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Technical Report TA User Project

Real-time Price-based Energy Management Strategies of Commercial Buildings

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Abbreviations

AS	*Ancillary Services*
BEMS	*Building Energy Management System*
DR	*Demand Response*
DSM	*Demand Side Management*
DSO	*Distribution System Operator*
EM	*Energy Management*
EMS	*Energy Management System*
EV	*Electrical Vehicle*
HVAC	*Heat, Ventilation and Air Conditioning*
IPE	*Institute of Physical Energetics*
RES	*Renewable Energy Sources*
RTS	*Real Time Simulation*
SOC	*State of Charge*
TSO	*Transmission System Operator*

Executive Summary

ROFOC project implemented by members of Institute of Physical Energetics (IPE) with a goal to test Energy Management (EM) system strategies model on a commercial type building with price-based Demand Response (DR) program for future implementation. The IPE buildings load was used as the base of the model that was tested in real-time in Real-time Simulator at SINTEF laboratory with an algorithm and measurements provided from IPE member side. The goal was achieved; variations in implementation are summarised in conclusions with diversity in profit with implementation costs taken in mind. The most beneficial set up option has been highlighted from various compared results with a specific algorithm that provides the highest profit.

This project provides detailed results, conclusions and issues for EM strategies used in commercial type buildings. The results are provided using real-time simulation (RTS) of EM system strategies with different setup equipment and unique case studies. The case studies were selected by electricity market price change criteria, because the main focus of the DR program in EMS system are the price signals from NordPool. The project model is a pure simulation with its algorithms set in RT-Lab and real-time data of load and price streamed from the IPE building and NordPool, respectively.

The simulation results show, that the impact from created flexible loads is low, and therefore flexible load consumption rate should be evaluated before the Smart socket connection, to get the profit faster and decrease the pay-back time of socket. The storage installation simulations results showed, that greatest impact can be achieved with smallest storage type. During the simulation test cases two different types of storage charge/ discharge process were tested. Due to the typical price change for 24h period, the most effective storage use is one charge/discharge time per 24h period.

Setup of each tested model is based on the use of buildings total load with add-ons such as flexible load and storage. For accurate comparison, the tests carried out in the study used fixed flexible load behaviours for each test case. Storage, on the other hand, had variety of changes in its working algorithmic logic affecting charge/discharge cycle amount and in storage capacity amount. Table 1 highlights profits of each study test performed. The highest results in flat profit can be seen with larger storage capacity, although when their implementation costs are considered a different result appears. Most efficient storage capacity for building is the smallest tested storage capacity – 50 kW, bearing the lowest profit per case, but significant implementation cost reduction must be acknowledged. This decision was also confirmed by comparing different capacity storage income per one installed kW, with previously mentioned storage capacity having the highest saving rate.

State-of-the-art chapter provide theoretical background for Demand Side Management and Energy Management systems technologies and authors vision in this field. Chapter 3, Executed Tests and Experiments provide technical information about implemented algorithms during the ROCOF project. Finally, details of the finished studies are discussed in the results and conclusions section with specific recommendations of changes in the model and their presentations.

General Information of the User Project

The Institute of Physical Energetics (IPE) is a leading research institute in Latvia in the field of analysis of complex energy systems, founded in 1946. The IPE has a strong national expertise in the technological, policy, institutional as well as in the socio-economic dimensions of energy-environmental issues.

Research at IPE integrates the entire supply chain of the energy system – from energy resources, energy generation and energy transmission to final consumption. Thus IPE´s activities cover a wide scope of energy research issues, such as the simulation & optimization, modelling and analysis of the energy-environment interactions, energy-environmental policy studies, renewable energy resources and technologies, energy efficiency improvements, electrical devices and technologies and regional energy sector development analysis.

The Project was implemented by researchers from IPE Smart Grid Research Centre which is a centre for competence within R&D of the smart grids, with focus on technology transfer, education, and technological solution adaptation in Latvian Power System. Since 2011 Member of European Energy Research Alliance Joint Programme on Smart Grids and since 2014 founder of National SG platform.

Current projects
- FP7, ELECTRA (European Liaison on Electricity Committed Towards long-term Research Activities for Smart Grids)
- ERA-Net Smart Grids Plus, CloudGrid (Transnational CLOUD for Interconnection of Demonstration Facilities for Smart Grid Lab Research & Development)
- ERA-Net LAC, ITCity (An ICT platform for sustainable energy ecosystem in smart cities)

Visiting group members:

Ervin Grebesh
- Research assistant in Smart Grid Research Centre, Institute of Physical Energetics, Latvia;
- E. Grebesh obtained his MSc and BSc degrees from Riga Technical University in 2016 and 2014, respectively. Currently, he is studying at RTU to obtain a Doctoral degree;
- His research interest include: DR, EMS, DSM, DLR and CCGT/CHP optimization.
- Involved in ERA-NET SG + project ‘’CloudGrid’’;

Ivars Zikmanis
- Since 2017 has been working at IPE as a research assistant;
- I. Zikmanis holds BSc from Riga Technical University (2016). Currently taking his MSc thesis at RTU;
- Master’s degree thesis is complemented by ERIGRID project.
- Involved in ERA-NET SG + project ‘’CloudGrid’’;

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Research Motivation

With high penetration of smart hardware and software based technologies the system control of the EMS for building and household are becoming even more popular due to ready solutions from hardware and software base to create EMS. New buildings are using HVAC (Heating, Ventilation and Air Conditioning) systems for energy efficiency and smart control of the building ecosystem. Energy efficiency as passive saving is used almost everywhere. Household and flat EMS are basically used for entertainment system and lighting control, however energy saving projects are still not massively used in the commercial sector.

