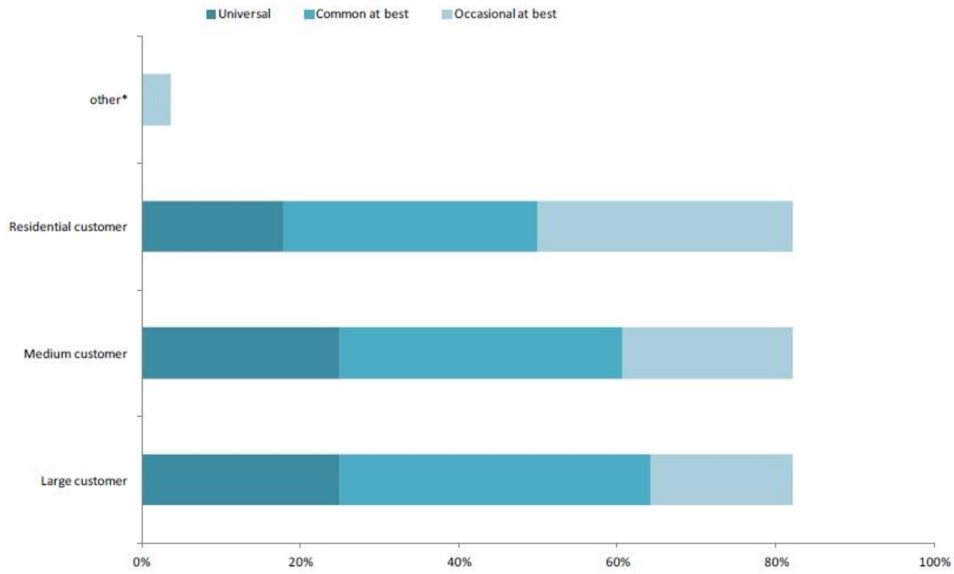
The main objective of the end-user is to consume electricity so as to maintain a desired level of comfort at a minimum cost. In the premise of implicit DR and according to the specific program they participate in, consumers are informed about the electricity price or DR events and are allowed to make their own decision on whether and how to curtail their energy consumption, or incur the increased cost of consumption at each particular time.

#### *4.1.2.6 ESCO*

Apart from the aforementioned entities, another stakeholder that can potentially participate more dynamically in the DR-enabled energy market is the Energy Service Company (ESCO). ESCOs traditionally offer supplementary energy-related services to consumers, such as energy savings, conservation and retrofitting solutions. With the advent of implicit DR, the ESCO can offer further consultation and optimization services based on the time-varying tariffs (DRIP, 2014).

### 4.1.3 Implicit DR status in European countries

According to the 2014 report by the Agency for the Cooperation of Energy Regulators (ACER), time-varying supply tariffs were available to both commercial and residential categories of consumers in about 80% of EU states. These were more frequently used by large and medium consumers than by residential consumers (approximately 55% and 45% respectively in the EU states). Figure 4-3 presents the results on penetration of Implicit DR in EU countries from the aforementioned survey.



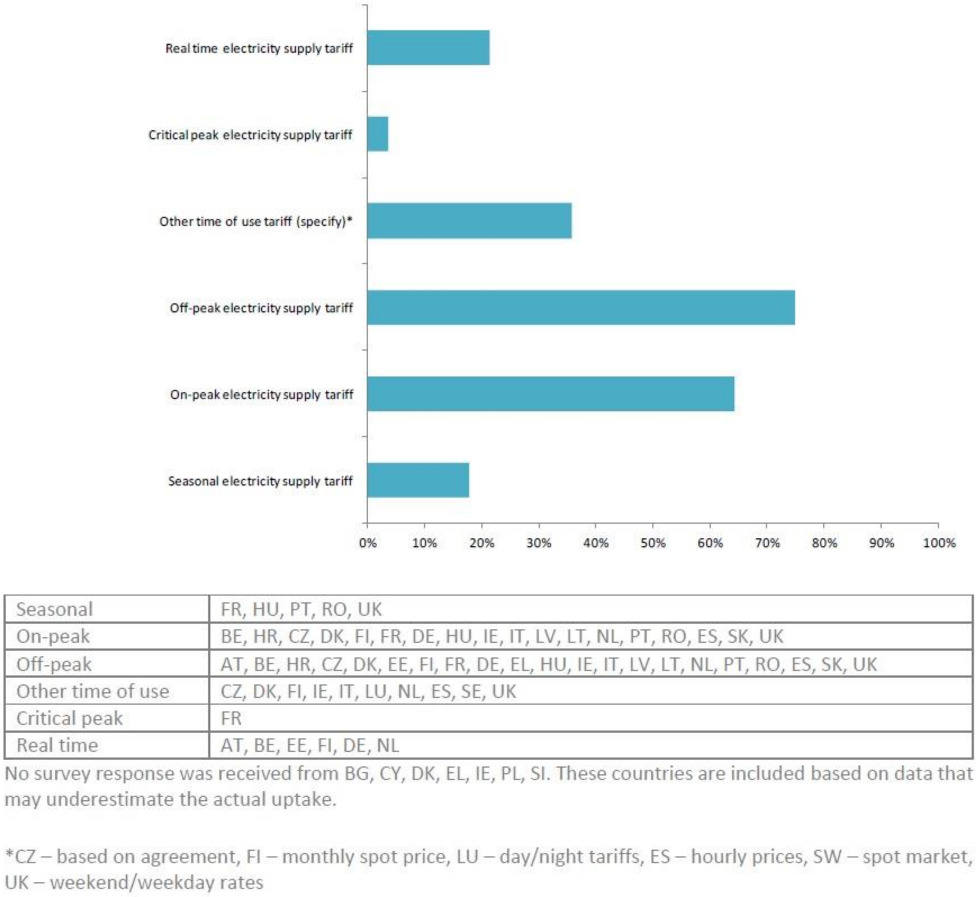
| | Universal | Common | Occasional | None |
|---|---|---|---|---|
| Large | BE, HR, EE, HU, LV, LT, PT | CZ, DK, FI, FR, IE, IT, NL, LU, RO, SK, UK | AT, DE, EL, ES, SE | BG, CY, MT, PL, SI |
| Medium | BE, HR, EE, HU, LV, LT, PT | CZ, FI, FR, IE, IT, LU, NL, RO, SK, UK | AT, DK, DE, EL, ES, SE | BG, CY, MT, PL, SI |
| Residential | HR, EE, LV, LT, PT | BE, CZ, FI, FR, HU, IT, LU, NL, RO | AT, DK, DE, EL, IE, ES, SE, SK, UK | BG, CY, MT, PL, SI |
| Other* | | | HU | |

No survey response was received from BG, CY, DK, EL, IE, PL, SI. These countries are included based on data that may underestimate the actual uptake.

*Hungary: Non-residential customers with connection capacity not exceeding 3x63A and public institutions

*Figure 4-3 Percentage of availability of Implicit DR programs in EU states. "Occasional" implies that time-varying tariffs are in principle available in those countries. Source* (ACER, 2014)

With respect to the types of Implicit DR programs encountered in the market at the time of the ACER study, varieties of ToU schemes were the most widely used, such as on-peak, off-peak tariffs (e.g. day/night or weekend/weekday rates), with approximately 60-70% of countries using them. Other ToU schemes, including RTP were also used in 30-40% of the EU states. In contrast, programs based on critical events were considerably underutilized, employed in less than 10% of the surveyed countries (ACER, 2014). Figure 4-4 shows the detailed results from the ACER study.



| | |
|---|---|
| Seasonal | FR, HU, PT, RO, UK |
| On-peak | BE, HR, CZ, DK, FI, FR, DE, HU, IE, IT, LV, LT, NL, PT, RO, ES, SK, UK |
| Off-peak | AT, BE, HR, CZ, DK, EE, FI, FR, DE, EL, HU, IE, IT, LV, LT, NL, PT, RO, ES, SK, UK |
| Other time of use | CZ, DK, FI, IE, IT, LU, NL, ES, SE, UK |
| Critical peak | FR |
| Real time | AT, BE, EE, FI, DE, NL |

No survey response was received from BG, CY, DK, EL, IE, PL, SI. These countries are included based on data that may underestimate the actual uptake.

*CZ – based on agreement, FI – monthly spot price, LU – day/night tariffs, ES – hourly prices, SW – spot market, UK – weekend/weekday rates

*Figure 4-4 Types of Implicit DR programs used in EU states. Source* (ACER, 2014)

### 4.1.4 Explicit DR

Explicit DR (also called “incentive-based” DR) refers to the scheme where the flexibility result of DR actions is sold upfront on electricity markets, either directly from large industrial consumers or through DR service providers, such as aggregators. Consumers receive specific rewards to alter their consumption profile upon request. These requests can be triggered by high electricity demand, flexibility needs, or an anomaly in the network. Explicit DR can thus be used both for economic reasons, as well as in emergency situations, to reduce load during times when the power grid is stressed to the point of jeopardizing reliability (Eurelectic, 2015).

Explicit DR is tightly associated with the concept of automated DR, which, in turn, relates to the level of DR decision-making automation. Explicit DR programs usually include the ability of the supplier of such services to have certain direct control over equipment on the consumer side, such as management systems, air conditioners and water heaters, on short notice (OpenADR, 2012). Specific hardware and communication infrastructure, not necessary for implicit DR, needs to be provided so that loads can be externally and remotely controlled for the set of DR actions (IEA, 2015).

### 4.1.5 Explicit DR schemes

Explicit DR programs are predominantly subcategorized according to the energy market they are applied in, and their consequent load commitment timescales. The main types of programs are listed below (ACER, 2014; Bertoldi, Zancanella, & Boza-Kiss, 2016; SEDC, 2017)

#### *4.1.5.1 Capacity Markets and Remuneration Mechanisms*

Capacity remuneration mechanisms (CRMs) were introduced by certain countries as a means of ensuring that a sufficient amount of electricity capacity will always be available. In capacity markets, the total required capacity is set over a time frame of months or even years. Capacity providers participate in the auction which results in capacity agreements, delineating the providers' obligations and the level of capacity payments that they receive. The costs are charged to the energy suppliers who in turn charge end consumers (ACER, 2013). Explicit DR flexibility is particularly suited for participation in the capacity market and CRMs in general, earning its value by reducing network peak demand (ACER, 2014).

#### *4.1.5.2 Wholesale Markets*

Wholesale electricity markets are where retailers look to trade sufficient energy in order to supply their customers. Wholesale is commonly performed in future day ahead markets, as well as intraday markets where electricity is sold 15-60 minutes prior to consumption time (Bertoldi et al., 2016). When wholesale markets are closed, the TSO is then responsible to maintain continuous balance to the micro second prior to consumption, based on balancing markets and ancillary services (see below). Due to the fact that explicit DR can provide reliable and measurable capacity, it is possible to participate in the wholesale markets, alongside power generation (Bertoldi et al., 2016; SEDC, 2017).

#### *4.1.5.3 Balancing Markets and Ancillary Services*

Balancing describes the situation after wholesale markets have closed, and a TSO acts to ensure that demand is equal to supply, in and near real time, in order to deal with intermittent sources of generation and network demand congestion (Entso-e, 2017). Ancillary services refer to the range of available options that the TSO can rely on so as to guarantee system stability. Examples include black start capability, which enables a grid restart after a blackout), as well as primary, secondary and tertiary frequency control, which guarantee the re-establishment of system stability automatically within seconds or minutes (Bertoldi et al., 2016). Explicit DR is particularly suited to the requirements of the balancing market, since response times to events can go down to as little as a few seconds. The balancing market was the first market in which DR capacity participated (Bertoldi et al., 2016).

### 4.1.6 Stakeholders in explicit DR

Participants and stakeholders in Explicit DR schemes include but are not limited to the entities described in the corresponding section regarding Implicit DR. Here we present the roles of previously described stakeholders in explicit DR, and describe the new stakeholders, aggregators and prosumers:

#### *4.1.6.1 Producer*

The role of the producer does not change significantly in explicit DR schemes. One concern though, that is usually tied to such programs, concerns the ability of consumers to generate their own power through Distributed Energy Resources (DER), and thus compete with traditional producers.

#### *4.1.6.2 TSO/DSO*

For TSOs and DSOs, Explicit DR can prove an invaluable tool for energy flow optimization in the grid. It can enhance the ability to transport energy more reliably with the same physical infrastructure, as well as allow the operators to provide more secure long term plans on network capacity.

#### *4.1.6.3 BRP*

BRPs operate under the same role and requirements here. Explicit DR can offer further advantages in their quest for energy balance, since BRPs can also rely on the contracted capacity flexibility offered by consumers.

#### *4.1.6.4 Aggregator*

Central in the Explicit DR scenario, the Aggregator’s role is to accumulate capacity flexibility from consumers/prosumers and sell it to the BRP or the DSO/TSOs. The objective of this stakeholder is to profit from the contracted flexibility by providing it in markets that are in most need for it, such as the balancing and capacity markets. The existence of the Aggregator is deemed necessary in order to alleviate flexibility uncertainty issues related to individual consumers. In tandem, the aggregator prevents consumers from facing the complexity and risks of direct participation in the markets.

#### *4.1.6.5 Retailer/Supplier*

The retailer assumes the same role as in Implicit DR. Potential benefits can be realized through the interplay between consumers, aggregators and retailers, since, depending on the business model, the capacity flexibility could also be invoiced through the retailer.

#### *4.1.6.6 Prosumer*

The prosumer is an extension of the traditional end-user, which not only consumes, but also produces energy through DER. While prosumer capabilities are not bound to Explicit DR, or DR in general, the information and communication infrastructure necessary for Explicit DR, can also help DER realize their full potential in the energy supply chain.

#### *4.1.6.7 ESCO*

ESCOs can potentially participate in the more complicated Explicit DR scene, by providing appropriate auxiliary services, again including portfolio optimization for their customers, as well as more tailored energy management amenities.

A diagram highlighting the various stakeholders and their interactions for realization of explicit DR, extracted from the USEF framework (see below), can be seen in Figure 4-5 (USEF, 2015a).

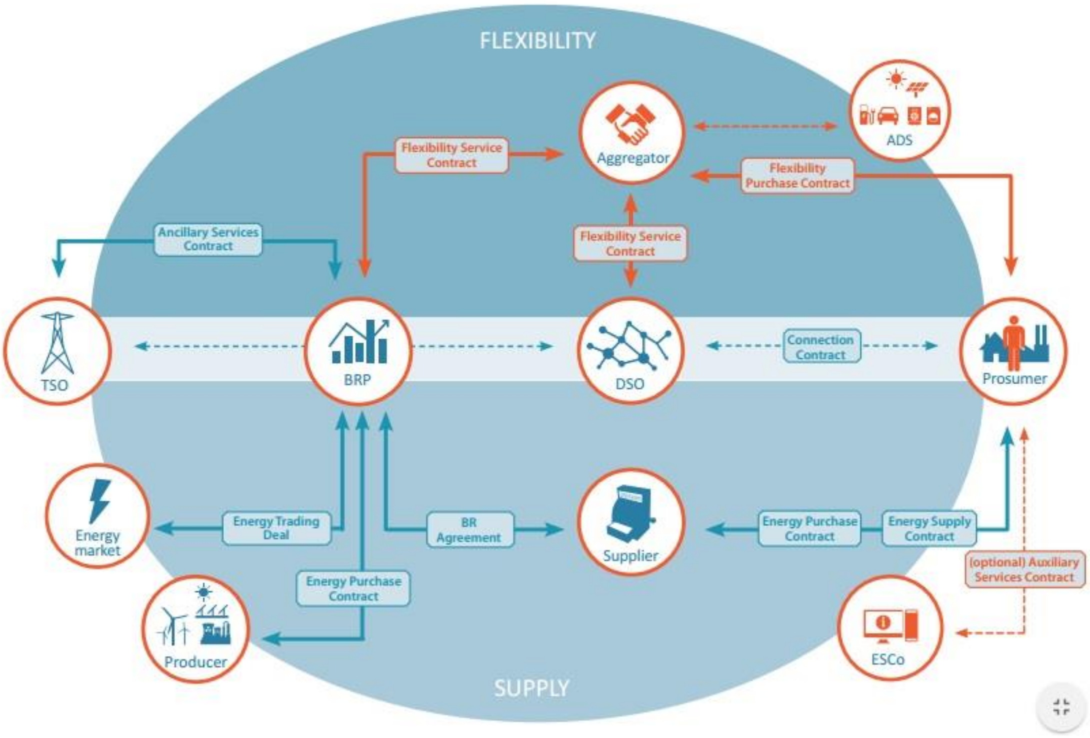


*Figure 4-5 Stakeholders and USEF proposed interactions between them for the realization of explicit DR. Source:* USEF, 2015a

#### 4.1.7 Explicit DR status in European countries

Surveys and reports on the status of Explicit DR in Europe have been presented, and are actively updated, from various organizations. Here we will summarize recent reports presented by three such bodies.

In a report published by the Agency for the Cooperation of Energy Regulators (ACER) in 2014, 28 EU member states were surveyed with regards to explicit DR penetration in the energy markets. Participation in the capacity markets, and generally in CRMs, was the least well exploited type of DR program, with only nine countries operating or planning to operate such mechanisms. Detailed results can be seen in Appendix 13.1. Wholesale market participation showed greater potential, with approximately 60% of surveyed countries having allowed, or planning to allow, demand resources in the markets directly. The results were similar with regards to the balancing markets, although fewer countries had existing or planned allowance of participation in the ancillary reserves (ACER, 2014).

In a more recent report by the European Commission's Joint Research Centre (JRC), published in 2016, the status of explicit DR in the 28 EU states was again assessed. In summary, three groups of states were recognized. For one, Belgium, France, Ireland and UK were the four countries that have enabled DR participation in at least some markets, as well as independent aggregation. The second group, consisting of Germany, the Nordic countries, Netherlands and Austria, have enabled DR market participation, although aggregators were not able to offer services directly to consumers, but rather to retailers and BRPs. Finally, the big group of countries comprising of Portugal, Spain, Italy, Croatia, the Czech Republic, Bulgaria, Slovakia, Hungary, the Baltics, Cyprus and Malta, Poland and Greece, was recognized as not seriously engaged in the necessary reforms to enable DR. Specifically, regulations allowing DR participation in the markets are not available, the roles of aggregators and DR service providers are not defined and there is no way to measure, pay and sell these resources. (Bertoldi et al., 2016).

Finally, the Smart Energy Demand Coalition (SEDC) published a 2017 report reviewing the regulatory structure for explicit DR in 18 European countries, as an update to its 2015 survey. In summary, they noticed a general increase in interest in most countries with respect to explicit DR, compared to their previous survey (SEDC, 2015, 2017). A colormap highlighting the status of explicit DR in the examined countries, according to the SEDC evaluation, can be seen in Figure 4-6.

In more detail, Switzerland, France, Belgium, Finland, Great Britain and Ireland were deemed to be in the most advanced stages of explicit DR incorporation, although further regulatory improvements could be performed. Austria, Denmark, Germany, Netherlands, Norway, and Sweden were identified to still possess regulatory issues regarding DR incorporation to the markets. Finally, Slovenia, Italy and Poland were reported to initiate changes in their regulations to enable DR, while Spain, Portugal, and Estonia either do not accept DR capacity in their markets, or do not have the regulatory framework to do so (SEDC, 2017).

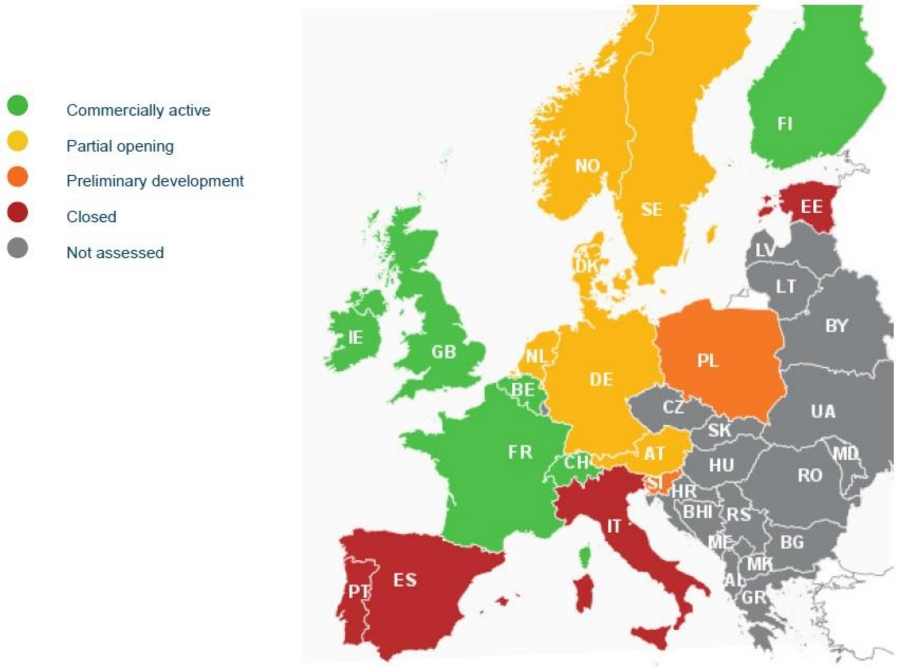


*Figure 4-6 Explicit DR status in 14 European Countries, based on the SEDC report. Source* (SEDC, 2017)

# 5 TECHNOLOGIES FOR BUILDING ENERGY RETROFITTING

## 5.1 INTRODUCTION TO HVAC TECHNOLOGIES FOR EE/DR

Heating, ventilation and air-conditioning (HVAC) accounts for almost half of the EU's energy consumption. Based on recent reports by the European Commission, in industrial applications 70.6% of energy consumption was used for space and industrial process heating, 26.7% for lighting and electrical processes such as machine motors, and 2.7% for cooling. In residential buildings, heating and hot water accounted for 79% of total building energy use. Although cooling currently accounts for only a small amount of residential energy consumption, demand is rising during the summer months (EC, 2016). It is clear that load control of HVAC systems can offer significant benefits in terms of both EE and DR, and this can be achieved by intelligent gathering of information and control of energy usage.

The function of the HVAC system of a building is to deliver to all its thermal zones the necessary heating and cooling required to maintain the specified comfort conditions. Depending on the installed HVAC system, the way in which this primary function is met varies, but generally speaking, a fuel (gas, oil, biomass, electricity, etc.) is converted into heat or cold, which is distributed around the building and transferred to the conditioned zones according to their specific heating and cooling demands.

HVAC systems therefore include the following 3 specific sub-systems which work together to deliver the required thermal conditions in a building:

- Generation sub-system
- Distribution sub-system
- Diffusion sub-systems

As detailed later in this report, the generation and diffusion sub-systems are present in all the HVAC systems however the distribution sub system is only present in centralised HVAC systems. Generally speaking, HVAC systems can be classified according to the centralization level and according to the fluid used to deliver energy.

With respect to the first criteria, HVAC systems are divided into centralized systems and decentralized systems.

#### *5.1.1.1 Centralized systems*

The main characteristic of a centralized system is that heat or cold generation units (e.g. boilers and chillers) are located in central plant rooms. Usually, the generation subsystem is formed by a heat generator and a cold generator, each including the adequate number of units to satisfy the demands of the building in a flexible way, so that the efficiency of the generation is maximized.

Centralized systems require the use of a fluid as a means of transporting the energy (hot or cold) around the building to all the thermal zones. As a result, in centralized systems a distribution sub-system is necessary. The characteristics of the distribution system will vary depending on the fluid used (water, air, refrigerant fluid), but it will be formed by a network of pipes, ducts, pumps and fans.

*Figure 5-1: Hot water generation plant (condensing boilers)*

Finally, centralized systems include a diffusion sub-system to carry out the final energy delivery to thermal zones according to their specific needs, so that thermal loads are met and heating and cooling demand satisfied. This sub-system will be formed by diffusion elements placed at zone level that will make use of the energy stored in the distribution fluid to condition thermal zones. The diffusion elements chosen will depend largely on the distribution fluid and will determine the prevalent diffusion mechanism (convection or radiation). Further details about diffusion elements will be given later in this report.

#### *5.1.1.2 Decentralized systems*

In contrast, the main characteristic of decentralized HVAC systems is the absence of separate heating and cooling generation plant. Generation is integrated into the diffusion equipment and placed at zone level, so there is no need for a distribution sub-system. The system HVAC system for each zone is then completely independent from that of other zones.

The main advantages of decentralised systems are their ability to adapt to any thermal requirements, the lower cost of the equipment and its installation and reduced space requirements. However, those advantages come at the expense of:

- Over-sizing the installed heating and cooling elements
- Inferior efficiencies compared to a centralized systems

With the exception of multi-split systems, other decentralized systems are only enabled to condition one single zone.

#### *5.1.1.3 Classification according to energy distribution and delivery fluid:*

With respect to the second classification criteria (delivery fluid), ASHRAE classify HVAC systems as follows (ASHRAE, 2008):

- All water systems.
- Water-air systems
- All air systems.
- Direct expansion systems (DX systems)

**In all water systems,** thermally treated water is pumped to the thermal in the building via a network of pipes. In the case of water systems, diffusion elements make use of the energy delivered by this water to condition the air of the zones by convection (fan coils, induction units, radiators, etc.), or to heat or cool the thermal mass of the zones (under floor heating, chilled ceiling, etc.) so that this energy is slowly released by radiation.

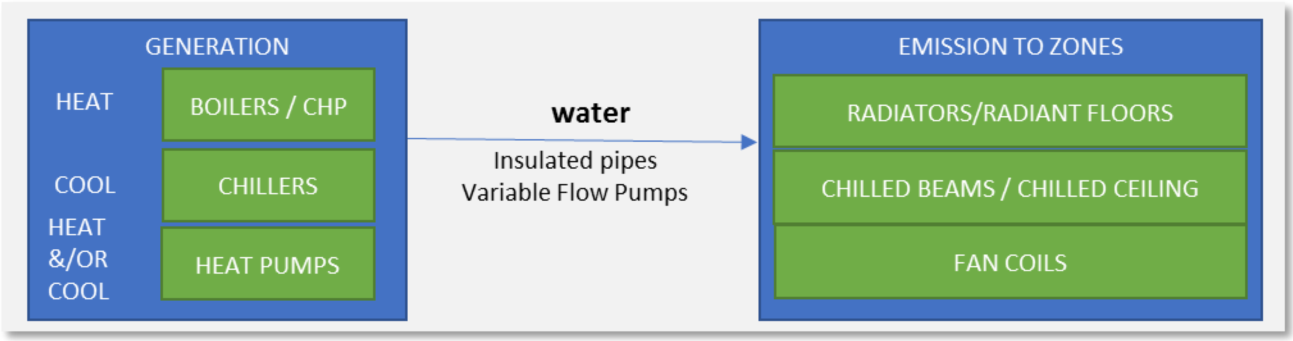


*Figure 5-2 – All water system*

The main advantages and disadvantages compared with other types of centralized systems are:

- Less space requirements to install the distribution pipe network.
- Lower energy consumption associated with energy distribution (the water flow rate in an all water system is significantly smaller than the air flow of an equivalent air system).
- Greater flexibility to define independent thermal zones in medium and small rooms.
- In order to adequately ventilate the building, it is often necessary to include an all air system in parallel to the water system (primary air handling unit)

**All air systems** present the following advantages and disadvantages with respect to other centralized systems.

- With a single system it is possible to satisfy all heating, cooling and ventilation needs.
- Greater space requirements to install the network of ducts
- Higher energy consumption due to the high volume of air distribution.