For the commercial and office type buildings, exclusive HVAC EMS is used for smart control of building devices to increase the comfort level of inhabitants. Hence, the potential of DR programs under EMS should be estimated.

In the ROCOF project the possibility of real-time control of the load part for shifting with price signal is observed. Storage system integration into commercial type building for increasing load behavior flexibility was also observed. The ROCOF results will be used for analysis of load control algorithm via price signal, the impact on savings from different EMS test cases and finalizing the EM strategies architecture.

1.1 Objectives

This project aims to:

1. Study the shiftable load saving potential for the commercial building under different test case scenarios.
2. Overview the add-ons potential for the commercial building under different test case scenarios.
3. Test the possibility to run the developed models under real-time conditions that will be useful for future tasks.
4. Gain the knowledge of real-time simulations and the OPAL-RT system.

1.2 Scope

The project consists of multiple EMS test cases with unique setup add-ons to compare the flexibility and impact on commercial building load. EMS can be achieved by load shifting, peak shaving, add-ons (PV, Electrical Vehicles, Wind Turbines, etc.) combinations and feeding electricity market price information. The results show the income from realisation of the different test cases that will be useful in the pilot project stage adaptation. Test cases that run under the OPAL-RT system allow the review of the EM strategies architecture that was presented by authors.

2 State-of-the-Art/State-of-Technology

Demand Side Management (DSM) is the planning and implementation of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape i.e., changes in the pattern and magnitude of a utility's load. DSM encompasses the entire range of management functions associated with directing demand-side activities, including program planning, evaluation, implementation, and monitoring [1]. DSM branches to DR and Energy Efficiency as shown in Figure 1. Energy efficiency is using energy with least amount of waste energy produced. This means reducing the cost of overall energy consumption with same or greater performance output, generally it is a passive efficiency. Active efficiency can be achieved with DR. DR is the change in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized [2]. In the price-based DR program, users can create their own load response to hourly changes in electricity market prices by shifting hourly loads from higher prices periods to lower resulting in user profit. DR programs can benefit not only the users, but the grid itself, reducing the load in peaks to reduce the chance of outage [3, 4]. In the incentive-based DR programs, users get compensated for their consumption reduction [5].

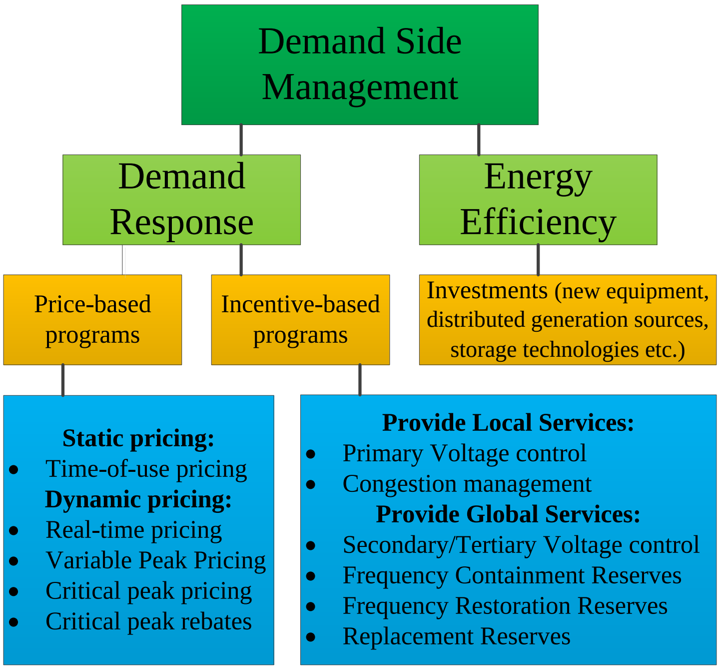

Figure 1: Demand Side Management core elements

Further details of price-based and incentive-based programs are given below:

Static Pricing

- Time-of-use pricing - typically applies to usage over broad blocks of hours where the price for each period is predetermined and constant. [6]

Dynamic Pricing

- Real-time pricing - pricing rates generally apply to usage on an hourly basis.
- Variable Peak Pricing - a hybrid of time-of-use and real-time pricing where the different periods for pricing are defined in advance (e.g., on-peak=6 hours for summer weekday afternoon; off-peak = all other hours in the summer months), but the price established for the on-peak period varies by utility and market conditions. [6]

Critical peak pricing - when utilities observe or anticipate high wholesale market prices or power system emergency conditions, they may call critical events during a specified time period (e.g., 3 p.m.—6 p.m. on a hot summer weekday), the price for electricity during these time periods is substantially raised. Two variants of this type of rate design exist: one where the time and duration of the price increase are predetermined when events are called and another where the time and duration of the price increase may vary based on the electric grid's need to have loads reduced; [6]

Critical peak rebates - when utilities observe or anticipate high wholesale market prices or power system emergency conditions, they may call critical events during pre-specified time periods (e.g., 3 p.m.—6 p.m. summer weekday afternoons), the price for electricity during these time periods remains the same but the customer is refunded at a single, predetermined value for any reduction in consumption relative to what the utility deemed the customer was expected to consume. [6]

Provide Local services

- Primary voltage control - is a process that is performed locally by each network element which has voltage control capability. The future schemes in addition to the conventional power plants are expected to include RES and DR. [7]
- Congestion management – takes place when the transmission or distribution elements are not sufficient to transfer the power according to market desires. Thus, congestion management is a tool for efficiently making use of the power available without violating the system constraints. [8]

Provide Global services

- Secondary/Tertiary Voltage control - The secondary voltage control in future grids can cover both the regional control within a certain zone of the transmission system operator (TSO) control area and the voltage control at the distribution system level. The secondary voltage and reactive power control at the transmission grid controls the reactive power at certain pilot-nodes in the transmission grid. Each pilot-node is representative for the voltage within a certain zone. The secondary controller changes the reactive power provided by the devices (power plants or reactive power equipment of the TSO (e.g. capacitors banks) or reactive power provided by distribution grids) within this zone until the voltage at the pilot-node is at the desired level. The secondary voltage and reactive power control of the distribution grid controls the reactive power at certain pilot-nodes in the medium voltage network of the distribution grid. The reactive power requested by the distribution system operator (DSO) can be provided by one or more aggregators which send the reactive power request to their devices which are present in the zone of a certain MV pilot-node or can be directly controlled by the DSO himself.

  Tertiary voltage control is a process that acts on a system wide scale and in a time range of about 10 to 30 minutes. The objective of tertiary voltage is to optimize the operation of the network by maintaining the required voltage quality and the substitution of reactive reserves. [7, 8]
- Frequency Containment Reserves - are used for the constant control of frequency. Control uses new resources as frequency-controlled demand from distributed loads and distributed control/MicroGrids. [8]
- Frequency Restoration Reserves - are used to return the frequency to its normal range and to release activated Frequency Containment Reserves back into use. Control includes an increased involvement of Non-programmable RES with centralized and local dispatching. The latter entails DSO to be responsible for the services towards TSO, participating in the ancillary service (AS) market. [8]
- Replacement Reserves - are used to restore the required level of operating reserves in the categories of FCR and FRR reserves due to their earlier usage. Control includes a number of potential resources at both transmission and distribution levels: consumers at LV distri-

bution level, Distributed Generators as wind and PV, centralised storage as pumped hydro and distributed storage as electric vehicle (EV). [8]

DR has many types and can be beneficial, but it has many market and policy barriers for providing AS. In [9], problems are acknowledged as a means of precautions to new DR users willing to participate in AS or aggregators that pursue creating adequate quotas as means of DR for AS by coupling together many residential loads. For IPE implementation of EMS there are many barriers, one of which is the amount of flexible load. Although IPE is a commercial type building, its flexible load is small, but it can be increased by using a battery storage system. Furthermore, the repay length for EMS system implementation is based on how many appliances will be controlled based on meters used and their unique consumption; all factors must be taken into account. The biggest threat in EMS implementation in IPE is lack of dynamic market pricing options that have been restricted to few instances, and none of them offer per hour dynamic price option, which is a crucial part to implement EM.

Energy storage device selection is important for flexibility, saving increase and future PV implementation. In [10], many different storage device types are overlooked with their respectful gains and drawbacks in using each device. Each storage type technical characteristics are summarised by these main criteria – storage capacity, discharge time, charge time, response time, efficiency, lifetime, availability and environmental impact. Different types of batteries must be considered, but implementation is planned inside of the building making batteries most viable solution. Capacity, lower costs and good overall performance is important for battery selection. There are many types of batteries - Li-Ion, sodium sulphur, nickel-cadmium, nickel metal hydride, and zinc bromine, but performance to size-wise Lithium Ion based batteries are great and highly used with decent discharge capacity over its numbers of life cycles [11, 12]. High energy density of Lithium based batteries provides its wide range of use - powering EV, appliances and entire households.

In [13], different configurations of households were studied. Two types of households were observed – with people living 24h inside and away during working hours. To calculate their profit from DR, social welfare is used, and each household differs in equipment and its configurations - no DR, DR with flat price, DR with real-time pricing, DR with storage and DR with storage in dynamic pricing. It's important to compare what impact human interaction can make on the results of the DR system.