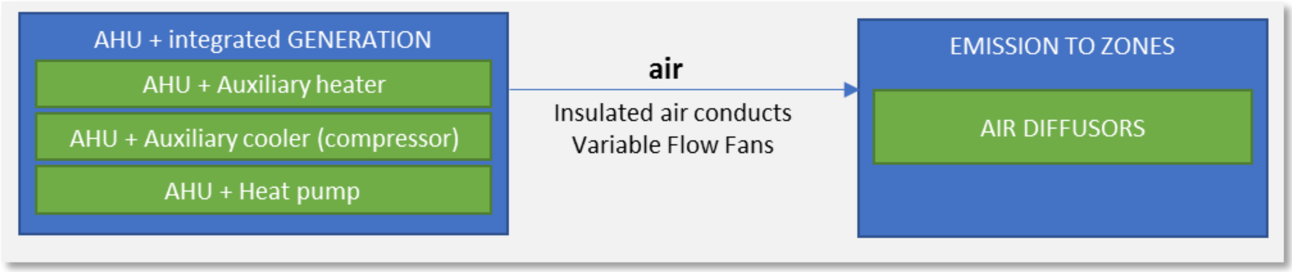


*Figure 5-3 – All air system*

In the case of these systems, the diffusion sub-system is formed by constant or variable air volume (CAV or VAV) boxes, diffusers (supply air) and exhaust grilles (exhaust/return air). In some cases, CAV and VAV boxes include additional heating (electric or hydronic) and cooling (hydronic) coils, to perform a final adjustment of the air temperature before its delivery to the thermal zones. A final quality of the all air system is that the energy delivery to the zones can only be performed by convection.

For ventilation purposes, the air treatment in other systems is performed at zone level (by fan coils, etc.), but in the case of all air systems it is carried out, at least partly, in a centralized form at air handling unit level.

**Water-air systems** combine the advantages of all water and all air systems. A primary water system supplies hot/cold water to a secondary air system that distributes the conditioned air to the thermal zones. The hot water can be generated by boiler, CHP or heat pumps, while the cold water can come for a chiller or a heat pump. The hot/cold water supplies the coils of an AHU were the air is treated before being sent to the occupied zones.

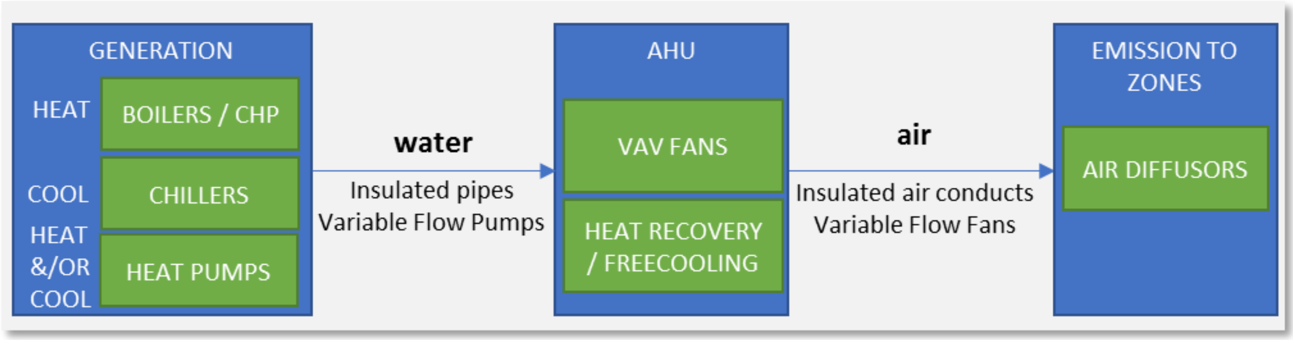


*Figure 5-4 – Air-water system*

The main advantages and disadvantages of an air-water system are:

- Reduced space (smaller air ducts) compared to an all air system while satisfying heating, cooling and ventilation needs.
- Temperature control is more difficult that with all water system, because water and air temperatures need to be managed carefully.
- Because this type of system is more complex, it tends to be more expensive.

In the following paragraphs, further details are given for the systems at three levels: the energy generation sub-system, the distribution sub-system and the diffusion sub-system located.

Generally speaking, **direct expansion systems** are not centralized system. In these systems, the elements that form the refrigerant fluid are separated in two units. The exterior unit, where the condenser of the cycle is placed, and the interior unit that includes the evaporator of the refrigeration cycle.

A variant of these systems are multi-splits systems that work on the same principle, but each exterior unit is connected to several interior units. This feature makes it possible to access a limited level of centralization. There are two aspects that limit the centralization potential:

- The maximum feasible length of refrigerant fluid pipes (25 m)
- The maximum amount of interior units that can be linked to an exterior unit. It is evident, that the maximum number of thermal zones that a multi-split system can supply is limited by the number of interior units.

## 5.2 HVAC CENTRALIZED SYSTEMS FOR DR

### 5.2.1 Description of the technologies

### *5.2.1.1 Generation sub-System*

#### 5.2.1.1.1 Hot water generation sub-system

As previously mentioned the hot water generation system will usually comprise of a group of water generators (not necessarily of the same type), adequately sized and sequenced so that the operating hours of individual units is optimised and the efficiencies are maximized. The generated hot water is then distributed around the building by the distribution sub-system to the diffusion units (radiators, fan coils, etc.) and AHUs of the HVAC system. In the following paragraphs, a summary description of the main types of hot water generators is given:

- CONDENSING BOILERS

Condensing boilers consume gas, rather than electricity which makes them less suited to DR opportunities, however, they are the most efficient type of boiler on the market. In a conventional boiler more than 10% of the total energy input is lost as latent heat via water vapour in the combustion flue gases. If the water vapour is condensed out of the flue gases, usable latent heat is released and can be returned to the heating fluid. It is important that the materials used in the condensing part of the boiler are not sensitive to corrosion from the acidic condensation products. Furthermore, the target flow temperature of condensing boilers can be adjusted according to the heating demand and exterior temperatures which prevents overheating and reduces overall energy consumption. They incorporate modulating burners that are usually controlled by an embedded regulation system with built in logic to control the output of the burner to match the load and give the best performance. These features typically give condensing boilers an efficiency of around 90%.

- **HEAT PUMPS**

Heat pumps are able to force heat to flow from a low temperature heat source to a higher temperature heat sink using the vapour compression refrigeration cycle. In this way they can transfer heat from natural sources in the environment such as outside air, ground water, or waste heat to a building to raise its internal temperature. Reversible heat pumps can also be used for cooling, where heat is transferred in the opposite direction (i.e. from the inside of the building to the outside).

Heat pumps run most efficiently when there is only a small temperature difference between the heat source and the heat sink. Therefore, heat pumps are usually coupled with low temperature distribution and diffusion systems such as under floors heating or chilled ceilings. (for heat pumps that produce thermally treated water).

The majority of heat pumps work on the principle of the vapour compression (reversible) refrigeration cycle which uses electrically operated compressors and pumps to drive the cycle. However, heat pumps can also use the absorption cycle which is a more complex system driven by thermal energy rather than an electrically operated motor or engine. Absorption heat pumps are often fired by gas, but other heat sources - including waste heat - can also be used.

Heat pumps can be classified by their heat source, and by the fluid used for energy distribution throughout the building. Thus air source heat pumps extract heat from outside air, ground source heat pumps extract heat from the ground and water source heat pumps extract heat from a body of water such as a river or tidal lake. Air-water heat pumps extract heat from outside air and use it to heat water which is pumped through the building heating system. Air-air heat pumps extract heat from the outside air and use it to directly heat the air inside the building. Water-water or water-air heat pumps work in the same way but extract their heat from a water source rather than the air.

#### 5.2.1.1.2 Cold water generation sub-system

The cold water generation sub-system consists of cooling plant that will be composed of an adequate number of cold water or cold air generators with optimized nominal powers and sequencing. The energy source can be either gas or electricity.

Two types of cold water generators can typically be found in office buildings:

- **CHILLERS**

Chillers remove heat from water using the vapour-compression or absorption refrigeration cycle. The chilled water is transported by the distribution system to diffusion units (fan coils, radiators, etc.) and to air handling units (AHU) where the energy is extracted and used to condition air in the thermal zones of the building.

According to the type of condenser used in the chiller, the central air-conditioning system can be either air-cooled (where the refrigerant flows through tubes and rejects heat to outside air that is drawn across them) or water-cooled system (where the condenser rejects the heat of the refrigerant to water flowing through it). Air-cooled chillers are usually located outside and consist of condenser coils cooled by fan-driven air. Water-cooled chillers are usually located inside a building, and heat from these chillers is carried by recirculation of water to outdoor cooling towers.

*Figure 5-5: Cool water cooling plant. Air condensed water chillers.*

- **AIR CONDITIONER**

Air conditioners work on the same principle as heat pumps, but operate in cooling mode only. As with heat pumps, cold water can be produced using air or water as a heat sink.

#### 5.2.1.1.3 Hot water and cold water generation sub-system

- **SYSTEMS WITH BOILERS AND CHILLERS**

To generate both hot and cold water in a centralized system, the traditional approach is to use a combination of boilers and chillers depending on the load requirements. The two systems are then independent.

- **REVERSIBLE HEAT PUMPS**

As described in Section 5.2.1.1.1, heap pumps can be reversible and thus provide cooling in addition to heating, although not at the same time. Reversible heat pumps use a reversing valve to change the direction of flow and the heat source and heat sink are exchanged. In cooling mode, an air-water heat pump removes heat from the inside and release it to outside air, while a water-water heat pump releases the heat to the water source.

##### 5.2.1.1.4 Hot air and cold air generation sub-system

Heat pumps can also be used to heat and cool the air directly via an air-air or a water-air unit. If the heat pump is reversible, it can provide both heating and cooling of indoor air. Air-air heat pumps use air as a heat or cool source and is used to condition air directly while water-air heat pumps use water as the heat or cool source.

#### *5.2.1.2 Ventilation systems*

The objective of the ventilation system is to control indoor air quality by extracting stale air containing indoor pollutants and replenish it with fresh air from outside. Uncontrolled ventilation results in high energy consumption because the fresh air brought into the building needs to be heated or cooled to maintain thermal comfort of building occupants. Mechanical ventilation with heat recovery allows building air tightness standards to be maintained by extracting heat from stale air leaving the building and using it to preheat the fresh air coming into the building. **Mechanical ventilation with heat recovery** is commonly used in energy efficient buildings. In residential buildings this is usually a standalone system but most tertiary buildings will already include some form of mechanical ventilation with heat recovery.

#### *5.2.1.3 Distribution sub-system*

##### 5.2.1.3.1 All water systems

As already mentioned above, when the distribution system is water based, a network of pipes is necessary to distribution hot or cold water. The distribution sub-system connects the energy generation sub-system with energy diffusers in each room of the building.

The distribution sub-system also includes all the required pumps that control the distributed water flows. Those pumps can have a variable speed control that allows continuous adjustment of the water flow rate according to the heating and cooling demands of the building. This improves the overall efficiency of the HVAC system. When the cooling plant of the building includes water cooled chillers or heat pumps, additional condenser pumps are necessary to circulate water to the cooling towers across the condensation fluid loop.

##### 5.2.1.3.2 All air systems

In the case of all air systems the distribution subsystem will consist of air handling units (AHU) and CAV and VAV boxes that will deliver thermally treated air through the corresponding duct network to the diffusion elements placed at zone level. An air handling unit consists of fans, heating coils, cooling coils, and filters and sometimes contains additional electric or gas fired preheaters. Its purpose is to condition the fresh air entering the building so that it is delivered to each zone at the required temperature and humidity, and to extract stale air from the building. Some air handling units contain a thermal wheel or recuperator to remove heat from extracted air and use it to preheat fresh air.

The air handing unit includes all the necessary elements to treat the air and deliver it under adequate temperature and humidity conditions:

- Filters

- Supply fans (optionally return fans)
- Heating coils (with heat water generated by the generation sub- system)
- Cooling coils (with cool water generated by the generation sub-system)
- Dehumidification section
- Humidification section
- Air supply, exhaust and recirculation dampers.
- Heat recovery heat exchangers (sensible or latent)

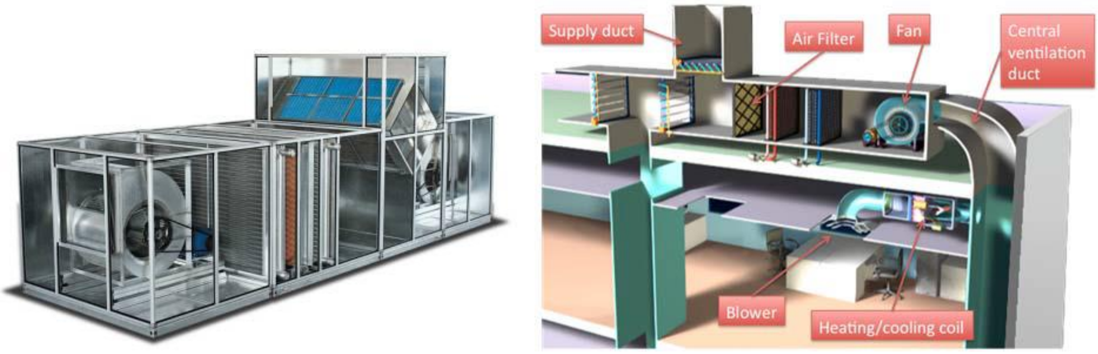


*Figure 5-6: Air handling unit. With supply and exhaust fans and energy recovery.*

#### 5.2.1.3.3 Water- air systems

The water-air system has a mix of pipes and pumps for the primary water systems and of ducts and fans for the secondary air system. The heat exchange between the two systems is done via an AHU with cooling and heating coils.

### *5.2.1.4 Diffusion sub-system*

#### 5.2.1.4.1 Hot water diffusion sub-systems

- RADIATORS

Hot water generated in a boiler, is circulated by pumps through radiators within the building. Radiators can be individually controlled by a central temperature control system or by a local valve on each radiator (convective heating).

- HYDRONIC RADIANT FLOOR HEATING

This system uses a boiler to heat water and a pump to circulate the hot water in plastic pipes installed in a concrete slab. The pipes, embedded in the floor, carry heated water that conducts warmth to the surface of the floor where heat is emitted by radiation to the room above (radiant heating).

*Figure 5-7: Hydronic floor radiant heating system*

#### 5.2.1.4.2 Cold water diffusion sub-systems

- STATIC DIFUSION SYSTEMS, CHILLED CEILINGS AND CHILLED BEAMS

Static cooling systems consist of ceiling-mounted panels or pipes that are cooled by chilled water. Heat is transferred from the room to the water in the panels or pipes by radiation or natural convection, without using fans to generate an air movement. There are two principal forms of static cooling: chilled ceilings and chilled beams.

With chilled ceilings, chilled water is passed through piping that is attached to the back of conducting ceiling panels. Alternatively, pipes may be embedded into precast ceiling slabs. As with any ceiling-mounted system, these devices need to be carefully integrated into the ceiling design along with the lighting and partitioning layout. Cooling is via radiation and convection. The radiation effect allows the thermal comfort of the occupants to be attained at higher room air temperatures than with air-only systems.

With static chilled beams, the room air is induced over finned chilled water pipes inside a casing using natural buoyancy effects.

Static chilled ceilings and chilled beams should not be used in spaces where a lot of moisture is generated as this could result in condensation problems.

#### 5.2.1.4.3 Hot and cold water diffusion sub-systems

- FAN COIL UNITS (4 PIPES)

Fan coil units contain separate heating and cooling coils and a small fan to blow air from the room, through the coils and back into the room. In general the fans run at constant speed and modern units are fairly quiet in operation. The term ‘four-pipe’ indicates that each coil has a supply and return pipe served by the central plant (with hot and cool water)

The output of the terminal units is usually controlled by changing the flow rates of the chilled or heated water through the coils in accordance with a local thermostat. Alternatively, dampers can divert the air within the unit to vary the air flow over the coils.

*Figure 5-8: Floor fan coil*

- FAN COIL UNITS (2 PIPES)

There are also 2-pipe systems which have only one coil and one pair of pipes from the central plant that either provide chilled or hot water according to the season. Changing from one to the other takes a certain time due to the system hysteresis. However, in mild weather conditions, it is difficult for the controls to decide whether the coils should be heating or cooling, or indeed whether different parts of the same building need heating and cooling at the same time. Hence this system is not adequate where either heating or cooling may be required, although it may be applicable where only cooling is needed, for instance in the core of a building.

*Figure 5-9: Split type fan coil (mounted on the false ceiling of the room)*

#### 5.2.1.4.4 Hot and cold air diffusion systems

- VENTILATION GRILLES

Ventilation grilles are used to supply and extract air from a room evenly and vertically without changing the direction of the air flow. The most common types are egg crate grilles, bar grilles and transfer grilles.

- DIFFUSER

Diffusers have profiled blades to direct the air flow and reduce its velocity. They are used for primarily for air supply and provide a better distribution of the air in the room. They are mainly installed in ceiling or walls, but special diffusers to install in the floor are also available.

### 5.2.2 Commercially available solutions

#### *5.2.2.1 Condensing boilers*

There is a wide range of boilers available on the market. Common manufactures of gas condensing boilers include Worcester, Vaillant, Ideal or Baxi. Manufacturers of condensing biomass boilers include BioCurve[1], Grant[2], Ökofen[3], Herz[4] and Weiss[5]. Table 5-1 shows prices estimations for both types of boiler and different capacities.

*Table 5-1 – Boiler prices*

| Type | Capacity | Price estimation in €/kW | Comments |
|---|---|---|---|
| Gas condensing estimation for common types and sizes boiler | Domestic 10-30kW | 120 | Traditional boiler with better efficiency. Requires hot water tank. |
| | Small 30-50kW | 120 | |
| | Medium 50-150kW | 100 | |
| | Large 150-250 kW | 90 | |
| | V Large >250kW | 60 | |

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[1] http://www.biocurve-heating.com/

[2] http://grantengineering.ie/high-efficiency-heating_products/wood-pellet-boilers/

[3] www.oekofen.com

[4] http://www.herz-energie.at/en/products/pellet-boiler/pelletstar-cond/

[5] https://www.weissboiler.com/chaudieres-2/boilers-product-lines

| | | | |
|---|---|---|---|
| Biomass condensing boiler | Small 30-75kW | 390-480 | Wood pellets / wood chips |
| | Medium 75-150kW | 284-340 | |
| | Large 150-300 kW | 180-194 | |
| | V Large >300kW | 122-150 | |

### 5.2.2.2 Chillers

Several different types of chillers are available on the market from a range of different manufacturers. In Table 5-2 some examples of price estimations of various type and sizes of chillers are shown.

*Table 5-2 –Chillers prices estimation for common types and sizes*

| Type | Capacity | Price estimation in €/kW | Comments |
|---|---|---|---|
| Compression chiller | <500 kW | 160 | Source:[6] ; |
| (air cooled) | 500-1000 kW | 115 | 1 USD = 0.8 EUR assumed |
| | 1000-2000 kW | 100 | |
| | >2000 kW | 80 | |
| Compression chiller | <500 kW | 140/-/- | Piston / screw / Turbo |
| (water cooled) | 500-2500 kW | 90/70/100 | |
| Absorption chiller | <1MW one stage | 1715 | Source:[7], |
| | 1-2MW one stage | 525 | 1 USD = 0.8 EUR assumed |
| | >2MW one stage | 410 | Water/Li bromide chillers |
| | <2MW two stage | 685 | Total installed costs |
| | >2MW two stage | 500 | |

### 5.2.2.3 Heat pumps

There is a wide range of size and type of heat pump available from several heat pump manufacturers including Mitsubishi, Carrier, Lenox, York. In the next table some examples of price estimations of various type and sized of chillers are shown.

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[6] FPL, Air-Cooled Chillers, URL: https://www.fpl.com/business/pdf/air-cooled-chillers-primer.pdf, last accessed 21/02/18.

[7] U.S. Department of Energy, Absorption Chillers for CHP Systems, Combined Heat and Power Technology Fact Sheet Series, May 2017, URL: https://energy.gov/sites/prod/files/2017/06/f35/CHP-Absorption%20Chiller-compliant.pdf, Last accessed 21/02/2018.

Table 5-3 gives prices estimation for different types and sizes of heat pumps.

*Table 5-3 – Heat pumps price prices estimation for common types and sizes*

| Type | Capacity | Price estimation in €/kW | Comments |
|---|---|---|---|
| Split DX system | Single split <5kW$_c$<br>Multi-split 5-15kW$_c$<br>VRF 15-100kW$_c$ | 275<br>245<br>245 | Reversible air-to-air heat pumps;<br>Cost of heat pump only; Average costs;<br>Source: [8]; 1GBP = €1.13; |
| Ground source heat pump | <10kW<br>10-20kW | 2710<br>2340 | Installed cost;<br>Source: [9]; 1GBP = €1.13; |
| Air-Air heat pump | <10kW<br>10-20kW | 1300<br>660 | Installed cost;<br>Source:[9]; 1GBP = €1.13; |
| Water-water heat pump | <200KW | 550-750 | Source[10]<br>Usually for geothermal |
| Air-water heat pump | <5kW<br>5-10kW<br>10-20kW | 1560<br>1340<br>630 | Installed cost;<br>Source:[9]; 1GBP = €1.13; |

#### 5.2.2.4 *Air handling units*

AHUs are modular units that can be installed in various configurations with a range of options and sizes. Examples of AHU manufactures include Daikin, Systemair, Barkell. A useful feature of AHU for DR is variable speed fans. The average total installed cost of retrofitting an existing motor to enable variable speed control is estimated around 740 €/kW[11].

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[8] Delta-ee, The Contribution of Reversible Air-to-Air Heat Pumps to the UK's Obligation under the Renewable Energy Directive (2009/28/EC), 2017, URL: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/680534/renewable-energy-reversible-air-to-air-heat-pumps.pdf, last accessed 21/02/18.

[9] YouGen, Heat pumps: an introduction, URL: http://www.yougen.co.uk/renewable-energy/Heat+pumps/, last accessed 21/02/18.

[10] CYPE Price database www.generadordeprecios.info

[11] Carbon Trust, Variable Speed Drives, 2011: URL: https://www.carbontrust.com/media/13063/ctg070_variable_speed_drives.pdf, last accessed 21/02/18.

For energy efficiency, heat recovery should be integrated to the AHU. In the case of the retrofitting of a 2,500 m$^2$ office building the options would be:

- A thermal wheel that would require an investment around 13,500€[12],
- A plate heat exchanger that would require an investment of around 13,500€[12],
- A run around coil that would require an investment of 6,780€[12].

#### *5.2.2.5 Variable flow water pumps*

Table 5-4 shows typical prices for variable speed heat pumps.

*Table 5-4 – Variable speed pumps prices estimation for common sizes*

| Type | Capacity | Price estimation in €/kW | |
|---|---|---|---|
| Variable speed pumps | DN25<br>DN50<br>DN100 | ca. 1000 EUR<br>ca. 3200 EUR<br>ca. 5000 EUR | |
| Frequency variator (to retrofit constant flow heat pump) | NA | 200 EUR | |

### 5.2.3 DR strategies in HVAC centralized systems

The strategies for DR and EE that can be implemented in a centralised HVAC system are described in this section. The strategies that can be employed depend largely on the subsystem of the HVAC that is being controlled to allow DR. For example, the strategy used at thermal zone level or diffusion subsystem may be different to the strategy used if control is at distribution or generation subsystem level. Nevertheless the three subsystems are connected, so a change in the diffusion subsystem will imply changes in distribution and generation subsystems and vice versa.

#### *5.2.3.1 Control in the Diffusion Subsystem or Thermal Zone*

At the diffusion subsystem or thermal zone, the demand of the HVAC system is controlled by adjusting parameters at thermal zone. The most common strategies are:

- **Global or zonal temperature setpoint adjustment:** The approach could be static or dynamic, depending on the system. The adjustment of the setpoints allows a reduction in the energy consumption of the HVAC plant. One degree of difference in the set-point temperature corresponds to a reduction of 7% in energy consumption.
- **Space pre-cooling / pre-heating:** Instead of starting the HVAC system at the time the first building occupants arrive, pre-cooling or pre-heating the building reduces peak energy demands and shifts the load to off peak times. This allows the buildign owner to take advantage of the reduced energy tariffs whilst providing the same level of comfort to the building users.

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[12] Carbon Trust, Heat Recovery, 2011, URL: https://www.carbontrust.com/media/31715/ctg057_heat_recovery.pdf, last accessed 21/02/18.

#### *5.2.3.2 Control at Distribution Subsystem or AHU if present.*

In the case where AHU is present the following control can be performed:

- **Complete control of AHU:** This allows for the controlling when the system is turned on or off, time schedule control**,** air temperature and flow control.

In the case of Air Systems, at distribution level the following strategies can be implemented:

- The fans could shut-down. When the fans can't vary their frequency this is the only control that can be performed.
- Control of the fan's flow rate. With Variable Frequency Drive (VFD) fans, the flow rate can be controlled based on fixed time schedules or even driven by actual demand.
- Increasing/decreasing supply air temperature.

In the case of Water Systems, at distribution level the following strategies can be implemented:

- The pumps can be shut-down. If the speed of pumps is constant, this is the only control option that can be implemented. In some cases, the pump speed could be higher than necessary so energy would be wasted.
- Reduction of pumps flow rate. With variable speed pump control with constant Δp (pressure difference at the pump), the pump speed is reduced at partial load (Optionally proportional Δp; pressure difference decreases at the pump with decreasing load).
- Increasing/decreasing supply water temperature.

#### *5.2.3.3 Control at Generation subsystem level*

In all the generation systems (boilers, chillers, heat-pumps) that have been described the following control options can be implemented:

- Interruption of loads. The generation system is stopped so the whole system (at distribution and diffusion level) is also stopped.
- Reduction to partial load: the generation subsystem loads are reduced and thus the load of the whole system is reduced.
- Time control schedules for the systems: the generation subsystem has different loads depending on a time control.