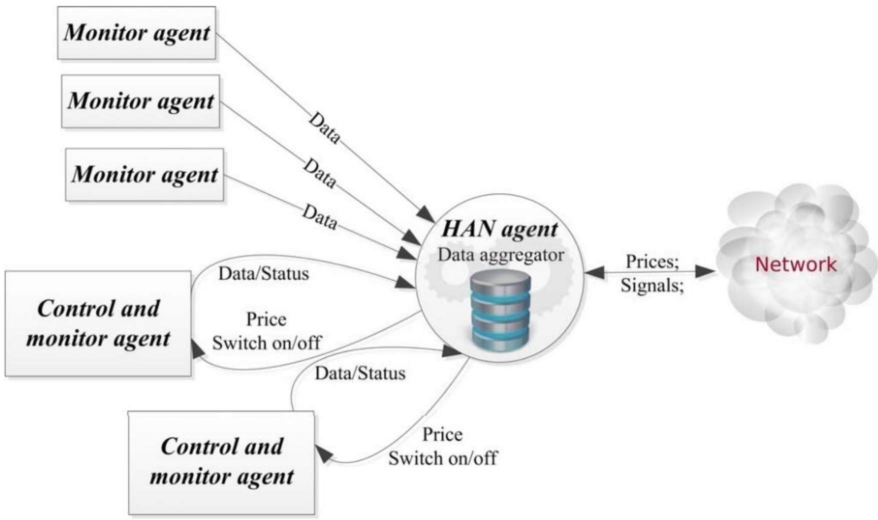

Figure 2: Socket system [14]

In [14], an overview of our lab testing for developing home automation system with automated energy consumption scheduling units for flexibility and controllable portion estimation, is provided. Figure 2 presents the idea taken from IPEs previous testing on DSM topic; it can be used to describe our model function. Monitoring agents would be sockets that control the connected load and data from network prices, and all of the connected loads would be evaluated and algorithm would make its decisions based on present actions, which will be discussed in the further chapters. Additionally, in [15] the feasibility of DR is studied for commercial buildings, but the implementation of sockets and there improvements are detailed in [16]. Early socket models had shortcomings that needed to be addressed to ensure DR program measurement accuracy. Therefore, the new model sockets excel in all previous socket parameters and simplify socket build while also reducing the cost per socket and increasing performance.

3 Executed Tests and Experiments

During the trans-national access stay period, the following two test cases were considered:

a. Test cases OPAL-RT system. Input data vector containing historical data of building total load and available flexible loads are loaded into OPAL-RT system every 1440 seconds and contain 1440 numbers of elements. Note that one second in simulation represents one minute in real-world. This has been adopted to increase the simulation speed. The flowchart of the algorithm is shown in Figure 3.
   a. Two test cases with weeks of low and smooth price change (only flexible loads);
   b. Two test cases with weeks of high price change (only flexible loads);

The main disadvantage of this model is that the real-time system uses historical data that are loaded with higher resolution than algorithm timestamp, which means that real-time change in input parameters will not happen.