If there is only one generation system for a whole building, the control in the generation will affect the whole building without distinguishing thermal zones.

Depending on the delivery fluid (water or air), the generation system can have the following additional control system:

Water driven generation systems:

- Supplied water flow rate can be controlled.
- Supplied water temperature can be increased/decreased.

Air driven generation systems

- Air flow rate can be controlled.
- Supply air temperature can be increased/decreased.

## 5.3 HVAC DECENTRALIZED SYSTEM

In a direct-expansion (DX) unitary system, the evaporator is in direct contact with the air stream, so the cooling coil of the airside loop is also the evaporator of the refrigeration loop. The denomination of these systems is due to the relative position of the evaporator with respect to the airside loop.

One of the most common reasons for selecting a DX system, especially packaged DX systems, is that, in a smaller building, it frequently has a lower installed cost than a chilled water system because it requires less field labour and has fewer materials to install. Packaged DX systems that use air-cooled condensers can be located on the roof of a building, in a small plant room, or even within the perimeter wall of the building.

### 5.3.1 Heating systems

In the case where the building only has heating systems, the equipment suitable for Demand Response includes:

- **Electric heater**: devices that convert electric current to heat by means of a heating element (electrical resistance). They act as both a generation and emission system simultaneusly.
- **Electric boilers with radiators:** Electric boilers usually use water pipes for distribution and radiators as emission devices.
- **Local electrical heaters:** Electric heating or resistance heating converts electricity directly to heat. They are autonomous systems that work independently. The efficiency of these systems in terms of primary energy is low comparing with the others (convective heating)

### 5.3.2 Heating and cooling systems

#### *5.3.2.1 Packaged DX systems*

These units integrate the refrigeration loop (evaporator, compressor, condenser, expansion device some unit controls) in a compact ‘package’. This allows the unit to be factory assembled and all components tested before installation including the electrical wiring, the refrigerant piping, and the controls. This equipment is usually installed on external walls .

#### *5.3.2.2 Split DX systems*

Alternatively, the components of the refrigeration loop may be split apart, allowing for increased flexibility in the system design. This is called a Split DX system. Separating the elements has the advantage of providing the system more design flexibility to match components in order to achieve the desired performance.

#### *5.3.2.3 Variable refrigerant flow systems (VRV)*

This is essentially a split system where a number of room units are served by one external condensing unit. Typically, the units can provide both heating and cool, and sometimes recover heat from one zone to be used in another zone. Distribution of heating or cooling is achieved with refrigerant circuits through which the flow rate is varied, rather than simply being turned on and off as is commonly the case with split units. The refrigeration pipe work is considerably smaller than air ducts or water pipes for the same heating or cooling capacity, and this simplifies distribution. However, there are other considerations when using refrigerant as a distribution medium for example, the system must be regularly checked for refrigerant leaks and large units (over 12kW) must have regular air conditioning inspections by a qualified person.

### 5.3.3 Implicit DR strategies for decentralized HVAC systems

The control strategies that can be implemented will depend mainly in the energy contract that the building user has but will typically include:

- Reducing or interrupting loads
- Using time controls to schedule pre-heating and pre-cooling of rooms.

In decentralized HVAC systems the distribution and diffusion subsystems are often combined. Examples of this type of system include electric boilers with radiators, and variable refrigerant flow systems (VRV). In these systems DR control can either be performed at generation level which controls the whole system, or at diffusion level by controlling the set point temperatures in the different thermal zones.

In some cases the generation, distribution and diffusion subsystems are combined in the same unit. Examples of this type of system include electric heaters, packaged dx systems, and split dx systems. In this case control at the generation level affects the whole system.

## 5.4 ELECTRICAL ENERGY GENERATION AND STORAGE

As stated previously, distributed energy resources play a significant role in DR. Apart from renewable solutions, electric energy generation and storage presents a potentially important source of load flexibility, which is useful for DR programs.

Electricity generation and storage technologies can be connected at the grid at different levels. In the transmission network, battery storage resources can be used as alternatives to standby generators for frequency regulation.

The electric generation and storage system to be considered in this section will be: CHP, fuel generators, PV panels and batteries.

### 5.4.1 Description of the technologies

#### *5.4.1.1 Combined heat and power units (CHP)*

This equipment can generate electricity and heat in a single process. A CHP unit is essentially an electric generator that produces on site electricity and makes use of the heat rejected by the unit’s cooling system to heat water which can then either be stored or used in the building’s heating system. This makes it possible to achieve high efficiencies of up to 90%, since both the electricity and the waste heat can be usefully used. This compares very favourable compared to a conventional power station which typically has an efficiency of around 30-45%. Thus a CHP unit reduces the amount of primary energy required to satisfy a given heat and electrical load for the site.CHPs usually run on natural gas, biogas or diesel but biomass CHP units, though less common, are also available.

In Table 5-5 the most relevant characteristic of the different CHP systems are displayed

| **Reciprocating Engines** | |
|---|---|
| Application field | Packaged units on most of the small-scale CHP installations (typically in the range of 50 kWe to 800 kWe output) |
| Prime mover | Spark ignition gas reciprocating engine |
| Electrical generator | Synchronous |
| Heat to power ratio | 1,5/1 |
| Overall efficiencies | Up to 90% (with condensing kits) |
| Fuel | Gas or diesel |

| **Gas turbines** | |
|---|---|
| Application field | Widely used for large-scale CHP (large buildings or multi-building sites) |
| Prime mover | Gas turbines |
| Electrical generator | Synchronous |
| Heat to power ratio | 1,5/1 to 3/1 |
| Overall efficiencies | Up to 80% |
| Fuel | Gas or light oil |
| **Micro turbines** | |
| Application field | 30-500 kWe |
| Prime mover | Micro turbines |
| Electrical generator | Synchronous |
| Heat to power ratio | 1,5/1 to 3/1 |
| Overall efficiencies | up to 85% |
| Fuel | Gas |

*Table 5-5 – Characteristics of the different CHP systems*

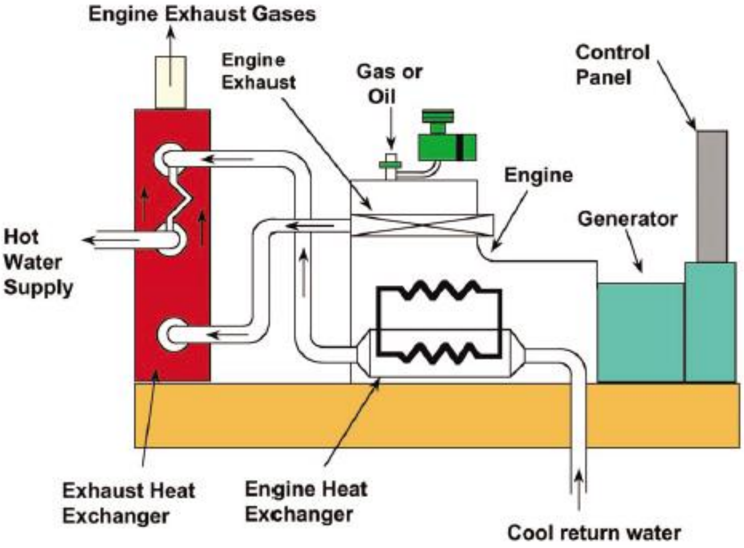

*Figure 5-10*: CHP system working principle (reciprocating engine)

Due to the fact that heat transfer losses are significant over long distances, CHP is most efficient when heat can be used in the place of generation. To this effect, micro-CHP systems, with capacities in the range of kWs, are gaining popularity in the DER market. Apart from their increased efficiency compared to current heating systems, their on-demand availability is desirable for DR purposes (Houwing, Negeborn, & De Schutter, 2011).

### 5.4.1.2 Fuel generators

Apart from CHP, traditional backup generators have also been utilized as DR resources. Consumers can participate in programs through which they allow utilities to make use of the emergency backup generators located at their premises to temporarily offload their energy usage from the grid during emergency DR events. The availability of backup generators enables large organizations to participate in emergency DR without disrupting normal operation, while also taking pressure off the grid and acting as a last resort to prevent blackouts. However, it must be noted that stricter rules are expected to be imposed on the use of fuel generators for these purposes, as these units are typically not energy efficient and can cause local air quality issues. (Depanian, 2016).

#### *5.4.1.3 Photovoltaic panels (PV)*

PV panels generate electric electricity that can be used for consumption on site or sold to the grid. In this case the legislation in the different European countries differs considerably, so the viable capacity, usage strategy and the business model of PV systems will be different in each county.

To be useful for demand response photovoltaic panels need to be installed in conjunction with a battery. The energy generated by the panel and stored during the day can then be used to displace load from the grid without disturbing the activity of the building.

#### *5.4.1.4 Batteries*

In this report, we are predominantly interested in on sited electrical energy storage, i.e. batteries, which can be used for profiling optimization of energy usage, as well as integration of distributed energy resources. Batteries discussed in this report are secondary (rechargeable) batteries, and store energy chemically.

Lead-acid batteries are already deployed extensively to support renewables deployment. Recent versions are reported to achieve approximately 3000 cycles at a 50% depth of discharge ensuring a service life up to 17 years for industrial systems. Molten salt batteries, similar to lead-acid batteries, have a more limited life cycle. They have an energy density of around 60 Wh/kg, a life of 1500-3000 cycles, and high operation temperature (>300°C). Lithium-ion batteries have a high-energy density and have a high conversion efficiency of around 80-90%. Their high power and energy density mean they are ideal for frequency regulation and other applications requiring relatively short discharge and high power performance. The latter type is most commonly found in battery storage products (IRENA, 2015).

### 5.4.2 Commercially available solutions

#### *5.4.2.1 Combined heat and power units*

This section gives examples of CHP units, which are attractive for combined EE/DR programs.

1. **2G Energy:** 2G Energy, from Germany, specializes in cogeneration systems for natural and biogas in the 50 to 2,000 kW power range, with combined heat and electricial energy efficiency of up to 90%. Applications range from residential to commercial and public buildings (2G Energy, 2017).
2. **MTT:** MTT, from the Netherlands, is developing micro turbines up to 30 kW electrical power for CHP and other applications. The use of a recuperator coupled with the gas turbine, results in an estimated increase in electrical efficiency of 16-25% compared to other micro turbines. Off-the-shelf generators operate with natural gas, although development of a clean combustor for liquid fuels, such as diesel, that will comply with future emission requirements is reportedly ongoing (MTT, 2017).

Installation cost of CHP systems vary significantly and are based on the system’s capacity, and the technology used. Prices are reported to range from $650 to $6500 per kW. Table 5-6 gives typical prices based on technology and capacity.

*Table 5-6 – CHP price estimation for common types and sizes*

| Type | Plant capacity | Price range €/kW (1 USD = 0.8 EUR assumed) | Comments |
|---|---|---|---|
| Gas turbine | <5 MWe | 2450 | Total installed costs; |
| | 5-10 MWe | 1600 | Source: [13]; |
| | 10-20 MWe | 1300 | |
| | >40 MWe | 1020 | |
| Micro turbine | <100 kWe | 2580 | Total installed costs; |
| | 100-200 kWe | 2520 | Source: [14]; |
| | 200-300 kWe | 2160 | |
| | 300-400 kWe | 2050 | |
| | >400 kWh | 2000 | |
| Spark ignition reciprocating engine | <500 kWe | 1300 | Source: [15]; |
| | 500-1000 kWe | 1300 | |
| | 1000-5000 kWe | 1000 | |
| | >5000 kWe | 750 | |
| Compression ignition reciprocating engine | <500 kWe | 1300 | Source: [15]; |
| | 500-1000 kWe | 1300 | |
| | 1000-5000 kWe | 1000 | |
| | >5000 kWe | 750 | |
| Steam turbine | <500 kWe | 910 | Total installed costs; |
| | 0.5-5 MWe | 545 | Source: [16]; |
| | 10-20 kWe | 530 | |

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[13] U.S. Department of Energy, Gas turbines, Combined heat and power technology, Factsheet series, 2016. URL: https://energy.gov/sites/prod/files/2016/09/f33/CHP-Gas%20Turbine.pdf, last accessed 21/02/18.

[14] U.S. Department of Energy, Microturbine, Combined heat and power technology, Factsheet series, 2016, URL: https://energy.gov/sites/prod/files/2016/09/f33/CHP-Microturbines_0.pdf, last accessed: 21/02/18.

[15] U.S. Department of Energy, Reciprocating engine, Combined heat and power technology, Factsheet series, 2016. URL: https://energy.gov/sites/prod/files/2016/09/f33/CHP-Recip%20Engines.pdf, last accessed: 21/02/18.

[16] U.S. Department of Energy, Steam turbine, Combined heat and power technology, Factsheet series, 2016. URL: https://energy.gov/sites/prod/files/2016/09/f33/CHP-Steam%20Turbine.pdf, last accessed: 21/02/18.

| Type | Plant capacity | Price range €/kW (1 USD = 0.8 EUR assumed) | Comments |
|---|---|---|---|
| Fuel cells | <50 kW | 8000 | Source: [17]; |
| | 50-500 kW | 7000 | |
| | 500-1500 kW | 3750 | |
| | >1500 kW | 3750 | |

#### 5.4.2.2 Fuel generators

| Type | | Price range €/kW (1 USD = 0.8 EUR assumed) | Comments |
|---|---|---|---|
| Electric generation by fuels | Gasoil generator | 200 | Source[18] |

#### 5.4.2.3 Photovoltaic panels

| Type | | Price €/kWp | Comments |
|---|---|---|---|
| Renewable electric generation | Monocrystalline silicon PV panels | 3000 | Source[19] |
| | Polycrystalline silicon PV panels | 3500 | Source[20] |

#### 5.4.2.4 Batteries

Examples of commercial products include the Tesla Powerwall and Powerpack. These rechargeable lithium-ion battery storage products manufactured by the Tesla company have capacities of 13.5 and 200 kWh respectively and are tailored for residential and commercial/industrial use. These units typically cost around $400/kWh. The batteries are optimized for daily cycling, such as for load shifting, and have an estimated life of 5,000 cycles (Tesla, 2017a, 2017b). Similar products have been introduced by other companies as well, such as General Electrics, LG and Sonnen (GE, 2017; LG, 2017; Sonnen, 2017).

Battery storage is still costly, although prices are quickly becoming more affordable. A survey from 2013 reported that many sensible storage systems had energy content between 70-90 kWh/m$^3$ and investment costs between €0.5-3.0 per kWh. PCM and TCS systems are significantly more complex and expensive. In the same survey, the cost of a PCM system was reported to range between €10-50

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[17] U.S. Department of Energy, Fuel cell CHP, Combined heat and power technology, Factsheet series, 2016. URL: https://energy.gov/sites/prod/files/2016/09/f33/CHP-Fuel%20Cell.pdf.
[18] CYPE Price generator www.generadordeprecios.info
[19] CYPE Price generator www.generadordeprecios.info
[20] CYPE Price generator www.generadordeprecios.info

per kWh, while TCS cost between €8-100 per kWh (IRENA, 2013). Table 5-7 gives estimations of battery prices for various technology.

*Table 5-7 – Batteries price estimation per types*

| Type | Installed cost per kWh of storage capacity (average) €/kWh | Comments |
|---|---|---|
| Electrochemical batteries (Li-ion batteries) | 480 | Source: [21].<br>1 USD = 0.8 EUR assumed |
| Vanadium Redox Flow battery | 280 | Source: [21].<br>1 USD = 0.8 EUR assumed |
| Flywheels | 2400 | Source: [21].<br>1 USD = 0.8 EUR assumed |

### 5.4.3 DR strategies for electrical energy storage and generation

Considering the electrical generation and storage systems available the following DR strategies can be implemented:

#### *5.4.3.1 Fuel electricity generator*

- Use electricity from fuel generator instead of from electric grid
- Export electricity from fuel generator at times of peak demand

#### *5.4.3.2 PV panels*

- Self-consumption of the electricity generated by the PV panels.
- Selling the PV electricity to the grid while using the grid electricity in the building

#### *5.4.3.3 Batteries*

- Store electricity in the battery: electricity form the grid or electricity generated in the PV panels can be stored in the batteries during the valley periods when the electricity is more affordable.
- Use electricity from battery: the stored electricity is used when the energy tariffs are higher, reducing the consumption from the grid.

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[21] IRENA, Electricity storage and renewables: cost and markets to 2030, 2017. URL: http://www.climateactionprogramme.org/images/uploads/documents/IRENA_Electricity_Storage_Costs_2017.pdf, last accessed 21/02/18.

## 5.5 THERMAL ENERGY GENERATION AND STORAGE

### 5.5.1 Description of the technologies

#### *5.5.1.1 Solar thermal collectors*

Solar thermal collectors use the energy of the sun to heat water. The resultant hot water is primarily used for domestic hot water (DHW), but can also be used for space heating. Solar thermal collectors are usually used with a hot water tank to store the hot water until it is required for use, but seasonal storage systems can also be connected to store unused energy for longer time periods.

#### *5.5.1.2 Water tank*

Water tanks are used to store hot or cold water produced by a generation system. The size of the water tank will depend on the requirements of the building but in general tanks can be used to store energy from intermittent renewable energy sources and need to be well insulated to keep the water inside them at the desired temperature.

#### *5.5.1.3 Borehole storage*

Borehole storage allows long term thermal storage. This enables thermal energy to be collected at whatever time of year it is available and used whenever it is needed. Heat from solar collectors or waste heat from air conditioning equipment can be gathered during hot summer months and then released during the winter months, when it is needed. The drilling of vertical boreholes is more feasible when constructing a new building as it can be carried out as part of the preparatory ground works. Boreholes are typically 155mm in diameter and the number required varies from one to several hundred depending on the size of the building and its thermal requirements.

### 5.5.2 Commercially available solutions

#### *5.5.2.1 Solar thermal collectors*

There are several types of solar thermal collectors including low, medium or high heat solar collectors. The medium heat types are generally used for commercial or residential applications to provide domestic hot water or space heating. The most relevant and commonly installed technologies are the following:

- Flat plate collectors have two horizontal pipes at the top and bottom, called headers, and many smaller vertical pipes connecting them, called risers. Heat-transfer fluid (water or a water/antifreeze mix) is pumped from the hot water storage tank (direct system) or heat exchanger (indirect system) into the collectors' bottom header. From there it travels up the risers collecting heat from the absorber fins, and then exits the collector via the top header.

- Evacuated tube collectors offer a way to reduce the heat loss from the tubes into the environment. This type of collector consists of rows of parallel transparent glass tubes, each of which contains an absorber tube in place of the absorber plate to which metal tubes are attached in a flat-plate collector.

- Integrated collector storage (ICS or batch heaters) system is a technology that places the water tank in a thermally insulated box. This is achieved by encasing the water tank in a glass-topped box that allows heat from the sun to reach the water tank. The walls of the box are thermally insulated, reducing convection as well as radiation to the environment.

Prizes vary significantly depending on the technology and the size of the system. Some examples are given in Table 5-8.

| Type | Installed cost per kWh of storage capacity (average) €/kW | Comments<br>Source[22] |
|---|---|---|
| Flat plate collectors | 250-450 €/kW | 150-300 €/$m^2$ |
| Evacuated tube collectors | 600-950 €/kW | 450-650 €/$m^2$ |

*Table 5-8 – Examples of prices for solar thermal systems*

#### *5.5.2.2 Water tank*

Water tanks are made from a wide variety of materials including steel, aluminium, reinforced concrete and fiber glass. In order to prevent heat loss they are insulated with glass wool, mineral wool or polyurethane. The size of the tanks commonly used vary from a few hundred liters to a few thousand liters but can reach over one thousand cubic meters in special applications.

Tank cost vary with type, capacity and size. The storage temperature varies also the price of the tank. As an approximation the cost is 2-6€/liter.

#### *5.5.2.3 Borehole storage*

Borehole thermal energy storage systems are composed of one to hundreds of vertical boreholes which can be either grout- or water-filled depending on geological conditions. The geology of the surrounding ground can be anything from sand to crystalline hard rock. The majority of the cost relate to the geotechnical works, and as such are highly variable as it depends on the specific ground conditions. In general the thermal efficiency of boreholes increases, and the specific construction cost decreases with size.

### 5.5.3 DR strategies for thermal energy generation and storage

Thermal storage offers opportunities for DR by allowing heat to be produced at a time when it is not needed and used later when the price of electricity is high or there is high demand on the grid. Considering the Thermal generation and storage systems the following DR strategies can be implemented:

#### *5.5.3.1 Solar thermal collector + water tank*

- Store heat from the collector to the water tank
- Use heat from the water tank

#### *5.5.3.2 Water tank/borehole*

- Store heat in the water tank/in the borehole

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[22] CYPE Price generator www.generadordeprecio.info

- Use heat from the water tank/from the borehole

## 5.6 LIGHTING SYSTEMS

Lighting is a major part of energy consumption in buildings, closely following the yearly energy consumption of HVAC systems (Ziegenfus, 2012). Commercial and office buildings in particular have more artificially lit floor space than any other building type. Consequently, lighting systems constitute an important component for the dynamic load management service. A lighting system comprises of light sources, lighting controllers which control the power consumption of individual luminaires, sensors (e.g. occupancy or daylight sensors) that provide information used to adjust the dimming levels and communication infrastructure to enable information exchange between the management system, the controllers and the sensors (Husen, Pandharipande, Tolhuizen, Wang, & Zhao, 2012).

Lighting can play a passive and active role in DR. The passive role involves optimizing energy consumption using appropriate technology and design, turning off or reducing loads when not in use, manual and automatic dimming, and institutional task tuning. These provide the end-user an economic profit regardless of peak demand. To take full advantage of the DR potential, lighting systems must expose further functionality and integrate components allowing remote load measurement and control. In addition, to optimize their effectiveness, it is important that the lighting controls can prioritize the sequence of operations and identify least to most invasive spaces and areas that shouldn’t participate at all. It should also take advantage of dimming technologies as opposed to simply on/off strategies. In all of the above scenarios it is a prerequisite that the lighting system should be able to connect to a central gateway to receive the demand response signal either directly or indirectly.

Lighting systems require additional information to react appropriately to the demand response commands. This additional input can be divided into two categories: inputs from people and inputs from devices, usually sensors (Rubinstein & Kiliccote, 2007). The first category of input is from people causing a change in the system due to comfort or conservation concerns. The second category is a sensor, which detects changes in the environment. Primary examples are motion, occupancy and daylight data. The data flow can go directly from the sensory instruments to the lighting controllers, or it can pass through the management system where it is utilized for the control of further DR-enabling appliances such as heating and ventilation systems. Whether the input is a person or a sensor, there must be some user interface between the input and the lighting system. This interface usually takes the form of a manual or automatic switch, a remote control, a lighting panel-board or a computer (Rubinstein & Kiliccote, 2007).

Prior to any assessment of the potential of lighting controls and DR strategies, the analysis has to reveal whether simple lamp/gear retrofits or replacements of luminaries are appropriate measures. This check should follow the principles depicted in Figure 5-11.

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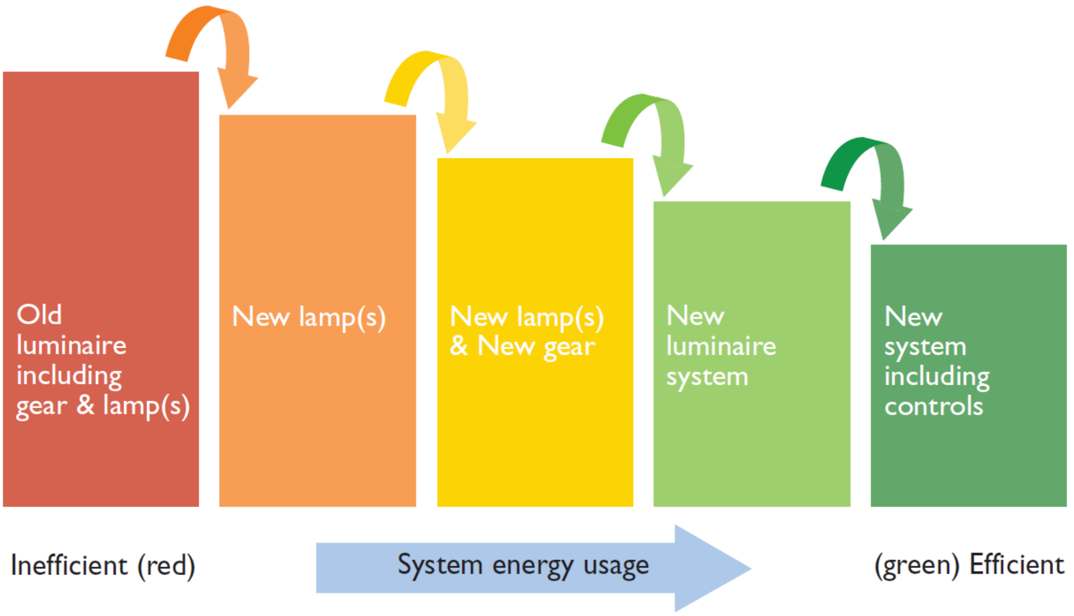


*Figure 5-11: Principle approach towards lighting energy-efficiency*

### 5.6.1 Description of lighting technologies

The required technologies for DR in lighting are occupancy or daylight controlled dimming luminaries. These kind of luminaries allow:

- **Occupancy or daylight controlled dimming:** With the dimming function the brightness of the lighting can be step-wise or continuously changed within the range 0% to 100%. The last brightness level set can be restored automatically when the lighting unit switches back on (memory function).
- **Constant light output:** The brightness of the artificial lighting is automatically set such that the required light intensity in the room is regulated to a constant value. The light intensity required in the room depends on the function of the room.
- **State change signalling:** Depending on requirements the dimmable lighting controller can be provided with switch-on and -off effects, for example, the stairway function with an advance indication that the lighting will switch off.

There are many commercially available dimmable lighting solutions, such as Philips, iDual, etc. The cost luminary without installation is around €20 euro.

### 5.6.2 DR strategies for lighting systems

The most common lighting control strategies for DR are as follows:

- **User control:** The user can switch the lighting on or off manually by means of various interfaces, for example, push-button, operator panel or PC control.
- **Timer control:** The lighting can be switched on or off by a higher level command (e.g. with timer or schedule control) established by the user. The priority and sequencing of manual, time-controlled and automatic switching must be defined. Switching off functionality, when someone is in the room should be possible as this is often required by regulations.

- **Occupancy or Daylight controlled switching:** The lighting in a room can be switched on or off. When people are present and the room brightness drops below a specified level, the lighting is switched on automatically or manually by the user. Once there is nobody in the room the lighting is switched off automatically after a configurable delay or once a specified level of room brightness has been exceeded.
- **Artificial lighting control**: This method of control takes available daylight into account at all times. Sufficient lighting with minimum energy expenditure can be accomplished by automatically dimming lighting during daylight hours when natural light is available. Dimmable luminaries are a prerequisite for this kind of advanced control.

## 5.7 FUTURE TECHNOLOGIES

### 5.7.1 PCM

Phase Change Material (PCM)-based systems enable higher storage capacities (e.g. in the order of 100 kWh/m$^3$ for ice-based systems) compared to traditional sensible heat storage methods. A large number of companies offer PCM-based solutions (raw materials) (Honeywell, 2017a; Kaplan, 2017; PCM, 2017; Rubitherm, 2017; Teappcm, 2017). The cost of a PCM system is reported to range between €10-50 per kWh

### 5.7.2 Electric vehicles

The advent of Electric Vehicles (EVs) has provided utilities with another asset relating to flexibility and reliability in managing and delivering electrical energy through their ability to reduce peak demand impacts and preserve power quality. Two types of interactions are possible between an EV and the power grid, namely Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G).

#### *5.7.2.1 Grid-to-Vehicle and Vehicle-to-Grid*

In G2V, energy is directed from the grid to an EV battery, while in V2G, the power flow is reversed, i.e. from an EV to the grid, by discharging the EV's battery. Due to the fact that EVs can behave both as a load to the grid and as a supplier of electricity to the grid, utilities can incorporate them into DR programs by managing the EVs charging/discharging time and rate of charge/discharge. For example, EVs can facilitate the supply/demand balance by discharging their battery during peak hours (peak shaving) and charging their battery during off-peak hours (valley filling). Most EVs are connected to the internet through a communication network, e.g. Wi-Fi, ZigBee or 3G. By using this communication channel, aggregators can collect EVs into groups of dispatchable loads to the grid. Furthermore, since EVs are likely to be plugged-in for long durations of 10–15 hours per day, they are useful for providing ancillary services, such as frequency regulation (Falvo, Graditi, & Siano, 2014; Gago, Pinto, & Silva, 2016; Kumar & Tseng, 2016).

#### *5.7.2.2 All Electric Vehicles and Plug-in Hybrid Electric Vehicles*

Different types of EVs exist in the market. For DR, two types are of interest, namely All Electric Vehicles (AEVs) and Plug-in Hybrid Electric Vehicles (PHEVs). AEVs are powered only by their battery, while PHEVs, have another power source, typically a traditional internal combustion engine, in addition to their battery. Finally, it must be noted that to enable EV V2G capabilities and through that DR, a further prerequisite is the existence of appropriate charging stations, which can operate bidirectionally. This technology is still relatively new and currently under testing (Ashton, 2016; Nissan, 2016).

#### *5.7.2.3 Charging Stations*

Electric vehicle charging stations are the point of contact between the grid and the vehicle batteries. Technologies for charging differ primarily with respect to speed. Slow charging (up to 3kW) is best suited for 6-8 hours overnight. Fast charging (7-22kW) can fully recharge some models in 3-4 hours. Finally, rapid charging units (43-50kW) are able to provide an 80% charge in around 30 minutes. Rapid chargers come in two charge point types – AC and DC – depending on whether they use alternating current or direct current (Zap-Map, 2017).

### *5.7.2.4 Commercially Available Solutions*

Most of the major car manufacturers are establishing themselves in the EV market, by offering cars of various types and styles. *NextGreenCar* reports the number of registered EVs in the UK between 2014 and 2016 as shown in Figure 5-12. In the following paragraphs, we present further details on two of the most popular EVs, based on these statistics.

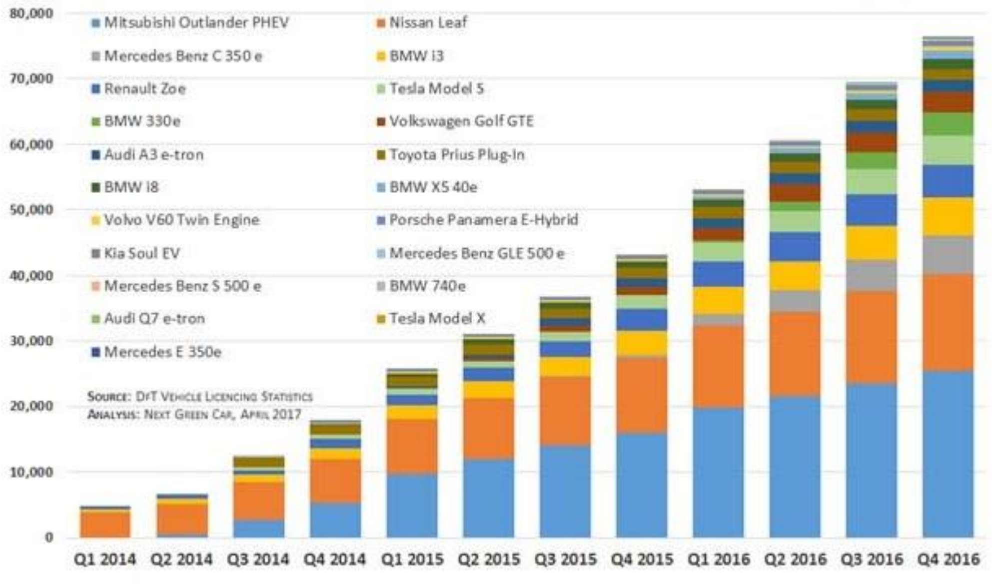


*Figure 5-12 Number of registered Electric Vehicles in the United Kingdom, for the years 2014-2016. Source (NextGreenCar, 2017)*

1. Plug-in Hybrid Electric Vehicles (PHEV)

   The Mitsubishi Outlander SUV is an example of a plug-in hybrid electric vehicle. It carries a 2 litre 4-cylinder gasoline engine, coupled with an electric powertrain. Two 60 kW electric motors independently power the front and rear wheels, while the gasoline-powered engine can be used as a generator for the motors and/or power the vehicle directly. The Outlander PHEV has a 12kWh lithium-ion battery pack capable of delivering an all-electric range of 52.3 km, and is fitted with regular and fast charging sockets. The vehicle offers three driving modes: EV Drive, Series Hybrid, and Parallel Hybrid. In the EV Drive mode, the vehicle is driven by the electric motors, with energy being supplied exclusively by the lithium-ion battery pack. In Series or Parallel drive modes, the generator produces electricity from the engine and stores it in the battery pack. An additional feature is that the car uses regenerative braking during normal deceleration (braking or coasting), with the front and rear electric motors working as generators so that electricity can be generated and fed back into the main battery pack.

2. All Electric Vehicles (AEV)

   Nissan Leaf is and all-electric vehicle, first introduced in 2010. The current version features 30 kWh battery packs with an official range of 172 km. Recharging receptacles vary between models, but in general both slow and fast charging sockets are provided, with estimated charging times from empty being 8 and 4 hours respectively. The vehicle is equipped with a telematics system via a built-in GPRS radio, which connects any time the car is in range of a cell tower. Based on this connectivity, the user is provided with remote control functionalities, such as turning on the air-conditioner or heater and programming charging functions. The remote functionality can be used to pre-heat or pre-cool the car prior to use while it is still charging so that less energy from the battery is used for climate control during the journey. The car is also equipped with an on-board timer, which can be pre-programmed to recharge batteries at a set time such as during off-peak rates, while a specific model also carries a small solar panel at the rear of the roof, which can charge the auxiliary battery.

#### *5.7.2.5 Costs*

Prices for EVs vary based on the features and technologies provided in specific models. Suggestive values for popular models range between €35-50,000 . The cost of home charging stations falls within the region of €500-1000.

# 6 BUILDING ICT TECHNOLOGIES FOR DR

This chapter presents a comprehensive overview of Information and Communication Technologies (ICT), which, in combination with Building Energy Management Systems (BEMS) and alternative energy supply systems, can provide automated communication and control, thus facilitating the deployment of NOVICE's Integrated Energy-Contracting Model. The material presented here has been extracted from a multitude of information sources, including previous European Union (EU) projects, academic publications and commercial websites. This information was gathered with a specific focus on Demand Response (DR) potential, and has been subjected to critical review.

Firstly, we delineate technologies that enable each and both DR types. Finally, we assess their potential in terms of DR, Energy Efficiency (EE), retrofitting necessity and cost.

## 6.1 ICT STANDARDS AND FRAMEWORKS FOR DR

The complicated nature of the power supply and demand market, along with the increasing number of stakeholders and the strict requirements for reliability and security, are some of the factors that make the definition and use of standards and protocols of particular importance in the emerging DR scheme. In the following paragraphs, we describe a number of such standards, related in particular with ICT for DR.

### 6.1.1 OpenADR standard

The realization of DR services, particularly explicit DR where automation of decisions is key, necessitates quick, fail-safe, consistent and secure bi-directional communication between a large variety of stakeholders, from power generation facilities, possibly through aggregators, and finally to consumers. Due to the large number of concerned parties and the specific strict requirements associated with energy supply, standardization on this communication is of paramount importance. The OpenADR standard, currently at version 2.0b, prescribes the information exchange between utilities and energy management control systems. In particular, the main features of OpenADR are (Maisonobe, 2010):

- Data model specification for the communication of pricing signals.
- Secure and reliable two-way communication infrastructure, in which the DR pricing signals can be sent with continuity and the automatic client can transform them in real time control operation.
- Use of the internet to transfer DR signals and open standards (e.g. SOAP and Web Services Standard) to realize the communication architecture.
- The option for the end-user to ignore DR events.

Figure 6-1 gives an overview of the OpenADR communication architecture. The system is modelled based on VTNs (Virtual Top Nodes) transmitting messages and VENs (Virtual End Nodes) receiving them. An Electric Power Company is a VTN, customers are VENs, while aggregators act both as the VEN of the power provider and the VTN for consumers. The protocol defines exchange messages between VTNs and VENs via the internet, including both PULL type (VEN acquires messages from the VTN by polling) and PUSH type (VTN sends messages to the VEN) communication models. In the example in Figure 6-1, the power producer VTN creates DR events according to the DR program and issues them to the aggregators or customers. Both aggregators and customers (VENs) perform processing based on the DR events received from the VTN, which in the case of aggregators are subsequently issued as new DR events to its consumers. Because of the automated nature of

OpenADR, end-users are usually implemented as HEMS (Home Energy Management System) or BEMS (Building Energy Management System) (Tetsuji & Yasuhisa, 2016). A key element of the OpenADR standard is the Demand Response Automation Server (DRAS), which is used to facilitate the automation of DR events and customer responses to them. In Figure 6-1 VTNs were implied to play the role of a DRAS as well, although this though is not necessary.

The standard allows a response signal to the DR event to travel back from VENs to the VTNs, and, in addition, other information can also be exchanged related to DR events, such as event name and identification, event status, operating mode, various enumerations characterizing the event, reliability and emergency signals, renewable generation status, market participation data and test signals (OpenADR, 2012).

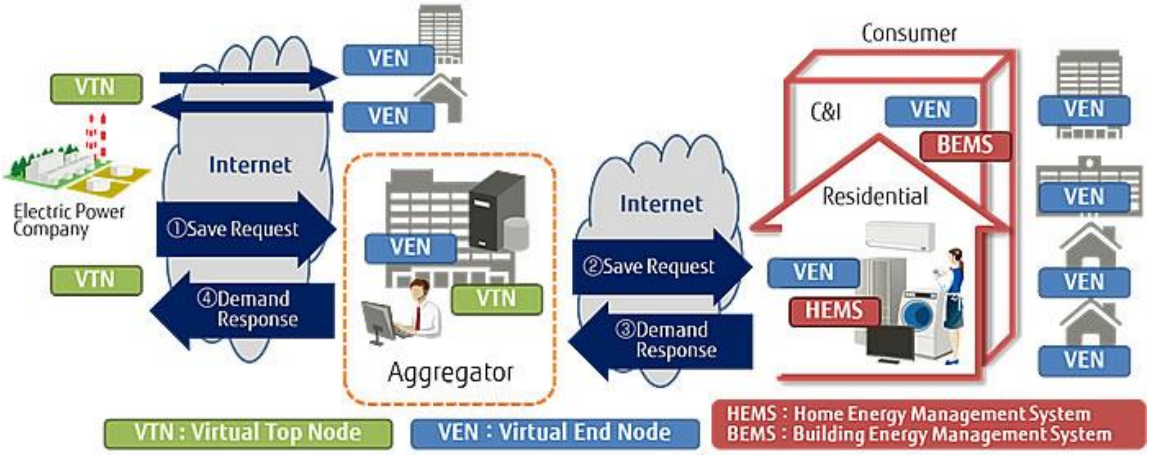


*Figure 6-1 OpenADR Communication Architecture. Source* (FUJITSU, 2013)

### 6.1.2 IEC 62746 standard

The International Electrotechnical Commission (IEC) 62746 standard named “Systems interface between customer energy management system and the power management system” prescribes system interfaces and communication protocols covering the whole chain between a smart grid and smart home/building/industrial area.

IEC 62746 has adopted as its basis the previously described OpenADR 2.0b protocol (IEC, 2014). In addition, the standard describes a set of use cases related to energy flexibility and demand side management, as well as an outline of potential upcoming Smart Building and Smart Home scenarios (IEC, 2015a). Finally, IEC 62746 provides a technical specification and architecture for the management of customer and distributed energy resources, that leverages other existing IEC standards, such as the IEC 61850 (IEC, 2015b). The role of the standard and its relationship with other IEC standards is illustrated in Figure 6-2.

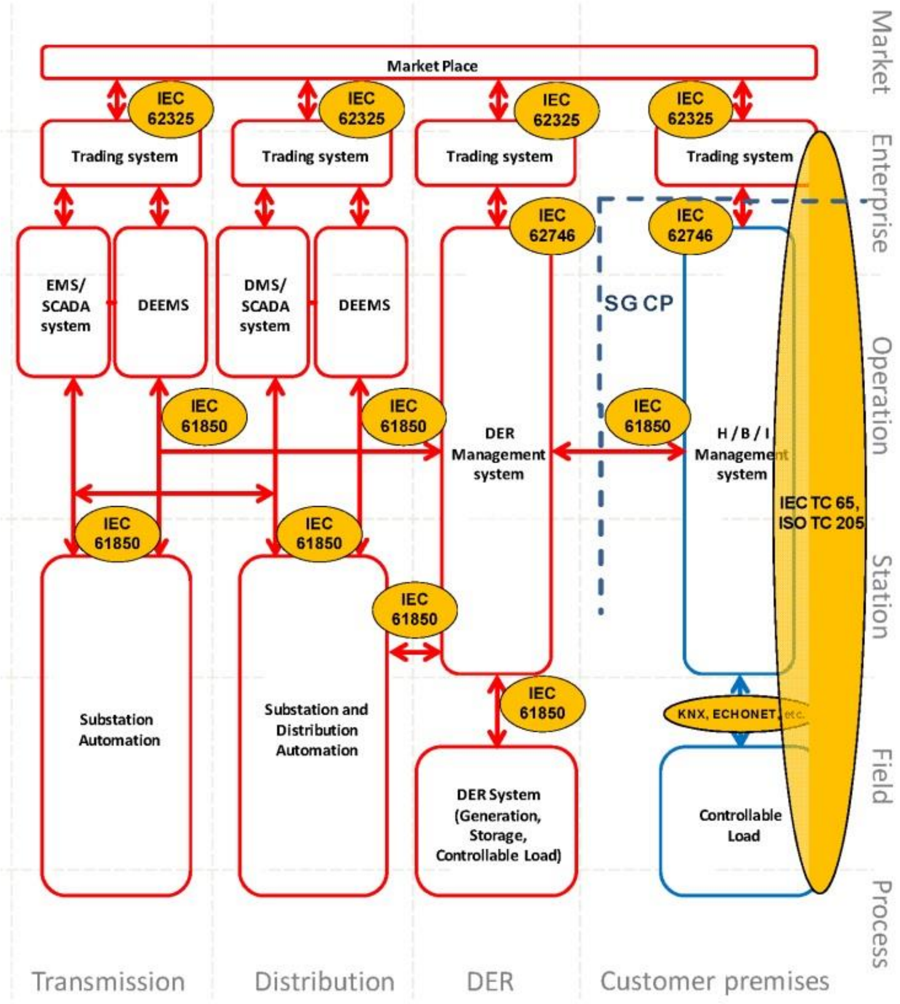


*Figure 6-2 The role of IEC 62746 and its relationship to other IEC standards. Source* (IEC, 2015b)

### 6.1.3 OneM2M technical specifications

The OneM2M global organization was founded from a number of ICT Standards Development Organizations across the world, including the European Telecommunications Standards Institute (ETSI), with the goal of creating technical specifications to ensure that Machine-to-Machine (M2M) Communications, and the Internet of Things (IoT) in general, can effectively operate on a worldwide scale (oneM2M, 2017). OneM2M standards aim at providing a solution to the problem of proprietary communication stacks and tight coupling between applications and devices, that is currently the norm (Rayes & Salam, 2017). Such a standardization can benefit a number of energy, and more specifically DR, use cases, such as energy analytics and smart meter reading (OneM2M, 2015).

The OneM2M functional architecture can be seen in Figure 6-3.The Field and Infrastructure domains, include the devices and gateways, and communication networks and data centres respectively (Rayes & Salam, 2017). OneM2M follows a layered model for M2M services, comprising of three layers: Application Layer, Common Services Layer and the Network Services Layer. The Application Entity (AE) implements an M2M application service logic. Each application service logic can be resident in one or a number of M2M nodes. An example of an AE is a power metering application, or a controlling application. The Common Services Entity (CSE) defines a set of common service functions of the M2M environments. These service functions are exposed to other entities through specific reference points (interfaces). Data and Device management are examples of functions offered by CSEs. Finally, the Network Services Entity (NSE) provides services from the underlying network to the CSEs. Examples of such services include location services and device triggering.

The specification further defines specific interfaces, called reference points, to allow information exchange and communication between interacting entities. The Mca and Mcn interfaces define communication flows between an AE and a CSE, and a CSE and NSE respectively. Mcc and Mcc' define the interactions between CSEs of the same or different, respectively, service provider.

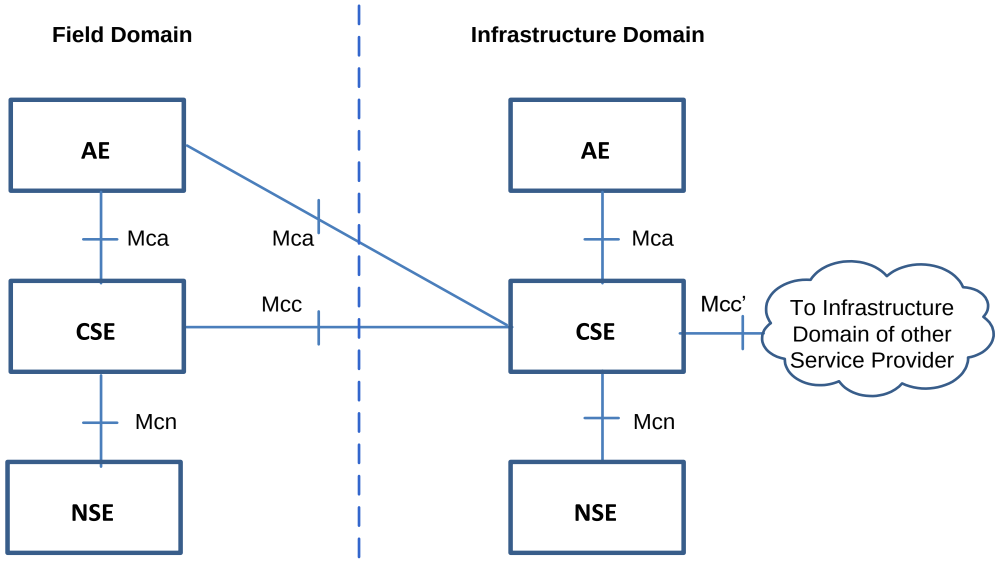


*Figure 6-3 OneM2M Functional Architecture. Source* (oneM2M, 2017)

### 6.1.4 USEF standard

The Universal Smart Energy Framework (USEF) standard was created with the objective of enabling cost-efficient connectivity of all smart energy projects and technologies. In more detail, the standard is designed to offer fair market access and benefits to all current and new stakeholders, define their individual roles and responsibilities, how they should interact, and how they can benefit, whilst at the same time restricting itself to a minimal set of specifications (USEF, 2015b).

One of the main parts of the standard is the USEF flexibility value chain, which utilizes DR through load shifting and the storage and management of locally generated energy, to provide new means of flexibility in the energy system (USEF, 2015a).

Figure 6-4 depicts the flexibility services, as defined by the standard, along with the associated stakeholders. The new role of the Aggregator plays a central role in the chain, since he is responsible for acquiring flexibility from prosumers, aggregating it, creating services based on this flexibility and finally offering these flexibility services to the markets (USEF, 2015a).

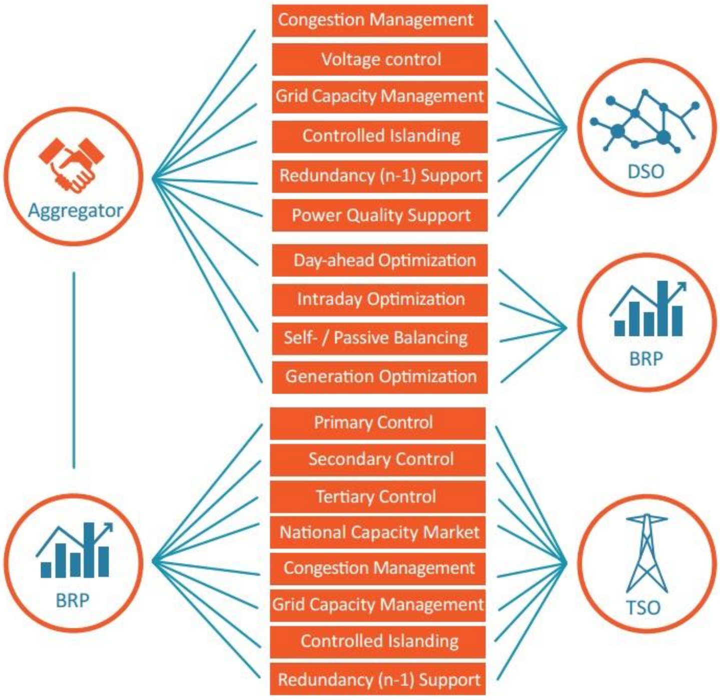


*Figure 6-4 Overview of the available flexibility services and the associated stakeholders in the USEF standard. Source* (USEF, 2015a)

The second important part of the USEF standard is the specification of a roles model, characterizing the different roles necessary for the new energy market, alongside their corresponding tasks and responsibilities, which can be implemented in various ways according to the local market and business needs. The accompanied interaction model distinguishes between the energy supply chain and the flexibility supply chain. While the energy supply chain is not changed, with respect to the established European energy market model, the flexibility supply chain is designed to maximize the value of provided flexibility (USEF, 2015a). An illustration of the flexibility chain is shown in Figure 6-5.

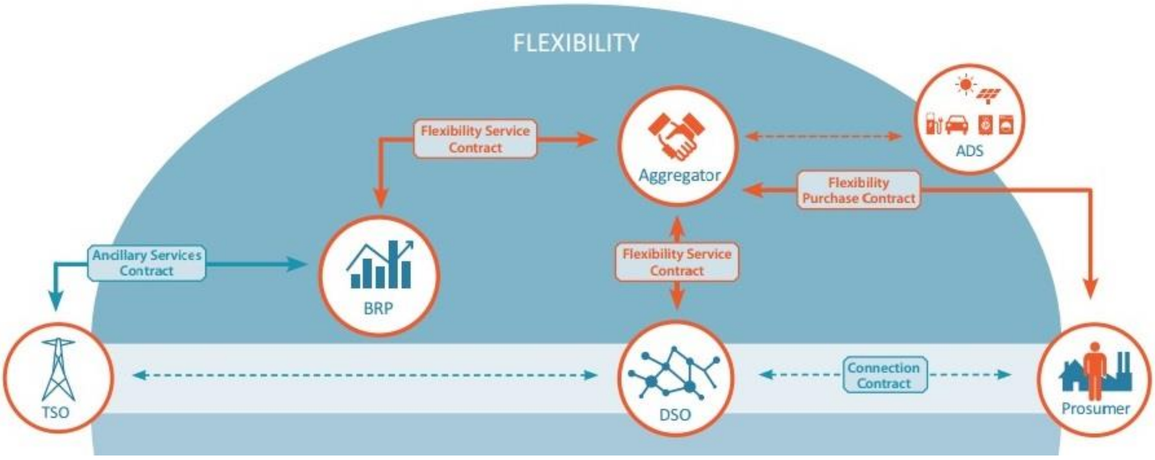


*Figure 6-5 The USEF's flexibility supply chain. Source* (USEF, 2015a)

Finally, USEF defines a Market-based Coordination Mechanism (MCM) along with new processes, in order to provide all stakeholders with equal access to a smart energy system. The MCM is split into five phases, namely Contact, Plan, Validate, Operate and Settle. The first phase includes the necessary contracting among the different stakeholders. In the planning phase the BRP and aggregator carry out an initial portfolio assessment and agree on this phase's results. During validation, the DSO determines whether the demand and supply of energy can be transported and distributed safely without limitations. If not, he can procure flexibility from the aggregators. The Plan and Validate phases can be iterated until forecasted energy is safely distributed. In the Operation phase, the actual assets are dispatched. The aggregator, BRP and DSO jointly maintain the system balance. Finally, in the settlement phase, any contracted flexibility sold among the BRP, DSO and the aggregator is settled (SEC, 2013; USEF, 2015a).

Enabling implicit and explicit DR programs necessitates a number of infrastructure upgrades to be made within the building areas, in comparison to the traditional hardware used for flat-rate energy tariffs. ICT technologies have a predominant role in these updates, since they, in combination with energy management systems, are required to provide 'interoperable, real-time and standards-based communication with service provider systems, seamless interaction with building occupants and in-home/ building devices, non-intrusiveness and automated control and operation on the basis of human-centric features'. In the following, mature technologies that allow the realization of implicit and explicit DR schemes are identified and described.

## 6.2 ICT TECHNOLOGIES FOR IMPLICIT DR

Implicit DR requires the installation of a few key technologies within the building, so as to provide utilities, business and residential customers with the possibility to monitor energy usage in a fine-grained scale, and allow demand modification according to electricity tariffs. In particular, we identify two main technologies necessary for implicit DR. First, Advanced Metering Infrastructures (AMIs), which, from the point of view of electricity suppliers, allow remote meter data reading of consumer-specific usage data, such as instantaneous and interval usage. This data is then utilized for dynamic pricing from the energy markets. Second, user communication and graphical interfaces, as well as applications that inform consumers on the time-varying tariffs and, possibly, further assist in the decision-making process regarding load control, through suitable energy analytics applications.