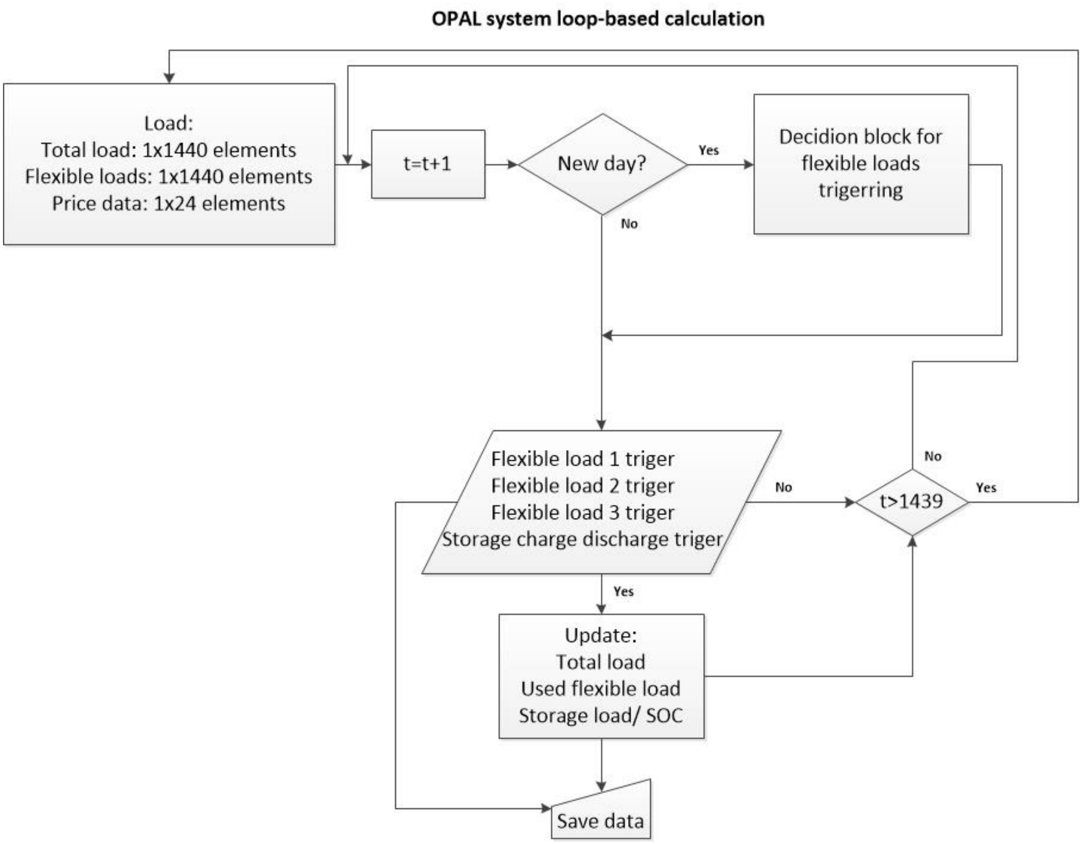

Figure 3: Algorithm with one- day loading resolution

b. Test cases that were working in OPAL-RT system with one- second step of calculation period and one- second step of data loading from MATLab. Flowchart of the algorithm is depicted in Figure 4.
   a. Two test cases with weeks of low and smooth price change (only flexible loads);
   b. Two test cases with weeks of high price change (only flexible loads);
   c. Six test cases with storage algorithm with **one** charge/discharge process for 24h horizon (Flexible load + storage) and with **low** price changes;
      - Inside 50/75/150 kWh storage capacity rates;
   d. Six test cases with storage algorithm with **one** charge/discharge process for 24h horizon (Flexible load + storage) and with **high** price changes;
      - Inside 50/75/150 kWh storage capacity rates;
   e. Six test cases with storage algorithm with **two** charge/discharge processes for 24h horizon (Flexible load + storage) and with **low** price changes;

- Inside 50/75/150 kWh storage capacity rates;

f. Six test cases with storage algorithm with **two** charge/discharge processes for 24h horizon (Flexible load + storage) and with **high** price changes;
- Inside 50/75/150 kWh storage capacity rates;

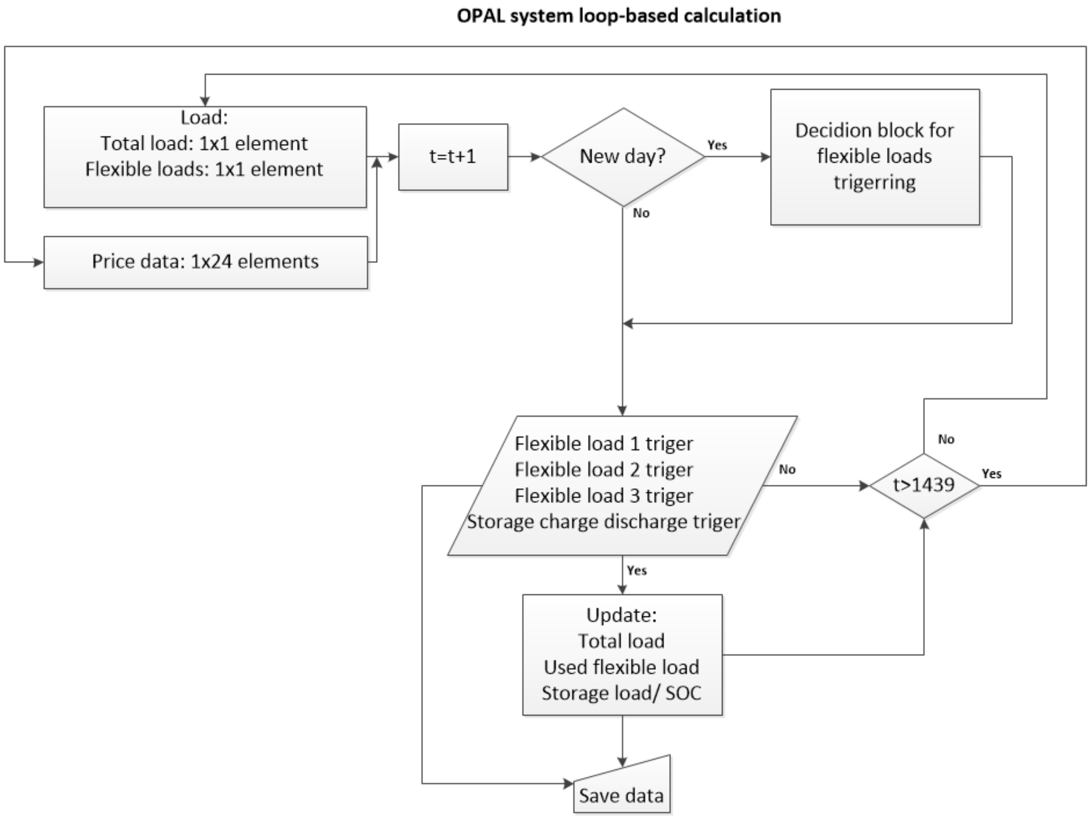

Figure 4: Algorithm with 1s loading resolution

3.1 Test Plan

- Run the model with 1 day of loading data in OPAL-RT system with different test cases – price zones; Done.
- Run the model with 1 s step of loading data in OPAL-RT system with different test cases – price zones (real-time scenario); Done.
- Run the model with 1s step of loading data in OPAL-RT system with different storage implementations and price zones; Done.
- Run the model with 1s step of loading data in OPAL-RT system using parsing from Ethernet for loading data. Not reached (not enough time during this stay period).

3.2 Standards, Procedures and Methodology

EM strategies are based on DR with a set reaction time and added EMS which ads the different user equipment possibilities. EMS classification is illustrated in Figure 5 below, main EMS strategies are shown in three layers describing each solution by a specific block. EM strategies are defined by three main criteria.