### 6.2.1 Advanced metering infrastructure

The Advanced Metering Infrastructure (AMI) constitutes the backbone of ICT technologies with respect to DR. AMIs, in their general form, are assumed to comprise of the following subsystems (Intracom, 2014; Longe, Ouahada, Ferreira, & Rimer, 2014; Römer, Reichhart, Kranz, & Picot, 2012):

#### *6.2.1.1 Smart Meters*

Smart meters lie in the heart of advanced metering, since they allow, at a minimum, the real-time or near real-time measurement of energy consumption and cost, which can be monitored, either automatically or on demand, both locally and remotely, through local and global network communications. Further capabilities can include metering of other consumption types such as gas and water, data processing, remote disconnection and reconnection capabilities, as well as integration with an energy management system.

#### *6.2.1.2 Meter Data Management Systems*

Meter Data Management Systems (MDMS) refer to application systems, along with databases and associated analytical tools that process the meter data and perform functions such as validation, estimation and storage of energy profiles. They also provide interconnection with billing systems and other application services. They are predominantly located at the utility's side, but can provide data tailored for end-user consumption as well.

### 6.2.2 Communication networks

The role of communication infrastructure is twofold. First, it provides interfaces linking smart meters to other electrical devices, allowing such management systems as in-home displays, which inform the consumer about energy consumption, prices or other emergency DR signals. Second, back-haul networks undertake the job of providing bi-directional communication to and from the smart meter devices and the MDMSs.

Through the aforementioned technology features provided by AMIs, implicit DR schemes (ToU, RTP, CPP, CPD) can be introduced in the market. In addition, AMIs have further benefits including increased consistency in billing periods, theft reduction and better troubleshooting. In summary, they provide efficient management of metering activities, which is a fundamental element needed for the introduction of other ICT technologies in power systems.

### 6.2.3 Commercially available solutions

A number of AMI solutions are offered in the market. Some prominent products are discussed below.

1. Huawei AMI:
   Huawei provides an integrated AMI solution, consisting of a master station DCP (Data Collection Platform), WAN (Wide Area Network), and NAN (Neighbourhood Area Network). The DCP contains a head-end and a MDMS system. The head-end system interacts with devices, manages communications protocols, adapts internet protocols, and collects and stores metering data. The MDMS manages data analysis, monitors the operating status of systems, compiles statistics, analyses reports, and further oversees operations and maintenance. The WAN supports various communication protocols, such as GPRS/3G, Ethernet, and medium-voltage Power Line Carrier (PLC). The NAN layer contains smart meters, Data Concentrator Units (DCUs), and local communication networks. Different communication protocols are supported between meters and DCUs, such as RS485, PLC, ZigBee, Sub-GHz or GPRS/3G. Smart meters integrate appropriate communication chips, e.g. the Huawei PLC chip, Sub-GHz chip or GPRS/3G chip. Applicability is reported to scale up to small state and large metropolitan grids (Huawei, 2013). Figure 6-6 shows the AMI architecture solution by the company.
2. Diehl AMI:
   The German company Diehl offers a complete AMI solution, which also allows integration with water and gas smart consumption metering. The MDMS system is provided in standalone, web-based and mobile versions. Communication between the MDMS and the data collectors and gateways can be performed through standard TCP/IP Internet and GPRS, while metering devices communicate with the gateways though wired or wireless M-BUS interfaces (Diehl, 2017).
3. Enel AMI:
   Enel, an Italian multinational manufacturer and distributor of electricity, also provides a complete AMI architecture. Communication between meters and local data concentrators is performed through Low and Medium Voltage PLC, while TCP/IP is used between concentrator and MDMS. The system provides the additional ability to employ multiservice data collectors, which can also aggregate heat, gas and water consumption using RF communication protocols (Enel, 2016).

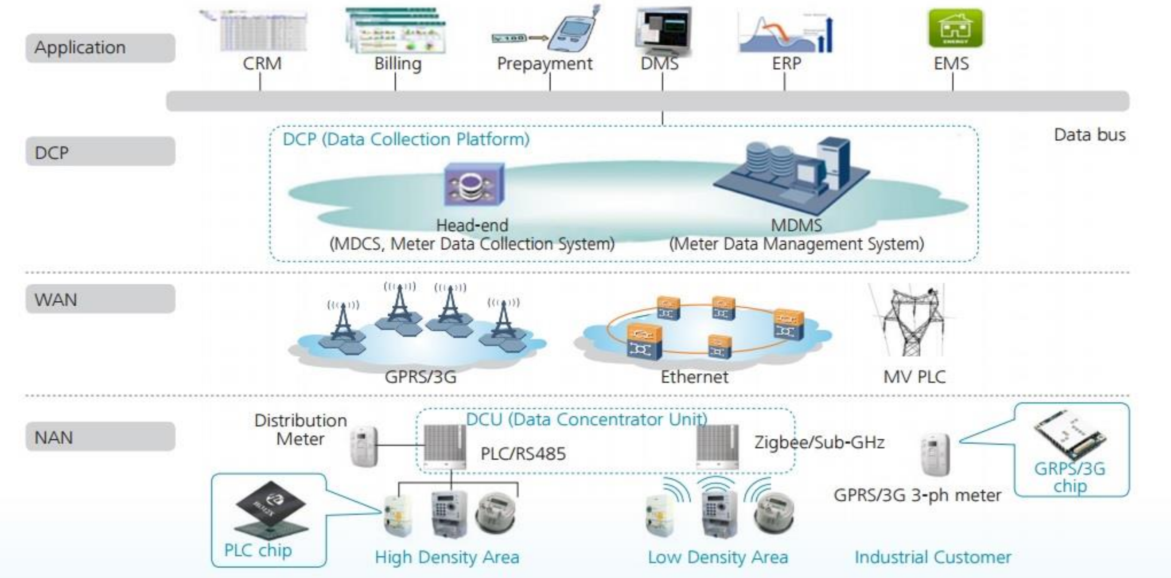


*Figure 6-6. AMI Solution by Huawei. Source* (Huawei, 2013)

#### *6.2.3.1 Cost*

Information on AMI installation and maintenance costs is scarce. Based on reported data on SmartGrid.gov, an online resource for information about the Smart Grid and government-sponsored Smart Grid projects in the US, the average cost of smart meters can be computed to be between 150 and 200 dollars per device (SmartGrid, 2015). Communication infrastructure and further IT systems cost can range from as low as the price of an internet connection, up to thousands, for a complete solution that will also allow complete bi-directional communication and automated control over individual loads and detailed data monitoring and analysis.

### 6.2.4 User interfaces and applications

An important aspect of implicit DR infrastructure is to provide the end user with correct, on-time and comprehensive information regarding energy consumption and cost, so as to facilitate the decision-making process. A number of different technologies can be identified with respect to this functionality:

#### *6.2.4.1 In-home displays*

In-home displays (IHDs) connect directly to the smart meter and/or the home and internet network, in order to supply the consumer with the appropriate information, which can range from real-time energy usage values and the associated cost, to critical electricity pricing events, time-varying tariffs associated with the DR program, as well as current and estimated bills.

#### *6.2.4.2 Mobile apps and Web-based Services*

Mobile applications and web services have emerged as an alternative to in-home displays, since they can serve the same purpose as IHDs, without incurring the additional cost of having to supply actual hardware devices. A further potential advantage of this technology is that it could drive manufacturers to adopt common communication protocols, increasing thus interoperability of the related infrastructure.

#### *6.2.4.3 Energy Analytics Applications*

Going a step further from simple reporting of observed consumption values, energy analytics applications have been created, which draw upon the accumulated energy data, collected via smart meters, and analyse these data to provide insights and possibly optimization suggestions regarding user consumption profiles and behaviour, both to the utilities and the end-users.

### *6.2.4.4 Commercially Available Solutions*

Due to the flexibility of communication pathways and the multitude of analysis opportunities, a plethora of commercial solutions exist in the market of user interfaces and applications. Below we demonstrate this fact and present a number of available products, provided by start-ups up to large multinational energy and ICT companies.

1. Landis+Gyr IHDs:
   Landis+Gyr, based on Switzerland, focuses on metering and other technologies which deal with management of energy. Among their range of residential, commercial and industrial products, they provide a number of IHD solutions, supporting wireless communication with smart meter devices, and been able to display energy and tariff data, as well as receive messages and alerts from the utility regarding tariff changes, planned power outages and other useful information (Landis and Gyr, 2016).
2. Elster IHDs:
   Elster, a provider of solutions for commercial, industrial, and residential heating systems and gas, water, and electricity meters, offer a range of IHDs, compliant with published government regulations. Functionalities include measurements of electricity and gas energy usage in terms of money, kWh and $CO_2$ emissions, message transmission to and from the utilities, such as prepayment or event information (Elster, 2017).
3. Atmel IHDs:
   Atmel Corporation, a manufacturer of microcontrollers and touch technology semiconductors, provide a wide range of IHD units, from simple wall-mounted LCD displays, to products with TFT displays and touchscreens. Consumption information can be transmitted to the IHDs through RF and/or PLC communication, while advanced IHD offers can also integrate consumption advice from energy providers, as well as additional functionality regarding home automation (Atmel, 2017).
4. Onnergy Energy App:
   Onnergy from Netherlands offer a free energy monitoring app. It allows both manual and automatic data input from a smart meter, and can manage electricity, gas and water consumption. In addition, it provides additional functionality, in the form of remote control functionality towards other smart devices, such as lights, thermostats, plugs and shutters (ONnergy, 2017).
5. British Gas My Energy App:
   British Gas provides its customers with a mobile application that allows users to track their energy use by day, week, month and year, compare energy usage to similar houses and receive recommendations on energy cost reductions (British Gas, 2016).
6. Wattics Energy Analytics Web Application:
   Wattics is an Irish company offering an energy management and analysis web-based platform tailored for ESCOs, energy managers and utilities. It provides a number of features, such as budgeting, cost/use reporting, energy price analysis, load forecasting, meter tracking and weather normalization. The cost per user comes to around 200$ per year (Wattics, 2017).
7. SMAP Energy Smart Meter Analytics Platform and AIswitch:
   SMAP Energy, a British-based start-up, provides two energy analytics applications tailored for the energy retailers and consumers respectively. The Smart Meter Analytics Platform (SMAP) provides utilities with a number of advanced data analytics applications, based on the concentrated consumption data of their consumers. In particular, it offers individual and aggregated consumer profile analysis, simulations of load shifts to allow formulation of appropriate business plans, as well as outlier and anomaly detection, which can help identify

faulty equipment. On the other side, Alswitch implements a recommender system for the end-user. It is a free web-based service aimed at analysing individual consumer habits and suggesting the most profitable deals (SMAP Energy, 2017).

8. Oracle Energy Analytics Suite:

   Oracle provides a comprehensive suite of energy analytics applications. Among others, the Utilities Analytics platform allows location-based analyses of energy events and issues incorporating Underpinning additional information, such as real-time weather data. The Utilities Network Management System performs predictive load and outage profiling, as well as grid optimization. Finally, the Utilities Opower Customer Service Interface is tailored towards the end users, which can view detailed monthly energy paralleled with weather and billing data (Oracle, 2017).

9. Silver Spring Networks:

   Silver Spring Analytics, a provider of smart grid products, headquartered in USA, offers a list of IoT applications, including energy analytics. Their Operations Optimizer software offers monitoring for meter data collection, delivery problems and meter safety issues, management of AMI deployments and AMI network performance. Furthermore, it can aggregate and analyse metering loads across a distribution system in order to identify asset risks and connectivity mismatches, support load planning, and estimate technical losses (Silver Spring Networks, 2017).

It is important to stress that this list is not exhaustive, but rather suggestive of the available technologies in the market. In addition, we have not reported on apps focusing primarily towards the residential user, which provide various functionalities such as monitoring and recommendation, but require manual input of the energy consumption data.

#### *6.2.4.5 Cost*

As implied by the extended list of available products, the cost of interfaces ranges significantly, based on a number of choices, such as software app vs dedicated hardware, data visualization vs data analysis, support and consultancy. Free applications for monitoring and simple analysis of energy consumption data exist. In-home displays can be acquired with an investment of about €100-200 (SmartGrid, 2015). Additional services can incur much higher costs.

## 6.3 ICT TECHNOLOGIES FOR EXPLICIT DR

While Implicit DR is quickly becoming established in the energy market, not least due to the relative ease of installation of the required ICT infrastructure in current buildings, the full potential of explicit DR can only be realized by further integration of new and updated technologies that will allow reliable aggregation of DR capacity and its participation in energy markets. A key requirement, not in place for implicit DR, is the need for increased automation, both with respect to data transfer and communication, and also management and control of electrical equipment and loads.

An overview of the different technological subsystems, whose interplay forms the necessary foundation for the implementation of explicit DR programs is shown in Figure 6-7. The Home/Building Energy Management System (HEMS/BEMS) constitutes the decision control centre and gateway between the building and outside world. It controls the main subsystems that can offer DR flexibility, namely Heating, Ventilation and Air-Conditioning (HVAC), Lighting, Energy Storage, Generation and Electric Vehicles (EVs). In the following, we describe these subsystems from the perspective of the utilized ICT technologies, and further present specific solutions currently available in the market.

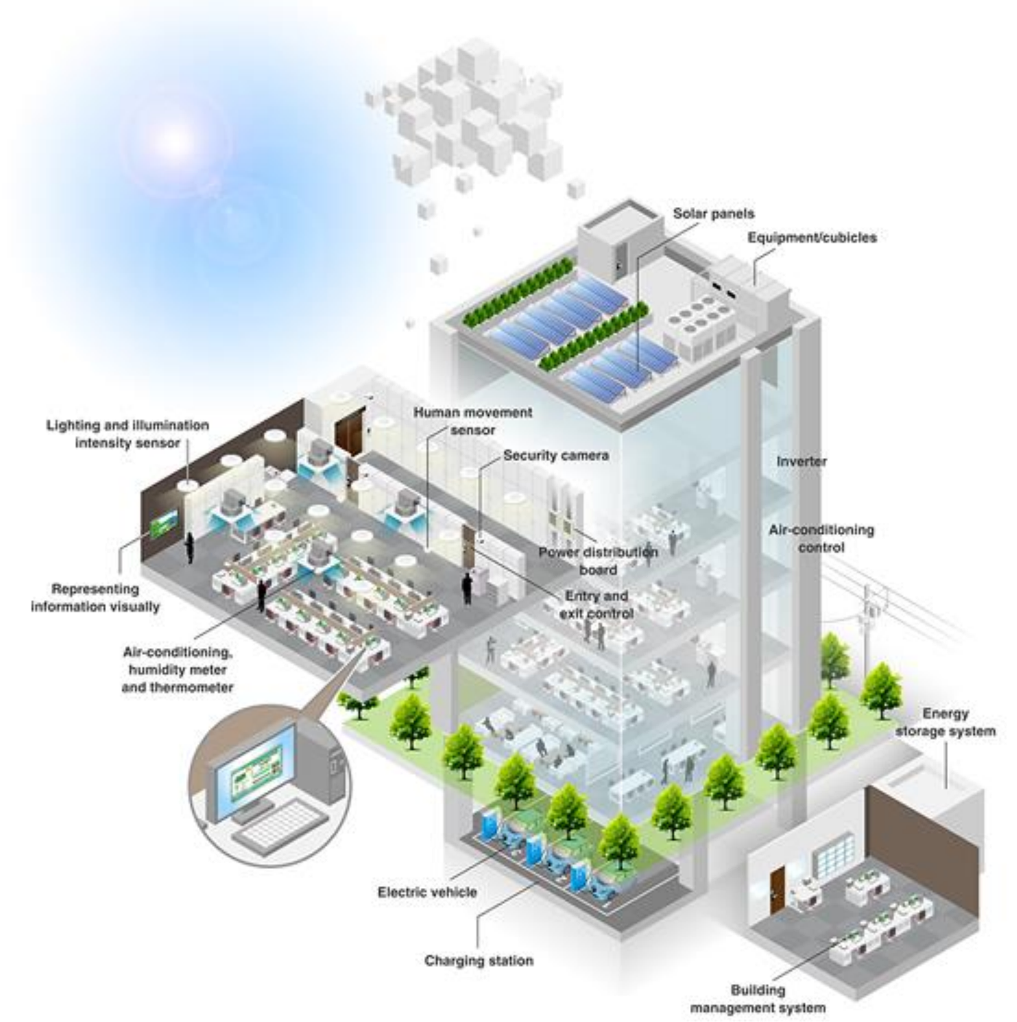


*Figure 6-7 Explicit DR enabling technologies. Source* (NEC, 2017)

### 6.3.1 Smart thermostats

The main component of an HVAC system that exposes DR control functionalities to the user and the utilities is the thermostat, which is responsible for the operation of thermostatically controlled loads, such as boilers, heat pumps, refrigerators and air conditioners. Smart thermostats offer automated operation of the various loads according to predefined or learnt comfort levels, as well as communication and information exchange with the advanced metering infrastructure and the building management system.

#### *6.3.1.1 Commercially Available Solutions*

Reported commercial solutions are limited to the case of smart thermostats, since these are the main DR enabling devices for HVAC, along with the communication infrastructure.

1. Google Nest:
   Google is offering a smart thermostat called Nest, which is a programmable and self-learning Wi-Fi-enabled thermostat, targeted for residential buildings and small businesses. A key feature of Nest thermostat is the incorporation of a machine learning algorithm, which learns people's schedule, and their preferred room temperatures at different times of day. Based on this learning process and the input from sensors, as well as other smart devices, such as the residents' mobile phone location, it can automatically alter its operational mode. Apart from

Wi-Fi connectivity, Nest has a built-in 802.15.4 radio element, which though uses a proprietary communication protocol (Nest, 2017).

In the US, EnergyHub, a provider of connected device management for utilities, has incorporated Nest's Rush Hour Rewards program to its DR portfolio. The Rush Hour Rewards program offers incentives to the end users to allow management of the thermostat's temperature through DR events, in order to maximize the load reduction while still keeping customers comfortable (EnergyHub, 2016).

2. Honeywell Commercial Thermostats:

   Honeywell make a range of thermostats, suitable for applications ranging from home use to heavy-duty industrial applications. Their commercial offerings allow connectivity with, and control of, up to 24 HVAC appliances (Honeywell, 2017b).

3. Siemens SED2 Variable Frequency Drives:

   The Siemens SED2 device is an example of a fan speed controller that can be integrated into ventilation systems, in order to allow control over the consumed load, and consequently enable fine-grained flexibility. The SED2 supports communication with the energy management system through a number of protocols, including building automation system protocols for easy network integration Modbus RTU and BACnet (Siemens, 2017).

#### *6.3.1.2 Cost*

The cost of smart thermostats per device has become more reasonable over the last few years, and should fall within the range of €150-400 per device (SmartGrid, 2015).

### 6.3.2 Supportive sensors and actuators

So far, we have described an array of information and technology solutions for the realization of flexible demand in the electricity capacity. It is of paramount importance though, when discussing and implementing such programs, to take into consideration the preferences and comfort requirements, as set by the end user. Occupancy information, which can be extended both to the occupants' number and identity, environmental conditions, activity, time of day, are, among others, factors that can dramatically affect the limits of acceptance for exterior control over loads, and need to be taken into consideration by the energy management system. To this end, the automated gathering of information relating to such variables can be crucial for DR. In the following paragraphs, we present the different types of supportive sensor technologies, with which DR programs can offer human-centric services and gain wider acceptance from the consumers.

#### *6.3.2.1 Occupancy sensors*

Occupancy sensors are devices that detect presence or absence in an area. This information can then be sent to building controllers which turn lights and other equipment on or off based on whether or not the space is occupied. This action can present significant energy savings, especially in commercial buildings. Technologies that are commonly used for manufacturing occupancy sensors include Passive Infrared (PIR), ultrasonic, and microwave. In addition, cameras, as well as environmental sensors, measuring temperature, $CO_2$ or even humidity could also be used for this purpose (Mullassery, 2015).

PIR sensors work by detecting heat movement. A pyroelectric element inside the device is calibrated to detect infrared radiation by human body movement. One important aspect of PIR sensors is that they are a passive energy component, meaning that they do not emit energy to detect movement. Therefore, during idle operations when there is a minimal movement, these sensors are highly efficient. Ultrasonic sensors send high frequency sound waves in the area and check for their reflected patterns. If these are changing continuously then occupancy is assumed. They are highly precise, since even small movements can be detected. This attribute though can also result in issues of false activation or unwanted triggering of the sensor, as the detection range may extend into adjacent spaces. Furthermore, any random movement of other systems, like airflow could trigger them. Microwave sensors are similar to ultrasonic ones, since they are also based on the Doppler shift principle, but instead of high frequency sound waves, they emit electromagnetic signals. Both previous types are active components and require a constant and continuous supply of electrical energy. Video feed from a camera can also be used for occupation detection, as well as more elaborate functions, including surveillance and identification. The cost of installation is higher, so consideration must be given here, on whether the additional features provided by this option are really required for the applications at hand.

#### *6.3.2.2 $CO_2$ and VOC Sensors*

$CO_2$ and Volatile Organic Compound (VOC) sensors can be used to monitor the quality of air in a room, and inform the HVAC and management system of the need for fresh air. Energy is saved when pollutant loads are low and ventilation can be reduced, which may occur during or after occupied hours. These types of sensor instruments can also provide information on the number of occupants in a room, as well as help detect problems in the ventilation system.

#### *6.3.2.3 Temperature Sensors*

Radiant building and room temperature play the prominent role in human thermal comfort. In DR programs, the user should be able to provide acceptable temperature limits, which the energy management system guarantees to satisfy at all times. For this purpose, temperature sensors must be integrated into the ICT infrastructure.

#### *6.3.2.4 Humidity Sensors*

Humidity is defined as the presence of water in air. The water vapour content or humidity can affect the occupant comfort, or even the operability of electrical devices and equipment. Thus, humidity monitoring is important both in commercial, as well as in residential spaces.

#### *6.3.2.5 Luminance Sensors*

Luminance sensor detect the intensity of the ambient light in its surrounding region. For the purposes of energy management, illumination information both within and outside the building area can be used to automate the luminosity in the lighting system.

Switching and dimming controllers are responsible for accepting signals from the management system or the user interfaces and provide on/off or dimming control for a small number of lighting loads. Such controllers may also provide bi-directional communication, offering back information on energy consumption and usage profiles.

#### *6.3.2.6 Commercially Available Solutions*

Most companies offering complete energy management solutions, also provide an array of suitable sensors. For example, Eaton, offers sensors combining PIR and ultrasonic technologies, to help eliminate false activations or deactivations (Eaton, 2017), while Leviton provides PIR-based sensors with built-in solar cells that draw on available ambient light to power themselves, and cameras with Wi-Fi connectivity, which also provide the ability to view live footage remotely (Leviton, 2017a, 2017c).

Concerning Luminance sensors Philips offers a wide set of sensors and actuators that allow lighting control according to different parameters.

#### *6.3.2.7 Cost*

The cost is comparable between the different types of sensors and ranges between €15 to 100 per device.

# 7 BUILDING ENERGY MANAGEMENT SYSTEMS (BEMS)

Energy management systems have as their objective the maximization of energy efficiency in a building, alongside minimizing energy costs for the consumer, by making clever use of the energy resources and loads available in a building. This key role necessitates the establishment of bi-directional communication to the other building equipment, for energy data collection and control.

With the advent of DR, the management systems are now required to support further interaction with external sources of information, e.g. energy suppliers and aggregators, and enable new functionalities such as load aggregation and critical DR event handling (Lee, 2016). At the same time, the systems must always respect the comfort levels and control constrains imposed on them. Figure 7-1 illustrates this intricate interconnection of BEMS with other entities in the energy network (Griful, Welling, & Jacobsen, 2016). Indicatively, a complete BEMS installation, including IoT-based controls and monitoring to a building (~700 square meter) can cost around $5000. Further, additional operation and maintenance fees may apply and should range between 15% - 20% of the annual revenues.

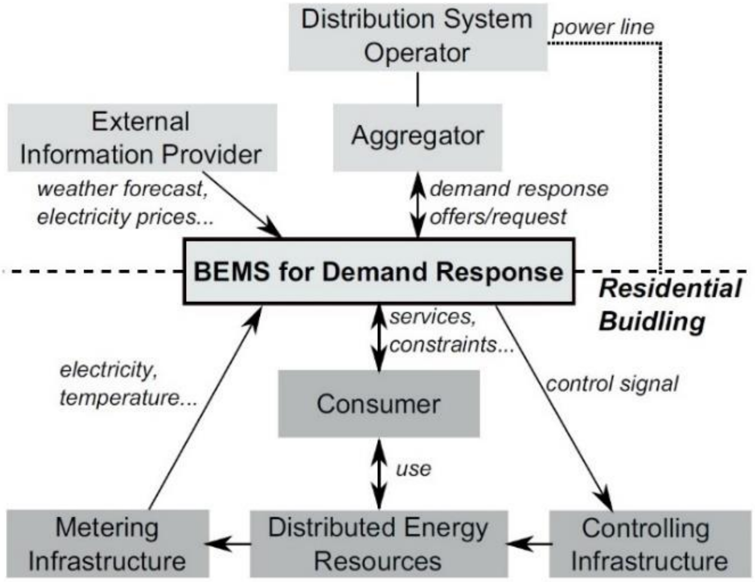
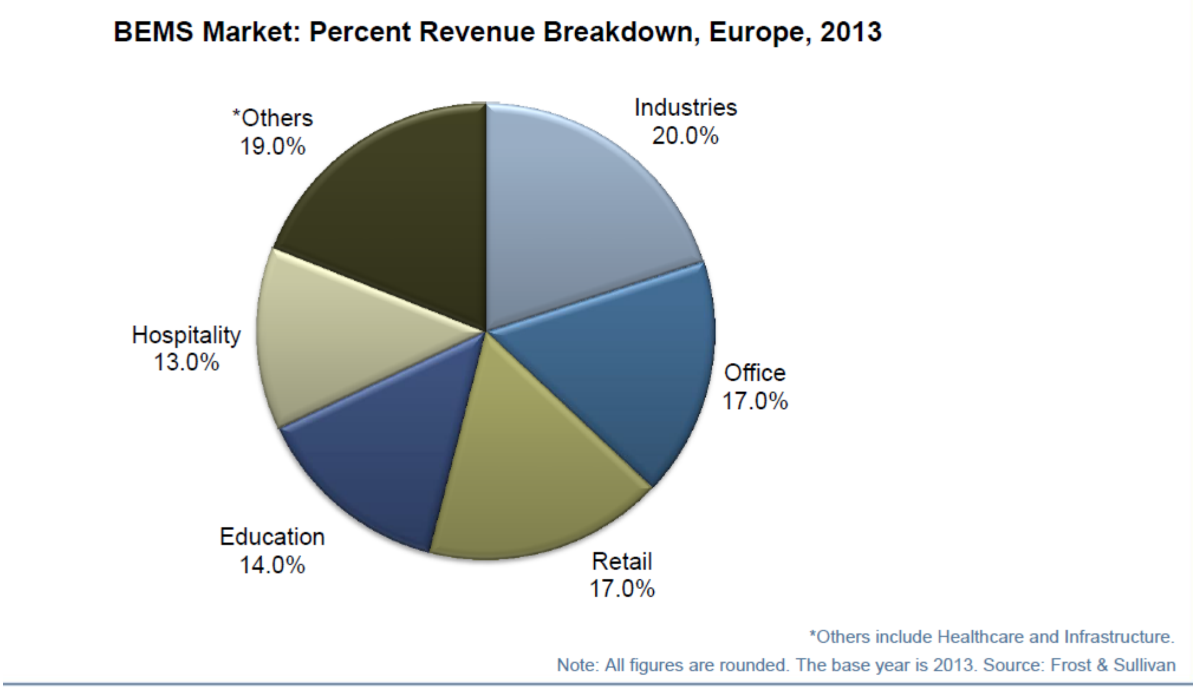


*Figure 7-1 The role of HEMS/BEMS in Explicit Demand Response. Source* (Griful et al., 2016)

## 7.1 EUROPEAN BEMS MARKET: MARKET SIZE AND KEY MARKET DRIVERS

There was always a blurred line between building automation systems, building management systems and building energy management systems. For the avoidance of confusion, the following analysis of HEMS and BEMS uses the following definition: BEMS measure, monitor, and track the actual performance of building services such as HVAC, lighting systems, and other key consumers of energy. They identify the deviation and ensure the operation is being managed and controlled to deliver the most energy-and emission-efficient level of productivity.