First criteria is the DR program dividing into – price-based, incentive-based and hybrid programs. Different programs have their own unique reaction triggers, the price-based DR reacts to changes in market price, but incentive-based trigger is a service type trigger with goals of increasing grid stability as benefit. Hybrid DR is the combination between price and incentive, where users' EMS reacts on price signal and system changes.

Second criteria is based on the user equipment level. Users with small generation units such as PV panels, wind turbines etc., or storage units are able to further increase their flexibility in load shifting and peak shaving thus decreasing electrical expenses by each additional equipment improvements. If there is a combination of add-ons in particular EMS, the object control tasks are becoming more complex and at the same time allow gaining more savings due to increased flexibility of the installed add-ons.

The last criteria is set on reaction time, which splits into three sections – real-time internal parameters, real-time internal and external parameters and forecasting system. RT internal parameters are the parameters that are obtained from the object where the EMS is installed – NordPool price, load consumption, state of charge (SOC), EV behaviour. External parameters – all the measurements outside of object that are measured by user: ambient temperature, natural lighting etc. Forecasting system algorithm can provide the most impact on consumption control but at the same time, it is the most complex block. Forecasting system can be used to forecast price changes, SOC and PV/wind generation.

Each criterion in EM strategies description is represented with increased complexity of EMS realisation and decreased outcomes as compared to the previous block.

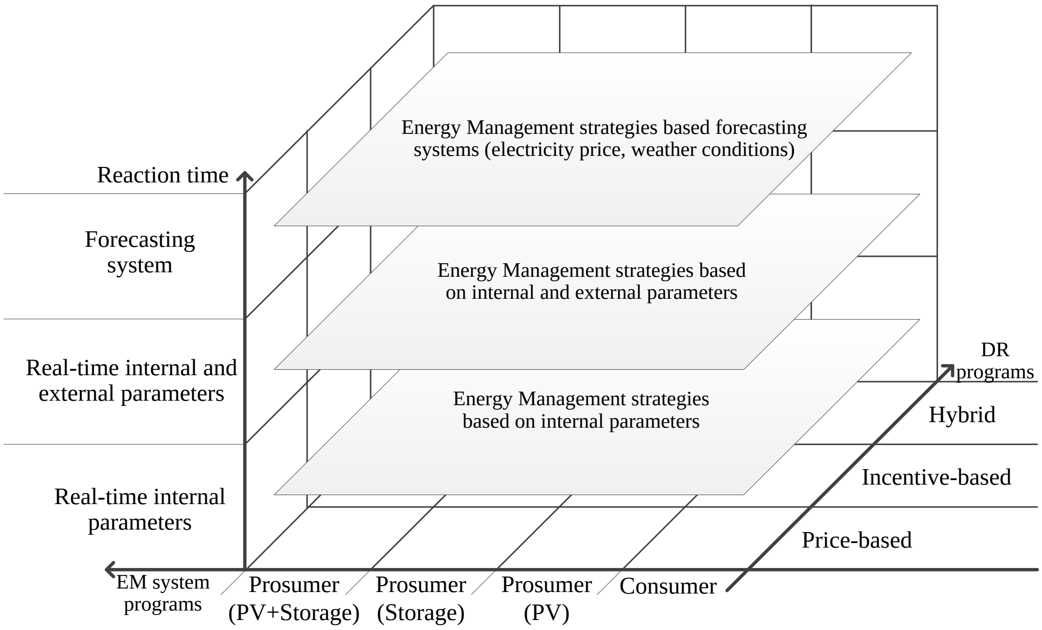

Figure 5: The architecture of EM strategies

EMS model in Figure 5 has many combination options and each additional next section on axis picked makes the realization more complex. Authors commercial building model criteria are set, for reaction time, RT internal parameters that can be measured inside the object will be used, with additional 24h ahead market prices provided from NordPool. DR program focuses on the market price to make its algorithm decisions on load shifting and storage management. The equipment setup is based on storage that is added to the base consumption with a flexible load amounts. The implementation of PV is planned to be added for increased efficiency.

Flexible load is divided into three types of different behaviour loads, their amounts and control algorithms. The shiftable load amount was taken as assumption from devices installed in the lab of ROCOF group.