The current total BEMS market in Europe is estimated at **$1,596 million for 2018** (Frost and Sullivan), with a compound annual growth rate of 11.2% (2013-2018). The main market segments are presented in Figure 7-2.



BEMS Market: Percent Revenue Breakdown, Europe, 2013

*Others include Healthcare and Infrastructure.

Note: All figures are rounded. The base year is 2013. Source: Frost & Sullivan

*Figure 7-2 – BEMS market revenue breakdown*

While this sustained increase in the market value was influenced by various factors, there are a few major trends that have influenced this market strongly and will continue to do so in the future:

- Increasing energy prices will continue to put pressure on the end-users and increase adoption of BEMS solutions.
- Big Data analytics and cloud-based infrastructure are expected to take a technology leap during the next 5 years, thereby helping the software markets linked BEMS to grow at an accelerated rate.
- EU buildings' directive and legislation mandates energy efficient buildings which will accelerate the adoption of Building Automation Services (BAS).

Convergence of ICT and building technology industries has made building automation more advanced in terms of complete integration, monitoring operations and maintenance features, and energy and demand management.

## 7.2 BEMS DESIGN, SALES AND DEPLOYMENT MODELS

At the moment the BEMS market is dominated by system integrators and distributors who together, amount for 60% of the market as shown in Figure 7-3.

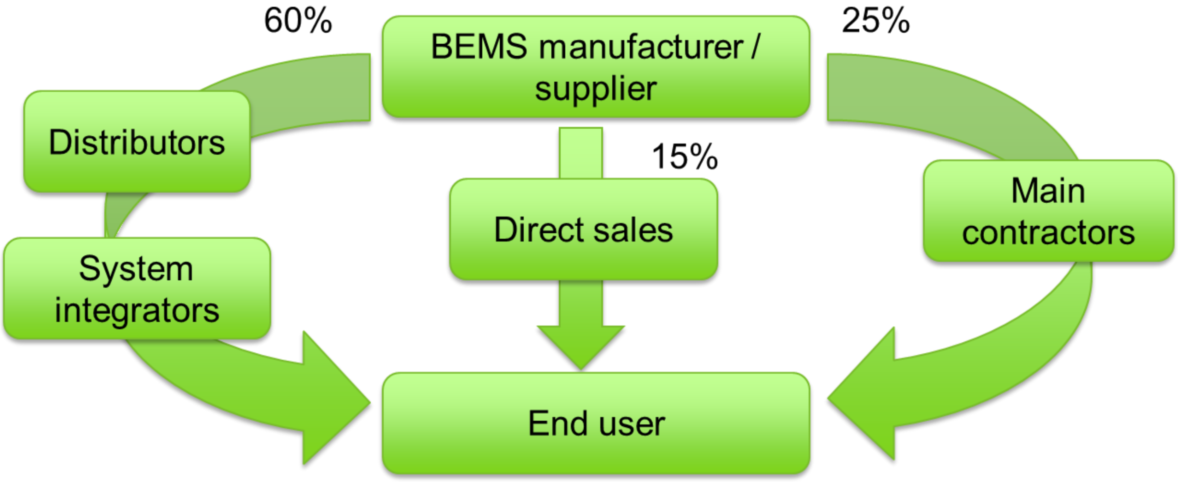


*Figure 7-3 – BEMS system distribution channel analysis*

The increasing interoperability of hardware components, use of open source software and standard communication protocols has allowed for system integrators to be able to offer a wide selection of hardware and software equipment, sometimes mixing new software solutions and monitoring equipment with existing building controls to enable a higher degree of monitoring and energy efficiency. Based on this, we can distinguish 2 types of system integrators:

- Independent SI – they offer a range of solutions from multiple vendors, sometimes mixing controllers, metering equipment and dashboard from different vendors.
- System Houses – they usually supply a single brand solution

Big companies such as Siemens, Schneider, Honeywell, and Johnson Controls dominate the high end of the market which is a complete solution delivery based business for large infrastructures. These companies feel the pricing pressure to compete in the **mid-market and lower end of the market**, which includes **medium sized and standalone small buildings**.

As a breakdown between hardware and software components, the total revenue in the BEMs market is dominated by hardware products such as metering, monitoring and control systems. The average physical price of a BEMS hardware unit is forecasted at $450 in 2018.

The BEMS software market has a totally different structure from the hardware market in terms of technology and its growth had been driven by the emergence of cloud based services and decreasing cost of generating, storing and analysing large sets of data in order to extract meaningful results. This has resulted in proliferation of service providers / consultants focused just on data management and value added services. The average software price for a BEM solution is forecasted at $5000 for 2018.

## 7.3 BEMS TECHNOLOGIES

As a technology, BEMs sit at the intersection of building automation systems and ICT solutions. Simple BEMs solution could be considered software tools that allow tracking of energy spending by type, make simple correlation analysis (such as degree days analysis) and overlap those analysis to the users profiles to identify potential energy savings. Actionable points are issued to facility managers / energy efficiency managers and they rely on operation and maintenance staff as well as end users to implement those actions. At the opposite end of the spectrum, there are fully integrated BEMS which have independent data collection, data analysis and strategy execution layers. These sometimes integrate energy metering data for electricity, heating and cooling with direct controls over the main assets – HVAC, chillers, boilers, RES, lights, elevators, access management, fire protection systems etc., and have complex strategies to support variable times of use tariffs, network access charges, demand response services, feed-in tariffs, and peak demand management so to ensure that maximum energy efficiency is achieved given the existing resources and the occupants profiles.

### 7.3.1 Energy bureau services

Energy bureau services provide the missing link between the energy metering services and the client dashboard / analytics layer that allows the facility managers to implement energy efficiency actions. However, they provide limited or no integration with the control infrastructure and very often this is limiting the ability of FM personnel to execute and implement the energy efficiency actions suggested by the system. Providers of services in this area include:

- Enernoc: their Energy Intelligence Software provides solutions for commercial buildings as well as manufacturing facilities. The platform offers features such as real time monitoring, facility optimisation and analysis, project tracking, utility bill management and sustainability reporting.
- Schneider Electric Energy bureau services – while Schneider offers complete end to end BEMS, one of their services is based just on an AMI and data analysis platform allowing customers to keep track of their electrical energy usage and cost and implement energy efficiency actions based on the platform recommendations.

### 7.3.2 Building Management Systems (BMS) solutions

Building Management Systems provide building owner and facilities managers with the tools to automate the operations of buildings. Traditionally, a BMS focus would be on providing controls over the main building processes – such as HVAC systems, backup generators, light systems, access control, fire prevention and suppression systems, etc. Typically, on commissioning, a strategy would be agreed with the building owners or end-user, incorporating requirements around occupants' level of comfort, operating on a daily, weekly and monthly basis, etc., as well as some energy efficiency strategies – e.g. optimal start. However, energy efficiency and energy management was not their primary functionality. Newer systems however sit much closer to BEMS as they provide out of the box some analytic tools and interfaces that allow automation of energy saving actions and integration with third party service providers such as ESCOs and Demand Side Response (DSR) providers. As with the BEMS, the European market is dominated by 4 major players which together concentrate more than 78% of the building automation market: Siemens, Honeywell, Johnson Controls and Schneider Electric. Their new range of BMS are designed to fully integrate with BEMS or form part of BEM platforms. Honeywell in particular now has 3 brands in their BMS offer, as their acquisition strategy in the past 5 years has been very aggressive:

- Trend: a UK based brand using proprietary protocols for their IQ series controllers.
- Centraline: a European company specialising in bringing building systems and services together such as lighting, sun blinds, security, metering, heating, ventilation and air-conditioning. This integration is done via Niagara framework, which is also owned by Honeywell.
- Saia Burgess Control – A Swiss brand specialised in SCADA systems suitable for highly automated industrial processes and programmable controllers.

Siemens' latest BA offer with their DESIGO brand is almost impossible to differentiate from the BEMS offer. Their new range of controllers are compatible with the most popular BEMS protocols such as Modbus and BACnet, offering support for retrofit actions as well as new design projects. The controllers are then integrated into a suite of dashboard and analytics services based on customer industry profiles and specific needs.

## 7.4 BEMS PROTOCOLS AND INTERFACES WITH DSR SYSTEMS

Depending on the specific technology pass adopted by the DSR providers, there are different ways of interfacing BEMS / BMS systems with Aggregators' platforms and edge equipment. There are 2 ways in which a BEMS can interface with a DSR system:

- Locally through DSR edge hardware – in this case, the asset dispatch signal is transmitted locally by the DSR hardware to the controlled asset. Depending on the type of edge hardware used by the DSR provider, this can be either a PLC, in which case communication with the controlled asset can be via any of the standard industry protocols such as BACnet, Modbus etc. or it can be a proprietary hardware that is using a digital or analogue signal that is interpreted by the BEMS in a particular way, or again using one of the industry standard protocols such as Modbus. This can include 0-10VDC or 4-20mA analogue signals that can be modulated to a certain asset output, such as the asset is conditioned to operate at say 50% capacity by sending a 12mA current signal.
- Remotely – the BEM system has a backend interface with the DSR system (usually via an API) and the BEM system has a DSR strategy implemented – e.g. when there is a dispatch signal received from the DSR provider via the API, the BEM will automatically start a backup generator or will limit the operation of certain assets to only a small percentage of their full power. The choice of API to be used between the systems usually depends on the BEMS vendor but typically this include standard RESTfull or SOAP architecture.

### 7.4.1 NIAGARA / SEDONA frameworks

Niagara is a Java software framework and infrastructure with a focus on three major problems:

1. Integrating heterogeneous systems, protocols and fieldbuses
2. Allowing non-programmers to build applications using graphical programming tools
3. Targeting highly distributed, embedded systems

The main components of the Niagara architecture are:

- **Programs -** there are typically four different programs (or processes) associated with a Niagara system:
  - ***Station*** is the Niagara runtime - a Java VM which runs a Niagara component application.
  - ***Workbench*** is the Niagara tool - a Java VM which hosts Niagara plugin components.
  - ***Daemon*** is a native daemon process. The daemon is used to boot stations and to manage platform configuration such as IP settings
- **Protocols -** there are typically three network protocols that are used to integrate the four programs described above:
  - ***Fox*** is the proprietary TCP/IP protocol used for station-to-station and workbench-to-station communication

  - ***HTTP*** is the standard protocol used by web browsers to access web pages from a station
  - ***Niagarad*** is the proprietary protocol used for workbench-to-daemon communication.
- **Platforms -** Niagara is hosted on a wide range of platforms from small embedded controllers to high end servers:
  - ***JACE***: the term JACE (Java Application Control Engine) is used to describe a variety of headless, embedded platforms. Typically, a JACE runs on a Flash file system and provides battery backup. JACEs usually host a station and a daemon process, but not workbench. JACEs typically run QNX or embedded Windows XP as their operating system.
  - **Supervisor**: the term Supervisor is applied to a station running on a workstation or server class machine. Supervisors are typically stations that provide support services to other stations within a system such as history or alarm concentration. Supervisors by definition run a station, and may potentially run the daemon or workbench.
  - **Client**: most often clients running a desktop OS such as Windows or Linux access Niagara using the workbench or a web browser.

Any systems using Niagara 4 will have the advantage of being able to interface with a wide range of legacy controllers using any of these protocols:

- Modbus (TCP over Ethernet or RTU/ASCII over RS-485/RS-232)
- BACnet IP / BACnet SM/TP
- Trend IQ/IP network
- LonWorks (this requires also a Lon-Chip to be added to the CPU board)
- CCN (Carrier Comfort Network)
- Tridium Fox/Niagarad (used by Honeywell, Johnson Controls and others)
- oBIX (Open Building Information Exchange) – allows further integration with systems and platforms such as Haystack / Django (Open Source)

One of the main drawbacks is the cost – the licensing systems applies per data point and per protocol and is payable annually, so complex systems with high data demands can easily ramp up operational cost in perpetuity.

On the plus side, the JACE controllers and their equivalent are well known in the industry, contractors are in most cases familiar with installation, configuration and commissioning processed and the platform is perceived as reliable.

### 7.4.2 BMS protocols

#### *7.4.2.1 BACnet*

BACnet is "a data communication protocol for building automation and control networks." BACnet was developed by a committee formed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). To achieve interoperability across a wide spectrum of equipment, the BACnet specification consists of three major parts. The first part describes a method for representing any type of building automation equipment in a standard way. The second part defines messages that can be sent across a computer network to monitor and control such equipment. And the third part defines a set of acceptable LANs that can be used to convey BACnet communications.

#### *7.4.2.2 MODBUS*

As a serial communications protocol published by Modicon in 1979 for use with its programmable logic controllers (PLCs), it has become a de facto standard communications protocol in industry, and is now the most commonly available means of connecting industrial electronic devices. Modbus filled some of the needs of the building-automation community prior to BACnet but, coming from the industrial world, it was not originally designed for the needs of buildings data.

#### *7.4.2.3 EnOcean*

EnOcean is a proprietary solution aimed at BMS, defining the physical medium, the communication medium and sensor profiles. EnOcean technology is based on the energetically efficient exploitation of applied slight mechanical excitation and other potentials from the ambiance using the principles of energy harvesting.

#### *7.4.2.4 KNX*

KNX (pronounced Konex) is an OSI-based network communication protocol for intelligent buildings. KNX covers whole stack from presentation down to physical layer. Devices are interconnected with multi-drop bus (ABB i-bus EIB). Datagrams contain typed data structures with standardized semantics.

#### *7.4.2.5 ZigBee*

Recently sensors, area controllers and zone controllers have been deployed on wireless mesh systems. 802.15.4 based mesh systems seem to be the technology of choice by most manufacturers due to the cost point of the radio technology and communication robustness. ZigBee is a suite of high-level communication protocols to be used over the IEEE 802.15.4 standard. ZigBee incorporates device and service discovery. ZigBee Device Objects (ZDO) exhibit the functionality in a given device, introducing a set of related commands. For a given profile and device, the ZigBee standard specifies which ZDOs should be supported and which clusters they can serve. ZigBee and ZigBee Pro have specified a proprietary networking solution, using features from the underlying IEEE 802.15.4 communication medium. In order to expand the interoperability to other media such as low-power 802.11 and Powerline Communication (PLC), IP networking is being integrated, placing ZigBee over the IP stack for resource-constrained networks currently standardised at the IETF. Subsequently, ZigBee abandons networking and moves towards application profiles and device and service discovery.

#### *7.4.2.6 Z-Wave*

Z-Wave was initially designed for consumer light control systems by the Danish company Zensys. This later evolved into Z-Wave, a proprietary System on a Chip (SoC) home automation protocol on an unlicensed frequency band in the 900MHz range. The chip for Z-Wave nodes is the ZW0500, built around an Intel MCS-51 microcontroller with an internal system clock of 32 MHz. The RF part of the chip contains an GisFSK transceiver for a software selectable frequency. With a power supply of 2.2-3.6 volts, it consumes 23mA in transmit mode. Its features include AES-128 encryption, a 100kbps wireless channel, concurrent listening on multiple channels, and USB VCP support. These features made the Z-Wave ideal for low power sensors, however the protocol hasn’t gained much traction outside the smart home automation applications. While there are off the shelf available Z-Wave sensors, the protocol seems to be lacking integration / support with traditional BMS hardware vendors.

### 7.4.3 IoT protocols:

#### *7.4.3.1 MQTT*

MQTT (MQ Telemetry Transport or Message Queuing Telemetry Transport) is an ISO standard (ISO/IEC PRF 20922) publish-subscribe-based messaging protocol. It works on top of the TCP/IP protocol. It is designed for connections with remote locations where a "small code footprint" is required or the network bandwidth is limited. The publish-subscribe messaging pattern requires a message broker.

#### *7.4.3.2 CoAP*

The Constrained Application Protocol (CoAP) is a specialized web transfer protocol for use with constrained nodes and constrained networks in the Internet of Things. The protocol is designed for machine-to-machine (M2M) applications such as smart energy and building automation. Like HTTP, CoAP is based on the wildly successful REST model: Servers make resources available under a URL, and clients access these resources using methods such as GET, PUT, POST, and DELETE. Since HTTP and CoAP share the REST model, they can easily be connected using application-agnostic cross-protocol proxies. Like HTTP, CoAP can carry different types of payloads, and can identify which payload type is being used. CoAP integrates with XML, JSON, CBOR, or any data format of your choice. CoAP is designed to use minimal resources, both on the device and on the network. Instead of a complex transport stack, it gets by with UDP on IP. A 4-byte fixed header and a compact encoding of options enables small messages that cause no or little fragmentation on the link layer. Many servers can operate in a completely stateless fashion.

### 7.4.4 Software integration through common protocols and software interfaces

The two most widely used protocols by DSR equipment and BEMS are Modbus (TCP/IP or RTU) and BACnet. This can be native – e.g. the DSR provider is using off-the-shelf gateways which are compatible out of the box with Modbus/BACnet, or through customised library implementation if the DSR provider is using a bespoke edge equipment.

A standard example of asset control via Modbus interfaces is presented below in Figure 7-4 (using KiWi Power proprietary edge hardware):

### 7.4.5 Hardware integration through analogue interfaces

Existing building controls which are used for complex assets such as HVAC or chillers will normally have an analogue input port. This can be via 0-10V or 4-20mA. Similarly, the DSR edge equipment will have an analogue output providing either a voltage or current signal. The asset controller then needs to be configured to interpret the analogue input in a consistent way, e.g. 4mA – operate at 0% capacity and 20mA operate at 100% capacity, with intermediate values being extrapolated. As an example, if a 1MW generator receives a 12mA signal, it will modulate the output to 500kW.

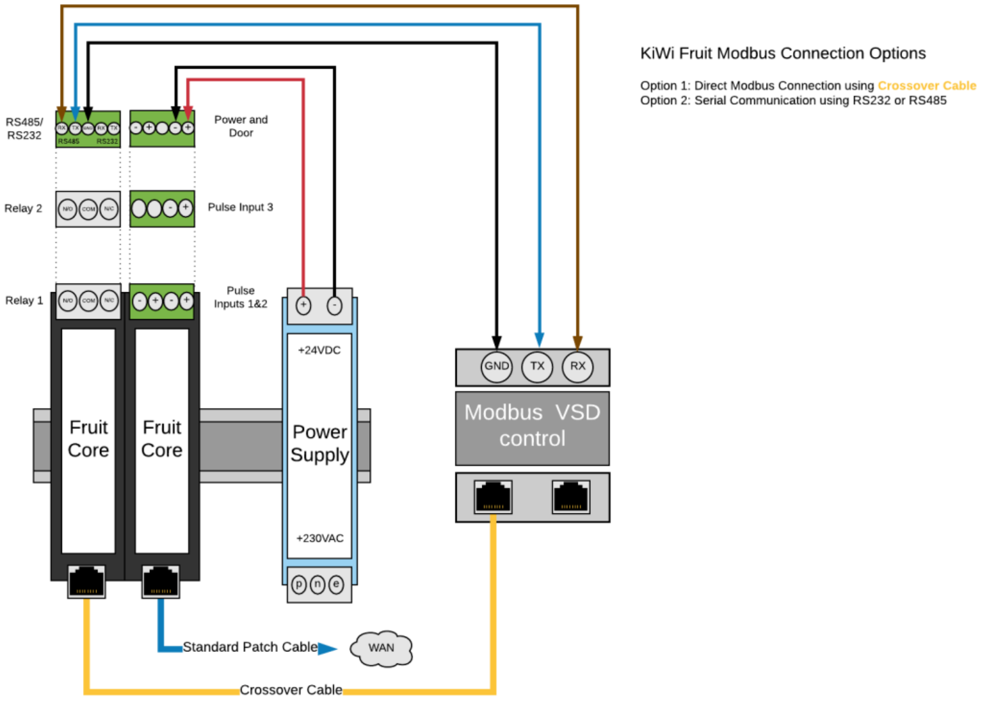


*Figure 7-4 – Asset control via Modbus for Demand Response dispatch*

The M2M integration via API is a more complex example and is done based on a client by client basis as each BEM deployment is done in a different environment and has different security and operational requirements.

## 7.5 LIGHTING SYSTEM MANAGEMENT SYSTEMS

Lighting system management systems are the central element of the lighting installation. Their main purpose is to monitor lighting fixtures and the other parts of the systems, and manage their activities based on user operational preferences and energy-related events. These systems may work independently or under guidance from the building management system.

### 7.5.1 Commercially available solutions

A number of complete commercial solutions for lighting are available in the market. Two example products are listed here:

1. Exergy Lighting System:

   Exergy is offering a number of components for the creation of an automated lighting system. The XRG-1000 networkable control system allows management of interior and exterior lighting systems using both wired and wireless communications. Through the use of common protocols, such as Open ADR, XRG-1000 also provides the ability to communicate and coordinate its actions with the building energy management system. Exergy's 502 and 600 switching controllers provide wireless and wired independent on/ off control respectively of one or two lighting loads and dimming control via one or two isolated 0-10V interfaces. The wireless ZigBee (with 128-bit AES encryption) and wired DALI specification standards are used for communication to and from the lighting control centre. The controllers additionally provide inputs for luminance or photo sensors, such as the XRG-300 and XRG-410 components. Finally, the company offers wired user control interfaces, e.g. the XRG-250, which provides a 5-button user interface, where each switch can be programmed via software assignment over the system's network (Exergy, 2017).

2. Leviton Lighting System:

   Leviton offers lighting systems based on their two lighting and energy management controllers, Lumina and Lumina Pro, tailored for residential and small-business, with the maximum number of controllable loads being 64 and 256 respectively. Communication includes both wired and wireless options, and control of wireless ZigBee and Z-Wave devices is allowed. Dimmers, switches and combination controllers, such as their Vizia RF+ 4-Button Zone Controller, incorporate wireless communication to the main controller using the Z-Wave protocol. Finally, the company offers both illuminance sensor and PIR occupancy sensors (Leviton, 2017b).

### 7.5.2 Cost

As indication of the costs related to the lighting system, Leviton's Lumina controllers cost around $800-1000, but they offer additional energy management capabilities. Further hardware, such as controllable dimmers and switches can range between €30-100 per device.

## 7.6 ICT TECHNOLOGIES AND THE DUAL EE/DR ENERGY SCHEME FOR BUILDING RETROFITS

### 7.6.1 Technologies used for energy efficiency

According to the same survey mentioned above, certain technologies are more often included in EPC programs as means for providing significant energy savings, and thus improving energy efficiency of the buildings. Figure 7-5 summarizes the findings of the survey. As expected, technologies that have been previously mentioned to be the most energy consuming are at the top of the list. In particular, high efficiency lighting equipment and control modules, along with HVAC systems are the most often encountered improvements offered in EPCs, alongside building energy management systems. Combined Heat and Power appliances also have a high percentage, while various types of heat pumps are offered in around 30% of the programs (Garnier, 2013).

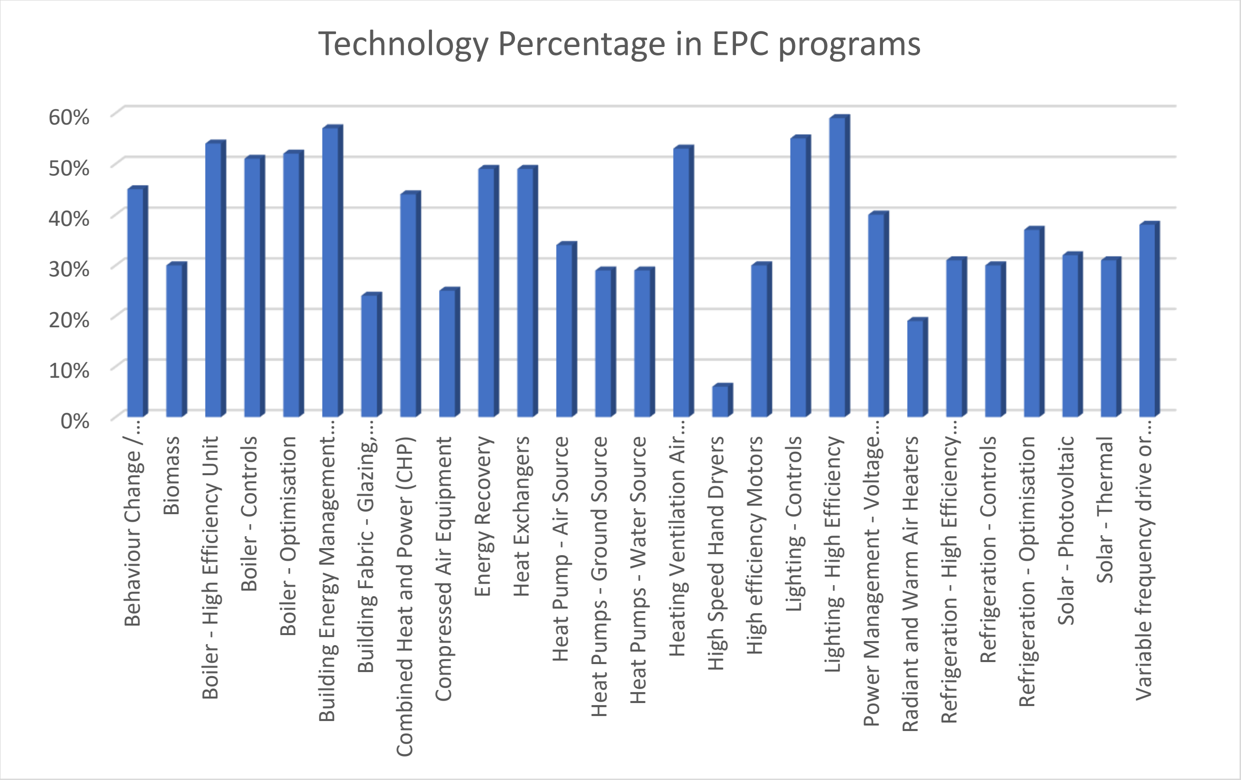


*Figure 7-5 Technologies encountered in EPC program. source* (Garnier, 2013)

# 8 COMFORT STANDARDS AND DR FACILITATION

## 8.1 GENERAL THERMAL COMFORT FEATURES

The main thermal comfort indexes being used to describe and characterise indoor environments are PMV (Predicted Mean Vote) and PPD (Percentage of People Dissatisfied). PMV represents the mean thermal sensation of a large group of building occupants in a scale (Figure 8-1 left) from -3 (cold) to +3 (hot) with 0 designating thermal comfort (neutral). The calculation of PMV in engineering applications depends on four environmental parameters (air temperature, air velocity, mean radiant temperature, relative humidity) and two occupants-related parameters (activity level and clothing thermal insulation). There is an empirical relationship between PMV and PPD where a PMV range between -0.5 and +0.5 corresponds with a PPD value of less than 10% (figure 6.1 right).

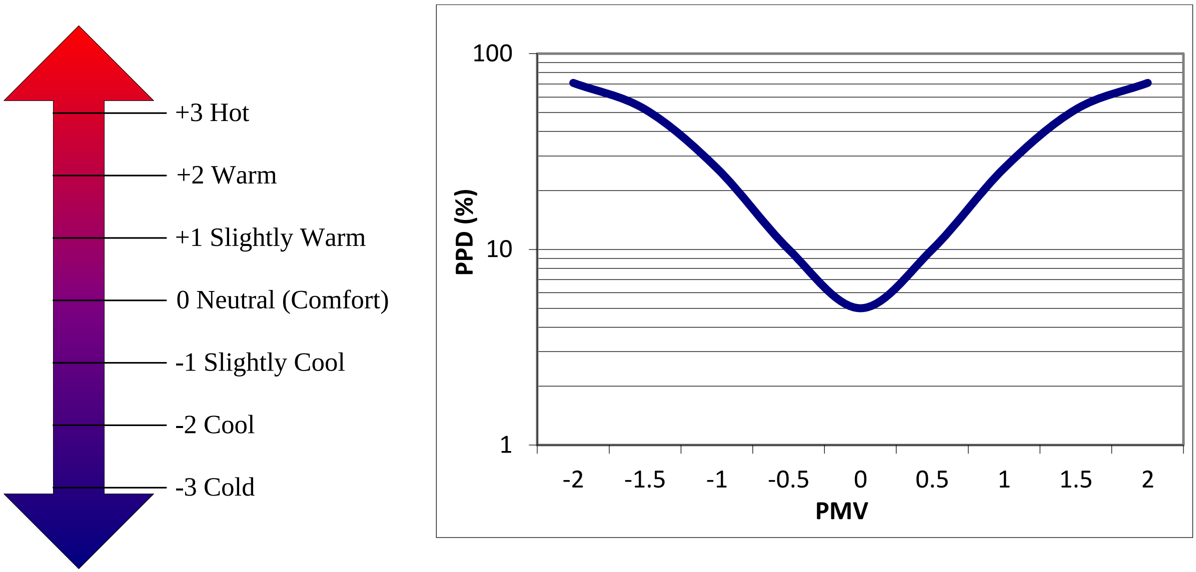


*Figure 8-1: PMV scale (left) and relationship with PPD (right)*

Another variable that is commonly used in describing thermal comfort is the operative temperature that is a combination of the mean radiant temperature and air temperature. The operative temperature is very useful since it combines the two most important environmental parameters for thermal comfort which are also the ones that are mostly affected and controlled by HVAC.

During the 1990s there was a lot of criticism of the PMV model and its ability to describe comfortable conditions in non-mechanically air conditioned buildings. The outcome of the research in this field was the adaptive comfort model which related the indoor comfortable operative temperature with external weather conditions. The fundamental assumption of the adaptive approach was based on the presumption that when a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort. The adaptive model was soon adopted by all international standards as an alternative method to describe comfort conditions in buildings with no mechanical air conditioning. Figure 8-2 shows such a comfort range under the adaptive model relating the indoor operative temperature with the running mean outdoor temperature. It should be noted here that from the perspective of demand response provision from HVAC systems, the adaptive comfort model is of no direct interest since it applies to non-mechanically air conditioned buildings. However, an argument can be made that there are similarities in cases of buildings with no mechanical conditioning and buildings in which HVAC systems are subjected to demand response. Those similarities lay in the fact that in both cases the occupants in those buildings have their indoor environmental conditions not fully and strictly regulated and controlled within narrow comfort ranges but influenced and affected by either weather or market dynamics.

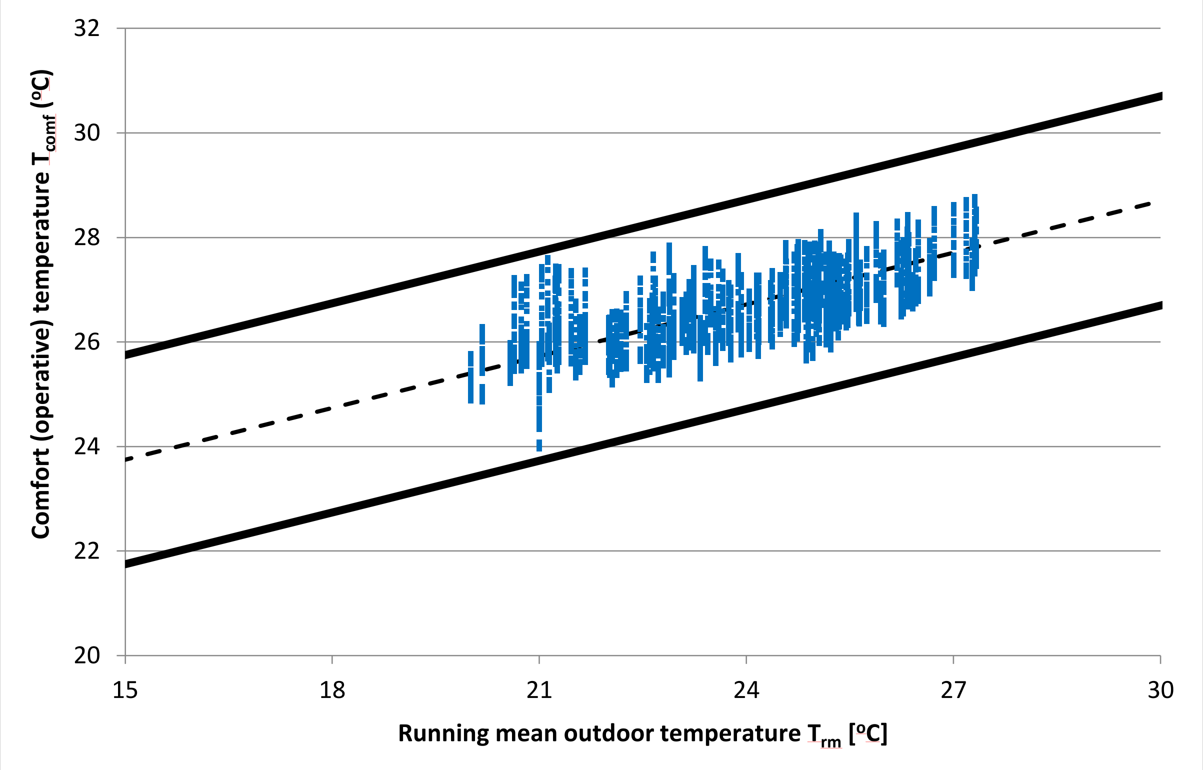


*Figure 8-2: Comfort range under the adaptive model*

## 8.2 THERMAL COMFORT STANDARDS

In characterising and evaluating indoor thermal environments there are three main international standards that are commonly used:

- ASHRAE Standard 55-2013 (ASHRAE, 2013) titled: Thermal Environmental Conditions for Human Occupancy
- ISO Standard 7730-2005 (ISO, 2005) titled: Ergonomics of the Thermal Environment—Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria
- EN Standard 15251-2007 (CEN, 2007) titled: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings—Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics

All three standards are being regularly updated. The ISO standard has been reviewed by the respective committees in 2015 and has been confirmed as it is. The EN standard is currently under revision as it has been mandated from the recast of the Directive on the Energy Performance of Buildings (EU, 2010). The new standard is under approval by the working number FprEN 16798-1.

In the following paragraphs the most important features – with relation to the provision of DR from HVAC systems – of the ASRHAE Standard 55 will be presented since this is the standard that is most up to date, commonly used and referenced. Whenever features of other standards are mentioned they will be clearly attributed.

## 8.3 THERMAL COMFORT ALLOWANCES FOR PROVISION OF DEMAND RESPONSE

In principle, there are two areas that the standards provide potential to allow flexibility for provision of demand response. Those are the comfort ranges defined between minimum and maximum limits of comfort indexes (e.g. PVM or operative temperature) and the allowable exceedance hours outside the ranges during occupancy time. However, there is another limitation that the standards impose and is relevant to use of HVAC systems for demand response and has to do with allowable temperature variations during transient conditions. All those features are described in the following paragraphs.

### 8.3.1 Comfort ranges

As mentioned above, the recommended PMV range for indoor environments is between -0.5 and +0.5 which corresponds to a PPD value of 10% (usually standards prescribe ranked classes of thermal comfort quality of buildings based on the breadth of the comfort range. However, the PPD value of 10% is the most commonly used). Figure 8-3 presents the PMV comfort range for a specific indoor built environment against outdoor air temperature.

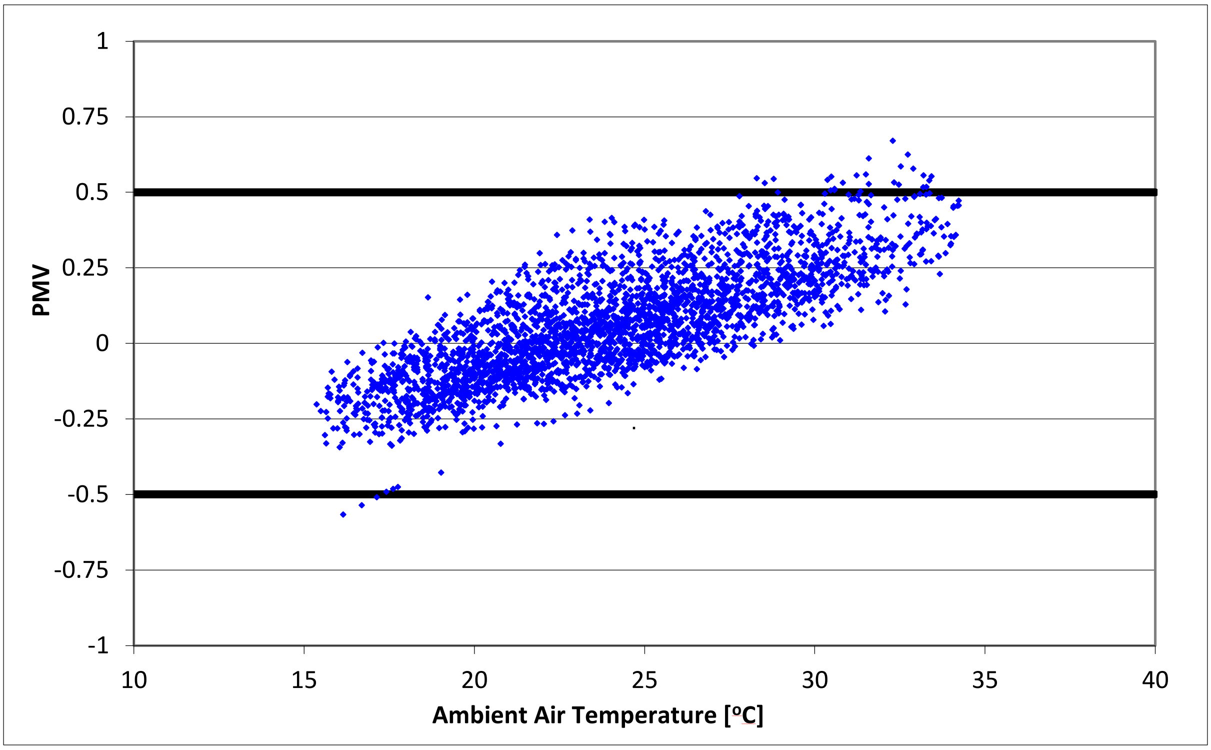


*Figure 8-3: Recommended PMV range*

For typical indoor conditions and occupants' activities, the recommended PMV range can be manifested in recommended ranges of operative temperature which are far more useful for engineering design. Figure 8-4 shows such operative temperature ranges for typical summer and winter conditions. Those correspond to air speed of 0.1 m/s, metabolic activity of 1.1 met (e.g. typing) and clothing insulation of 1.0 clo for winter and 0.5 clo for summer conditions.

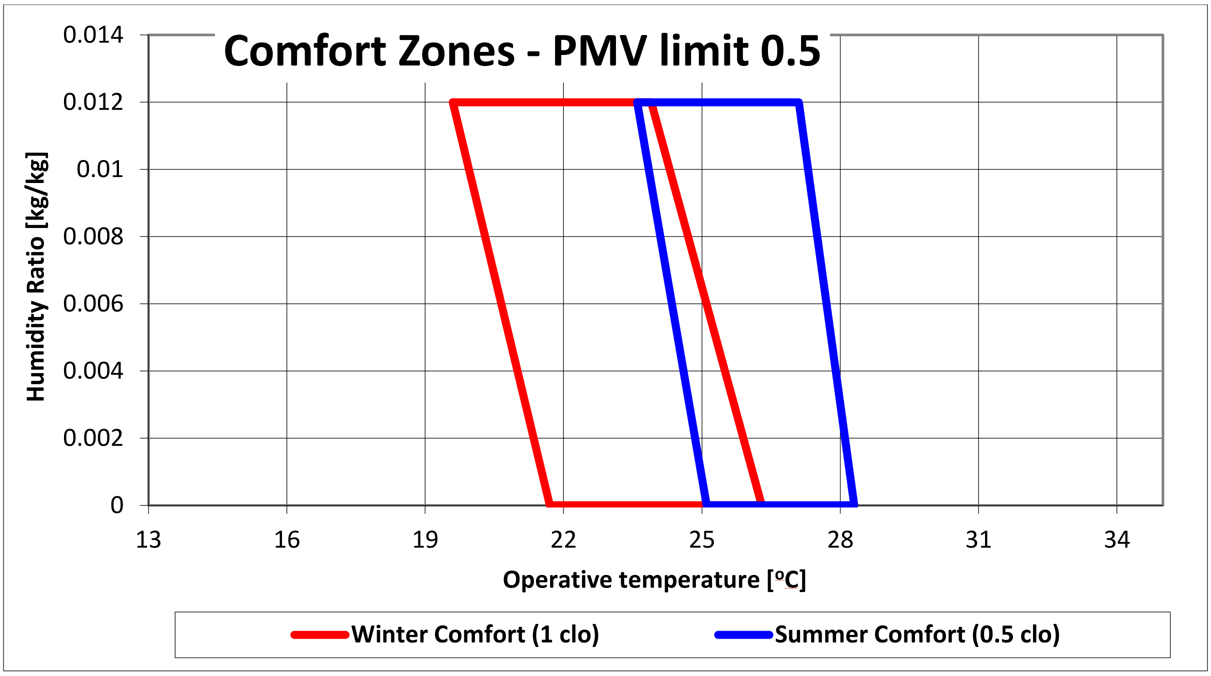


*Figure 8-4: Comfort zones based on operative temperature*

For summer conditions and assuming a relative humidity value of 50% the operative temperature for thermal comfort ranges from about 24°C (humidity ratio of 0.009) to 27°C (humidity ratio of 0.011). That does gives significant range to deploy demand response services through HVAC since the temperature can float amongst those limits. However, as described in the next paragraphs, those temperature ranges are referring to steady state conditions. During transitional periods the rate of temperature change is also important in determining comfort and thus can affect the effectiveness of HVAC systems curtailment in demand response events.

### 8.3.2 Ramps, drifts and cycles

Cyclic variations are considered those cases where the operative temperature repeatedly rises and falls with a period of less than 15 minutes. In cyclic variations the maximum allowable peak to peak range of operative temperature should not exceed 1.1°C.

Temperature ramps and drifts are being considered in cases of monotonic non cyclic changes in operative temperature (or cyclic variations with a period greater than 15 minutes). Particularly, temperature drifts are defined as changes in operative temperature that are not controlled while ramps are actively controlled variations. The ASHRAE 55 Standard prescribes maximum temperature drifts and ramps according to **Error! Reference source not found.**. It is noted that both starting and e nd points for the drift have to be within the comfort ranges under steady state analysis. In general, wherever the peak to peak variation or the rate of temperature change during drifts and ramps is low the methods for steady state variation can apply.

| Time period | 0.25 h | 0.5 h | 1 h | 2 h | 4 h |
|---|---|---|---|---|---|
| Operative temperature drift | 1.1°C | 1.7°C | 2.2°C | 2.8°C | 3.3°C |

*Table 8-1: Maximum allowable operative temperature variations for ramps and drifts*

The maximum allowable operative temperature variations are also depicted in the chart of Figure 8-5. It is obvious that the breadth of acceptable variations decreases as the fluctuation frequency increases. For more than 4 cycles/hour the fluctuation frequency has negligible effect on the allowable breadth of temperature variation while the maximum breadth occurs in steady state conditions.

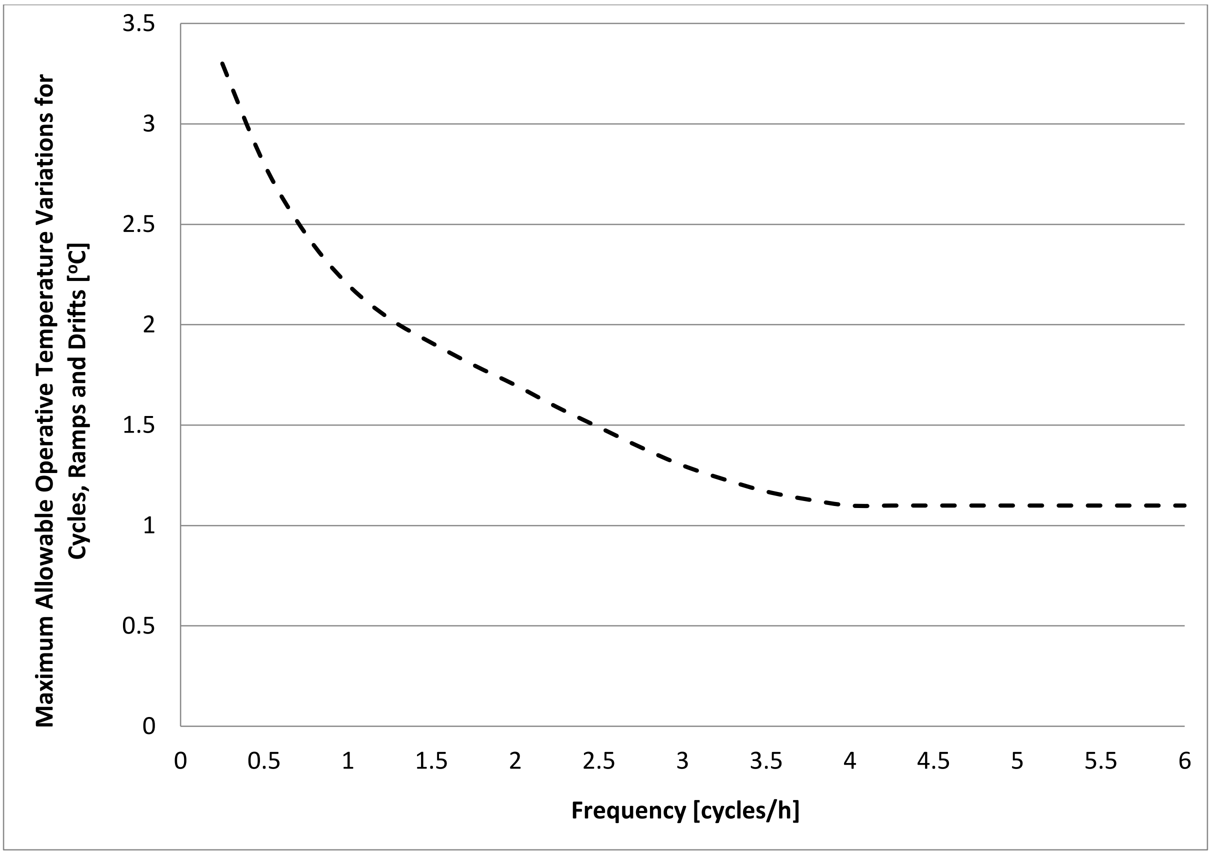


*Figure 8-5: Allowable operative temperature variations during transient conditions (cycles, ramps and drifts)*

In general, the comfort standards allow for a maximum occupancy time where recommended temperature ranges and thresholds can be exceeded. The level of comfort exceedance typically is quantified as a percentage of hours outside the comfort range over time, with or without weighting factors to account for severity (magnitude of difference between temperature limit and actual temperature). That weighting usually follows a degree-hours approach where the time during which the operative temperature exceeds the specified comfort range during occupied hours is multiplied by some function of the number of degrees beyond the range.

CIBSE Guide A (CIBSE, 2006) and CIBSE Technical Manual 36 (CIBSE, 2005) specify a maximum duration of comfort zone exceedance for 1% of occupied hours per annum as their criterion for overheating in naturally ventilated buildings, while EN 15251 gives a comfort-zone exceedance range of 3%–5%. ASHRAE Standard 55 does not prescribe such exceedance metrics since the available evidence currently cannot substantiate such quantification; however it clearly describes specific exceedance metrics and their calculation methodology.

There is also an inherent allowance on exceedance time – out of the comfort limits – that refers to the particular design weather data being used to calculate heating and cooling design loads. The use of design weather data using annual percentiles of 0.4, 1.0 and 2.0 (usually referring to ambient air temperatures) to size heating systems means that indoor conditions for 0.4%, 1.0% and 2.0% of the time respectively can exceed comfort design conditions. Similar annual percentiles are being used for cooling design conditions.

## 8.4 INDOOR AIR QUALITY

Most heating, ventilation and air conditioning systems (HVAC) re-circulate a significant portion of the indoor air to maintain comfort and reduce energy costs associated with heating or cooling outside air. When occupants and building operators sense air coming out of an air supply duct, it's virtually impossible to judge how much of this air is simply re-circulated air and how much is outside air. Having a good indoor air quality provides higher comfort to building users, and at the same time it is important to ensure a healthy environment.

Where indoor concentrations are elevated (compared to the outside air) the source is usually due to the building's occupants. People exhale carbon dioxide—the average adult's breath contains about 35,000 to 50,000 ppm of $CO_2$ (100 times higher than outdoor air). Without adequate ventilation to dilute and remove the $CO_2$ being continuously generated by the occupants, $CO_2$ can accumulate.

The most widely accepted standard is the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Standard 62. Some state and local codes have adopted the ASHRAE Standard 62 ventilation requirements.

Using $CO_2$ as an indicator of ventilation, ASHRAE has recommended indoor $CO_2$ concentrations be maintained at—or below—1,000 ppm in schools and 800 ppm in offices (see chart below). Clearly the outdoor $CO_2$ concentration directly impacts the indoor concentration. Therefore, it is critical to measure outdoor $CO_2$ levels when assessing indoor concentrations. ASHRAE recommends indoor $CO_2$ levels not exceed the outdoor concentration by more than about 600 ppm.

## 8.5 DISCUSSION

There have been several recent studies investigating the impact of demand response provision by HVAC systems on the thermal comfort of buildings occupants. The main actions adopted were cycling HVAC systems (e.g. air conditioners compressors) on and off, modifying set point temperature during demand response events or preconditioning in anticipation of events. Exploiting the comfort ranges indoor temperatures were allowed to oscillate between minimum and maximum thresholds. Focusing exclusively on thermal comfort for demand response the research from Zhang et al (2016) is of particular interest. They have used laboratory experiments with university student subjects to explore thermal comfort impacts of temperature cycles induced by direct load control strategies. Their results showed that the ASHRAE 55 limits on temperature cycles, ramps and drifts are overly conservative. It should be noted here that the respective limits of ISO 7730 are even more conservative in most cases.

In another aspect of thermal comfort assessment for demand response Kampelis et al (2017) introduced a Daily Discomfort Score to evaluate comfort conditions during HVAC demand response driven control. The Daily Discomfort Score was a function of a weighted hourly discomfort score and an additional penalty in the case of consecutive hours of discomfort. Their index was based on the adaptive comfort model since they assumed that it is suitable for the mixed-mode building with operable windows and locally controlled HVAC systems which they have used for their research. Their demand response scenarios were designed for pre-conditioning the building in the morning hours to take advantage of electricity tariffs during off-peak hours. In general, the extension of HVAC operation hours resulted in increased thermal comfort.