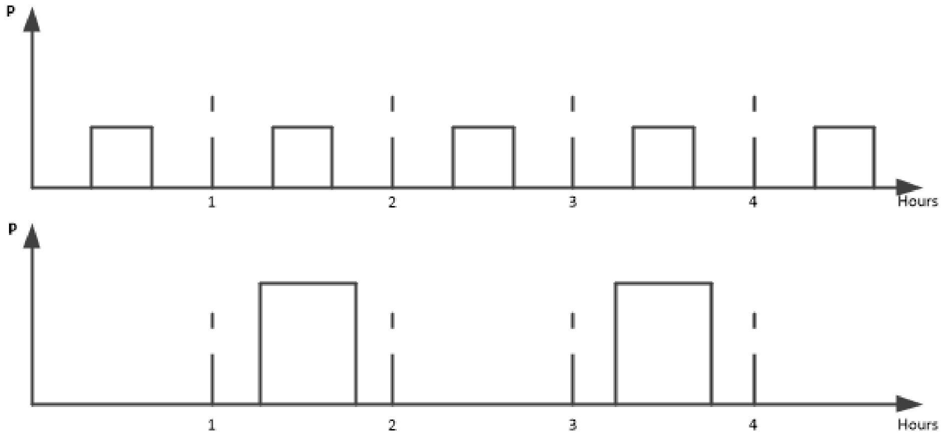

Figure 6: Load type 1 – boilers

Boilers are one of three types of flexible loads that get shifted to more economically efficient times. In Figure 6, upper graph, it can be seen how regular boiler would work, it works for only a part of the hour, but repeats its cycle constantly. The idea behind this type of load is to shift to n+1 hour, see Figure 4, lower graph. Shifting boiler type of load doesn't just increase the load, but also increases the time the boiler will be working in the shifted hour. This load shifts only up to 1 hour ahead, but a safe shift to one more hour ahead could be achieved knowing user interaction times, the amount used and boilers temperature sustainability.

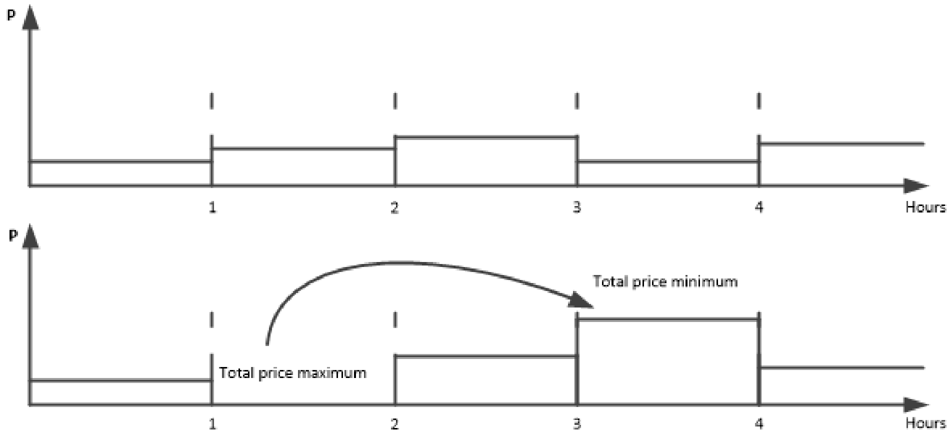

Figure 7: Load type 2 – low loads

Figure 5, upper graph, shows how load type 2 – low loads with known behaviour, could work on their own. Since this load type is with a known behaviour, it can be shifted up for each hour in the working hours. In Figure 7, lower graph an example can be seen, how the amount of known load at one price moment with maximum total price could be moved to an hour with lower total price.

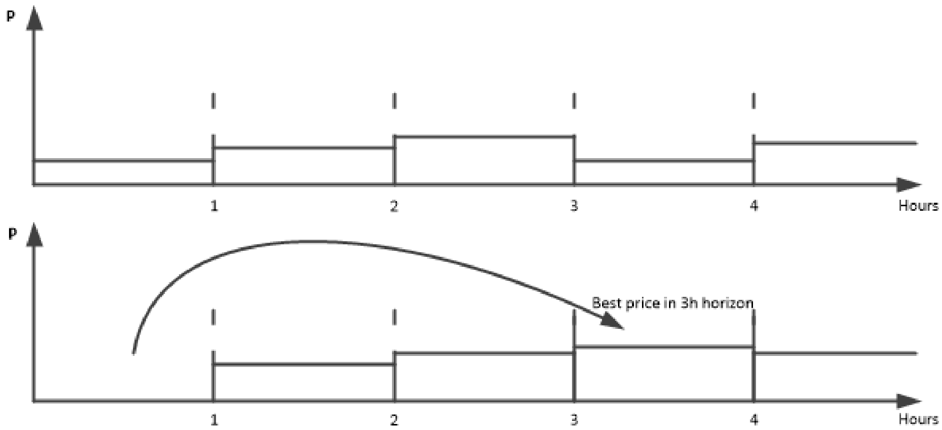

Figure 8: Load type 3 – shifting to +3h horizon

In Figure 8, upper graph, one can see an example of load type 3, difference between load type 2 is that the behaviour is not known and shifts are made purely based on price. In Figure 6, lower graph, an example of load type 3 shifting in 3h horizon can be seen. The load can be shifted for up to 3h horizon, but the only drawback is that no other shifting is done before the shifting operation is completed and only after a new shift can be performed.

3.3 Test Set-up(s)

Test setup using OPAL-RT system during all test cases was in pure RTS with no hardware connected. The OPAL-RT platform is OP56000 with 5 cores activated. The model is running with pure energy flows. The data of the total building load, flexible load potential and price signals are provided with 1s calculation step (recalling 1 min change in real world) from historical data of IPE buildings load and then is loaded in the OPAL system where algorithm for EMS is completing the building load control. However, the load data for new calculations to the model was provided with two methods that were described in Figure 1 and Figure 2.