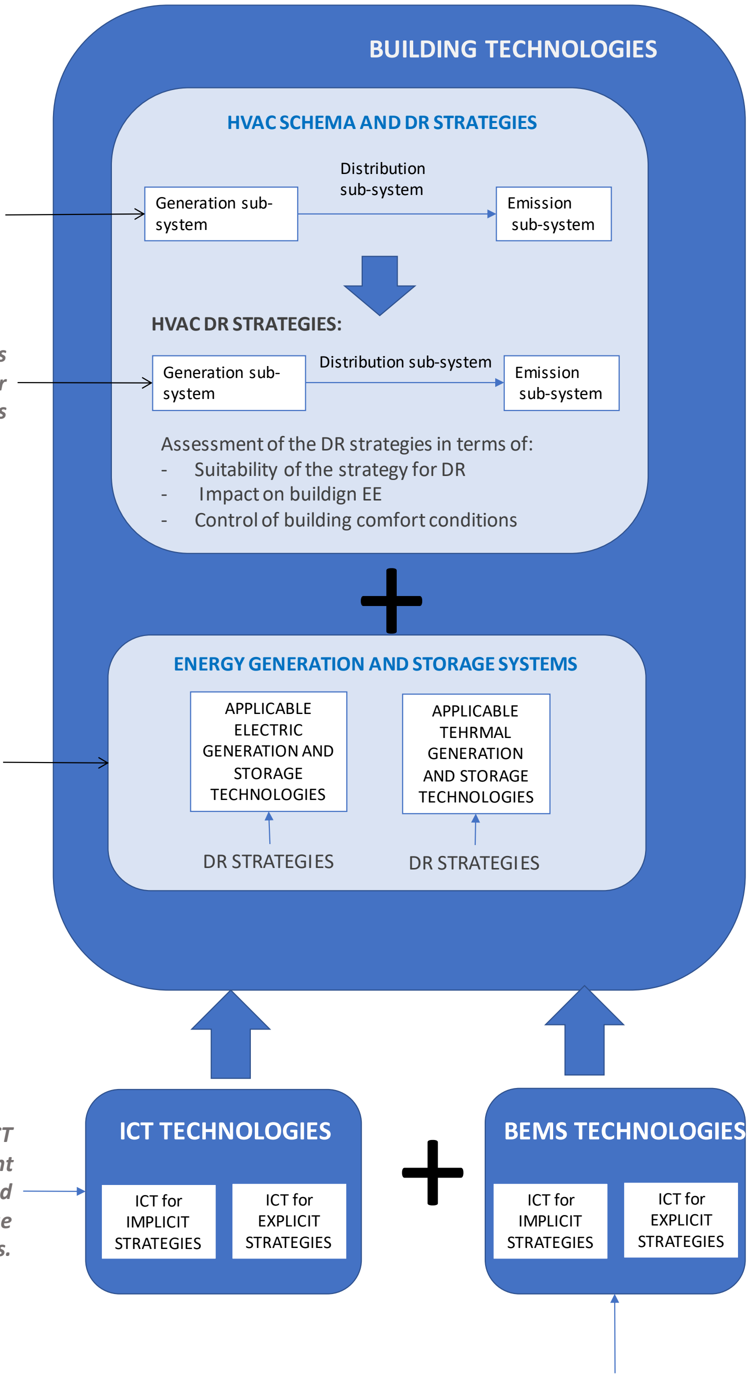
# 9 TECHNOLOGY KITS FOR EE AND DR SERVICES IN BUILDING RENOVATION

A set of ‘Technology Kits’ have been developed as part of this work with the aim of summarize the most appropriate technologies and combinations of technologies for DR and EE and how to control them to implement DR strategies. The purpose of the kits is to guide the building owners or managers to select the most appropriate and cost-effective technologies for DR to implement in their buildings. The full ‘Technology Kits’ can be found in as an Annex to this document entitled ‘Technology Kits for Energy Efficiency and Demand Response Strategies’

The Technology Kits provide the following summary of information:

- **HVAC Schema and DR strategies:** Description of HVAC centralized systems and the related implicit and explicit DR strategies. Considering the HVAC systems and the strategies an assessment of the suitability for DR strategies, impact on the building energy efficiency and the comfort conditions is assessed.
- **Energy generation and storage systems:** the thermal and electric generation and storage systems that can be coupled with the HVAC systems are identified. The applicable DR strategies are described.
- **ICT systems for implicit and explicit strategies:** for the identified technologies and strategies the required ICT technologies are determined.
- **BEMS systems for implicit and explicit strategies:** together with the ICT systems, the BEMS requirements to control building systems for implicit but mainly for explicit DR systems.

The following schema shows how the technology kits are organized in order to provide practical information for building retrofitting:



*Description of the HVAC system of the buildign*

*Description of the DR strategies that can be implemented for HVAC systems*

*Description of the THERMAL and ELECTRIC storage and generation systems that can combine with HVAC systems for DR strategies.*

*Description of the required ICT technologies in order to implement the DR strategies (implicit and explicit) in HVAC, and energy storage and generation systems.*

*Description of the required BEMS technologies in order to implement the DR strategies (implicit and explicit) in HVAC, and energy storage and generation systems.*

The template of the KITs is included below:

# Technologies for EE and DR strategies

CENTRALIZED SYSTEM

| | | | |
|---|---|---|---|
| DUAL DR& EE KIT | | | |
| Energy source | | | |
| HVAC SCHEMA | | | |
| HVAC DR STRATEGIES | | | |
| CONTROL LEVEL | STRATEGY AT THERMAL ZONE | STRATEGY AT DISTRIBUTION | STRATEGY AT GENERATION |
| DR STRATEGY | | | |
| SUITABILITY FOR IMPLICIT DR | | | |
| SUITABILITY FOR EXPLICIT DR | | | |
| IMPACT ON EE | | | |
| CONTROL ON COMFORT CONDITIONS | | | |
| COMBINATION WITH OTHER SYSTEMS | | | |
| APPLICABLE ELECTRIC GENERATION AND STORAGE TECHNOLOGIES | | DR STRATEGIES | |
| APPLICABLE THERMAL GENERATION AND STORAGE TECHNOLOGIES | | DR STRATEGIES | |
| IMPLICIT ICT TECHNOLOGIES | | | |
| EXPLICIT ICT TECHNOLOGIES | | | |
| IMPLICIT BEMS TECHNOLOGIES | | | |
| EXPLICIT BEMS TECHNOLOGIES | | | |

# 10 CONCLUSIONS

This Deliverable tries to identify the most suitable technologies for DR and EE in buildings. The output of this deliverable is a collection of different combination of technologies conforming technology kits for enhancing the exploitation of DR strategies while EE in buildings is improved.

Benefit of these technology kits is different for the different stakeholders participating in DR and EE market:

The kits are supposed to guide building owners or investors in the decision of the implementation of technology solutions of DR/EE strategies in their buildings, knowing that this would reduce their energy bill. This is an opportunity for a new business model for ESCO-s that not only offer energy savings to building owners during building operation, but also there is a second revenue stream due to interaction with the energy market.

These KIT-s offer Technology providers with useful information concerning how their products are compatible not only with EE but also with emerging DR strategies. These allows the technology providers to give advice to their clients, open new markets and orient their research and product development in the emerging DR business.

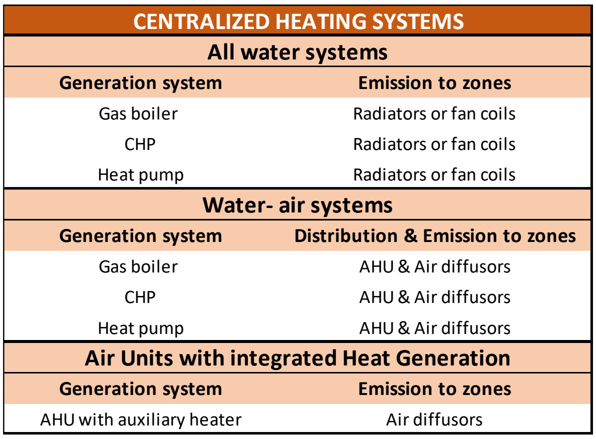
As the share of buildings applying DR strategies increases aggregators will see their business also increased. The KIT-s can path the way to accelerate the integration of DR strategies in buildings and thus DR business for aggregators.

Finally, policy makers can support new regulations and financing programs in order to promote the implementation of technologies that would allow the EE and the DR strategies in building.

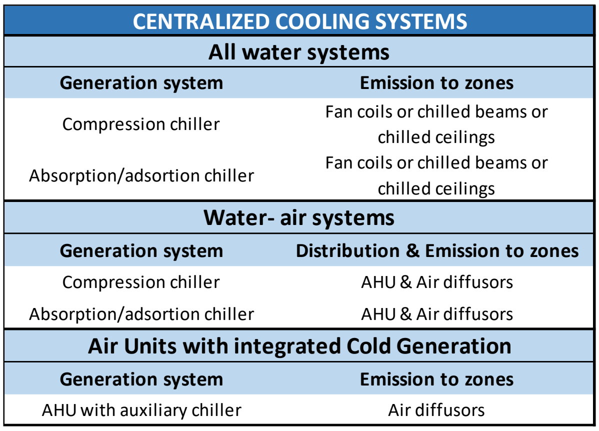
In order to elaborate the Technology KITs, the most common centralized HVAC systems in NOVICE target buildings have been identified, as well as the applicable combinations with electric generation and storage systems. Each kit has been completed with the required ICT and BEMS systems to be implemented.

The HVAC systems included in Technology KIT-s are the following.

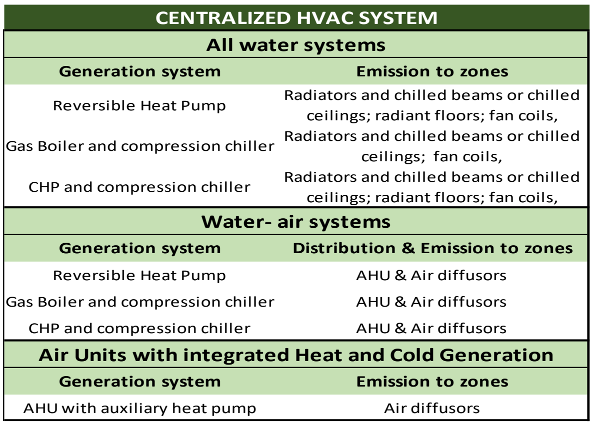
*Table 10-1: HVAC technologies included in the Technology KITs*



| **CENTRALIZED HEATING SYSTEMS** | |
|---|---|
| **All water systems** | |
| **Generation system** | **Emission to zones** |
| Gas boiler | Radiators or fan coils |
| CHP | Radiators or fan coils |
| Heat pump | Radiators or fan coils |
| **Water- air systems** | |
| **Generation system** | **Distribution & Emission to zones** |
| Gas boiler | AHU & Air diffusors |
| CHP | AHU & Air diffusors |
| Heat pump | AHU & Air diffusors |
| **Air Units with integrated Heat Generation** | |
| **Generation system** | **Emission to zones** |
| AHU with auxiliary heater | Air diffusors |



| CENTRALIZED COOLING SYSTEMS | |
|---|---|
| **All water systems** | |
| **Generation system** | **Emission to zones** |
| Compression chiller | Fan coils or chilled beams or chilled ceilings |
| Absorption/adsortion chiller | Fan coils or chilled beams or chilled ceilings |
| **Water- air systems** | |
| **Generation system** | **Distribution & Emission to zones** |
| Compression chiller | AHU & Air diffusors |
| Absorption/adsortion chiller | AHU & Air diffusors |
| **Air Units with integrated Cold Generation** | |
| **Generation system** | **Emission to zones** |
| AHU with auxiliary chiller | Air diffusors |



| CENTRALIZED HVAC SYSTEM | |
|---|---|
| **All water systems** | |
| **Generation system** | **Emission to zones** |
| Reversible Heat Pump | Radiators and chilled beams or chilled ceilings; radiant floors; fan coils, |
| Gas Boiler and compression chiller | Radiators and chilled beams or chilled ceilings; fan coils, |
| CHP and compression chiller | Radiators and chilled beams or chilled ceilings; radiant floors; fan coils, |
| **Water- air systems** | |
| **Generation system** | **Distribution & Emission to zones** |
| Reversible Heat Pump | AHU & Air diffusors |
| Gas Boiler and compression chiller | AHU & Air diffusors |
| CHP and compression chiller | AHU & Air diffusors |
| **Air Units with integrated Heat and Cold Generation** | |
| **Generation system** | **Emission to zones** |
| AHU with auxiliary heat pump | Air diffusors |

From performed analysis, it has been concluded that HVAC technologies based on electricity as energy source are most suitable for DR, because these technologies allow to implement strategies based on electrical loads shifting and also strategies based on the use of electricity depending on the energy tariff.

Considering this, among the previous systems, the ones identified as the most suitable for demand-response, both implicit and explicit, and for energy efficiency improvement are the following:

*Table 10-2: Most suitable HVAC technologies for DR strategies and EE*

| | |
|---|---|
| **CENTRALIZED HEATING SYSTEMS** | |
| **All water systems** | |
| **Generation system** | **Emission to zones** |
| Heat pump | Radiators or fan coils |
| **Water- air systems** | |
| **Generation system** | **Emission to zones** |
| Heat pump | AHU & Air diffusors |
| **CENTRALIZED COOLING SYSTEMS** | |
| **All water systems** | |
| **Generation system** | **Distribution and Emission to zones** |
| Compression chiller | Fan coils or chilled beams or chilled ceilings |
| **Water- air systems** | |
| **Generation system** | **Distribution & Emission to zones** |
| Compression chiller | AHU & Air diffusors |
| **Air Units with integrated Cold Generation** | |
| **Generation system** | **Emission to zones** |
| AHU with auxiliary chiller | Air diffusors |
| **CENTRALIZED HVAC SYSTEM** | |
| **All water systems** | |
| **Generation system** | **Emission to zones** |
| Reversible Heat Pump | Radiators and chilled beams or chilled ceilings; radiant floors; fan coils, |
| **Water- air systems** | |
| **Generation system** | **Distribution & Emission to zones** |
| Reversible Heat Pump | AHU & Air diffusors |
| **Air Units with integrated Heat and Cold Generation** | |
| **Generation system** | **Emission to zones** |
| AHU with auxiliary heat pump | Air diffusors |

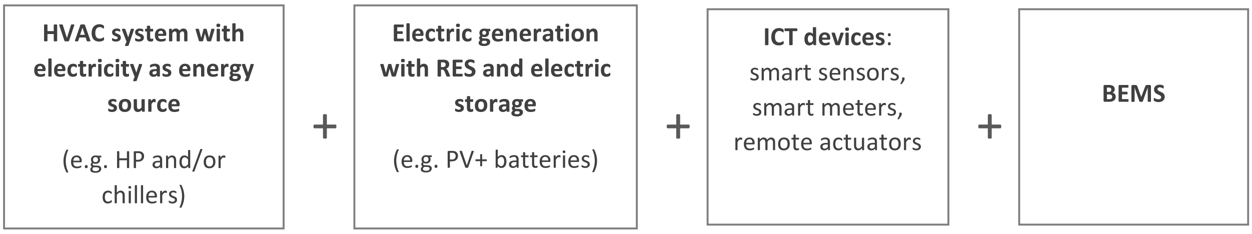
As it is observed we can conclude that the most suitable HVAC generators for DR and EE are Heat Pumps and Chillers. Nevertheless, HVAC generation systems must be combined with other technologies to assure the highest performance of the systems in terms of energy efficiency and demand- response potential.

Concerning the energy efficiency of the whole system, these generation technologies must be combined with insulated distribution networks (ducts and pipes) and variable flow fans and pumps.

And regarding demand response potential, in order to allow to implement more effectively Demand Response strategies, HVAC generation systems should be combined with renewable electric generation sources and storage systems, in particular, with PV panels and batteries.

Finally, the ICT devices and BEMS are required for implementing implicit and explicit DR strategies. BEMS allow to manage the whole systems, enabling optimized DR strategies and the interaction with the grid. BEMS also permits to maximize the energy efficiency of the whole system. ICT devices allow the physical execution of DR strategies. The main ICT devices required are smart sensors, smart meters and remote actuators.

Therefore, in summary, to achieve the most optimum scenario to implement implicit and explicit DR strategies while improving the energy efficiency in a building, the combination of the following technologies is recommended:



Detailed information to apply the whole systems are included in the Technology KITs annexed to this document. Considering the conclusions obtained from the performed analysis, among all presented technology kits, the most suitable ones are the following:

- Heat pump with all water system
- Compression chiller with all water system
- Reversible heat pumps with all water system
- Heat pump with water-air system
- Chiller with water-air system
- Reversible heat pumps with water-air system
- Air Units with integrated cold generation
- Air Units with integrated heat and cold generation

To make these results more accessible, NOVICE project partner, IERC, has developed a simple online tool guiding building owners and energy managers through the process of selecting the most appropriate EE and DR technology combinations for their buildings. The tool asks the user to specify the type of equipment already installed on site and guides the user to the most appropriate technology kit based on their selections. The tool can be accessed on the NOVICE project website at http://novice-project.eu/hvacRetrofitTool/

# 11 ACRONYMS

Agency for the Cooperation of Energy Regulators (ACER)
Balance Responsible Party (BRP)
Building Energy Management Systems (BEMS)
Capacity remuneration mechanisms (CRMs)
Combined Heat and Power (CHP)
Critical Peak Pricing (CPP)
Critical Time Rebates (CTR)
Demand Response (DR)
Demand Response Automation Server (DRAS)
Demand Side Response (DSR)
Distributed Energy Resources (DER)
Distribution System Operator (DSO)
Energy Efficiency (EE)
Energy Service COmpany (ESCO)
European Telecommunications Standards Institute (ETSI)
European Union (EU)
Heating, Ventilation and Air Conditioning (HVAC)
Information and Communication Technologies (ICT)
International Electrotechnical Commission (IEC)
Joint Research Centre (JRC)
Machine-to-Machine (M2M)
Real-Time Pricing (RTP)
Smart Energy Demand Coalition (SEDC)
Thermal Energy Storage (TES
Time-of-Use (ToU)
Transmission System Operator (TSO)
Virtual End Node (VEN)
Virtual Top Node (VTN)

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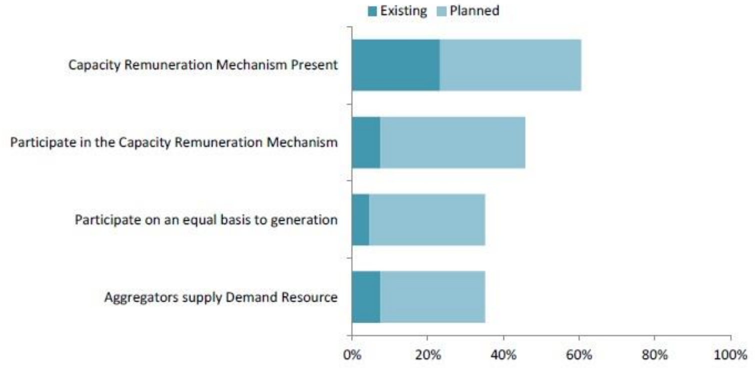
# 13 APPENDIX

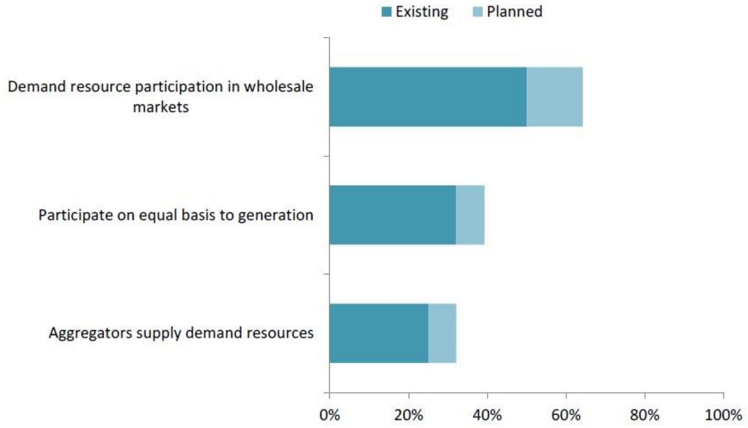
## 13.1 SUMMARY STATISTICS ON EXPLICIT DR STATUS IN THE EU



| | Existing | Planned | None |
|---|---|---|---|
| Capacity mechanism in place | BE, EL, IE, PL, ES, SE | FR, IT, UK | AT, BG, HR, CY, CZ, DK, EE, FI, DE, HU, LV, LT, LU, MT, NL, PT, RO, SK, SI |
| Participation in capacity mechanism | BE, SE | FR, IE, IT, UK | AT, BG, HR, CY, CZ, DK, EE, FI, DE, EL, HU, LV, LT, LU, MT, NL, PL, PT, RO, SK, SI, ES |
| On equal basis to generation | SE | BE, FR, IE, UK | AT, BG, HR, CY, CZ, DK, EE, FI, DE, EL, HU, IT, LV, LT, LU, MT, NL, PL, PT, RO, SK, SI, ES |
| Participation of aggregators | BE, SE | FR, IE, UK | AT, BG, HR, CY, CZ, DK, EE, FI, DE, EL, HU, IT, LV, LT, LU, MT, NL, PL, PT, RO, SK, SI, ES |

No survey response was received from BG, CY, DK, EL, IE, PL, SI. These countries are included based on data that may underestimate the actual uptake.

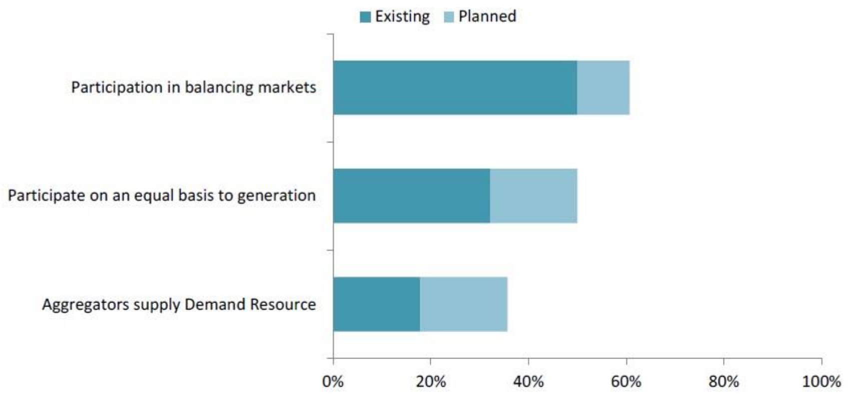
*Figure 13-1 Explicit DR participation in Capacity Remuneration Mechanisms. Source* (ACER, 2014)



| | Existing | Planned | None |
|---|---|---|---|
| Participation in wholesale market | BE, CZ, DK, FI, FR, HU, IE, IT, NL, PL, PT, RO, SI, SE | AT, DE, LT, UK | BG, HR, CY, EE, EL, LV, LU, MT, SK, ES |
| On equal basis to generation | BE, CZ, FI, FR, DE, IE, NL, PT, SE | LT, UK | AT, BG, HR, CY, DK, EE, EL, HU, IT, LV, LU, MT, RO, SK, SI, ES |
| Participation of aggregators | BE, FR, DE, IE, IT, NL, SE | FI, UK | AT, BG, HR, CY, CZ, DK, EE, EL, HU, LV, LT, LU, MT, NL, PL, PT, RO, SK, SI, ES |

No survey response was received from BG, CY, DK, EL, IE, PL, SI. These countries are included based on data that may underestimate the actual uptake.

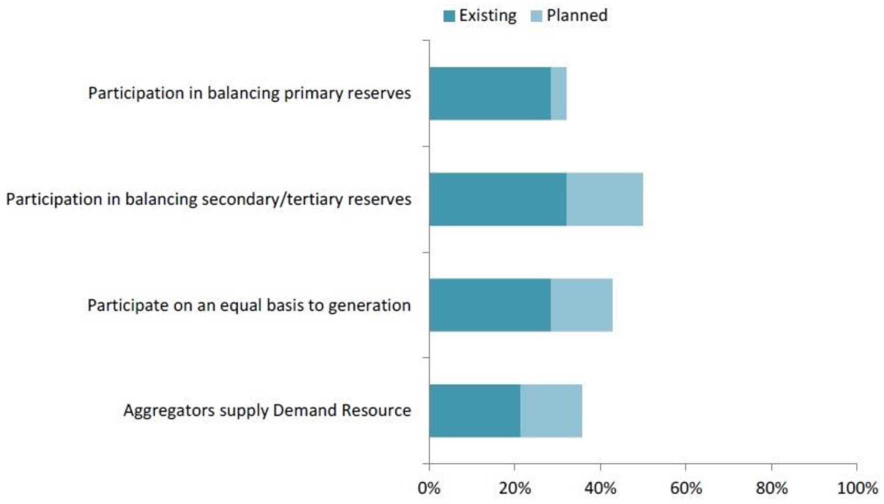
*Figure 13-2 Explicit DR participation in wholesale markets. Source* (ACER, 2014)



| | Existing | Planned | None |
|---|---|---|---|
| Participation in balancing markets | AT, BE, CZ, DK, FI, FR, HU, IE, NL, PL, RO, SI, SE, UK | DE, IT, ES | BG, HR, CY, EE, EL, LV, LT, LU, MT, PT, SK |
| On equal basis to generation | CZ, DK, EE, FI, FR, HU, ES, SE, UK | AT, BE, DE, IE, PL | BG, HR, CY, EL, IT, LV, LT, LU, MT, NL, PT, RO, SK, SI |
| Participation of aggregators | BE, DK, FR, NL, UK | AT, DE, HU, IE, PL | BG, HR, CY, CZ, EE, FI, EL, IT, LV, LT, LU, MT, PT, RO, ES, SE, SK, SI |

No survey response was received from BG, CY, DK, EL, IE, PL, SI. These countries are included based on data that may underestimate the actual uptake.

*Figure 13-3 Explicit DR participation in balancing markets. Source* (ACER, 2014)



| | Existing | Planned | None |
|---|---|---|---|
| Participation in primary reserves | AT, BE, DK, FR, IE, NL, SE, UK | DE | BG, HR, CY, CZ, EE, FI, EL, HU, IT, LV, LT, LU, MT, PL, PT, RO, SK, SI, ES |
| Participation in secondary/tertiary reserves | BE, CZ, DK, FR, HU, NL, SI, SE, UK | AT, DE, IE, PL, ES | BG, HR, CY, EE, FI, EL, IT, LV, LT, LU, MT, PT, RO, SK |
| On equal basis to generation | BE, CZ, DK, EE, FR, HU, SE, UK | AT, DE, IE, PL | BG, HR, CY, FI, EL, IT, LV, LT, LU, MT, NL, PT, RO, SK, SI, ES |
| Participation of aggregators | BE, DK, FR, DE, NL, UK | AT, HU, IE, PL | BG, HR, CY, CZ, EE, FI, EL, IT, LV, LT, LU, MT, PT, RO, SK, SI, ES, SE |

No survey response was received from BG, CY, DK, EL, IE, PL, SI. These countries are included based on data that may underestimate the actual uptake.

*Figure 13-4 Explicit DR participation in ancillary services. Source* (ACER, 2014)