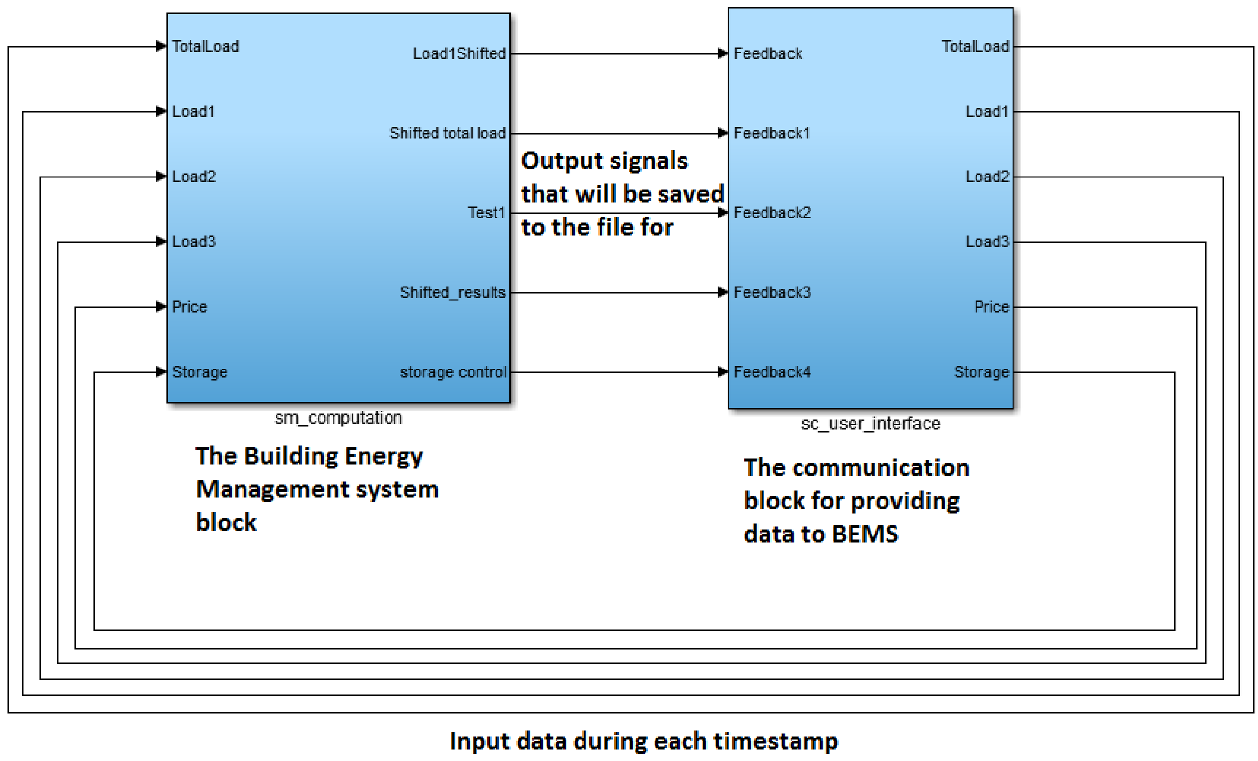

Figure 9: Input/output blocks in Simulink OPAL-RT

Figure 9 shows user interface block – SC and computation block – SM. SC block receives real time stream data from IPE building and market price from NordPool. Then it sends them with a small delay to the SM computation block where algorithm of Building Energy Management system (BEMS) works with three different types of loads and storage, deciding on actions based on pre-set criteria that are based on market price signals. After performing load and storage algorithms, the resulting data are stored and passed through back to SC block where the cycle begins a new until all of the case file is completed.

The BEMS algorithm block from MATLab Simulink is shown in Figure 10. Each flexible load block contains: the trigger block that basically is an hour when load should be stopped or increased (after shifting), shifted load memory block and action block for load increasing/decreasing. Storage block contains trigger block where hour is triggered to start charge/discharge process, action block provides charge/discharge process and memory block saves information about State of charge for the next calculation step.

Figure 10: BEMS in Simulink OPAL system

3.4 Data Management and Processing

- The data is saved after each iteration with 1s resolution;
- Some part of the saved data is used in the loop of real-time simulation for the next step calculation – SOC;
- Inside the model there is local storage for moving flexible load consumption to the next hours (FIFO block);
- The real-time simulation model has a 1 second time step while the actual input data stream is in 1 min resolution. In order to do more tests, it was decided to speed up the simulation by assuming 1 min time step in the real-world input data as 1 second in the real-time simulation;
- The result analysis is based on economic criterion – the impact of each test case on the prosumers bill.
- Test cases are also analyzed by shiftable load rate during the week, the possibility of decreasing peaks and providing savings from different flexible load types.
- The impact of different storage algorithms and storage capacity rate are also analyzed.

4 Results and Conclusions

a. Basic load

The building load flow and price during the four different test cases are shown in Figure 11. The results analysis is presented in this chapter focusing on the working days because the observed object is a building with commercial type load. In the figure presented below, the average consumption in different seasons of the year with different price pool is shown. Moreover, the second test case provides building consumption rate during the national holidays and with combination of low price in nordpool day ahead market price, the potential of savings is expected to be lowest.

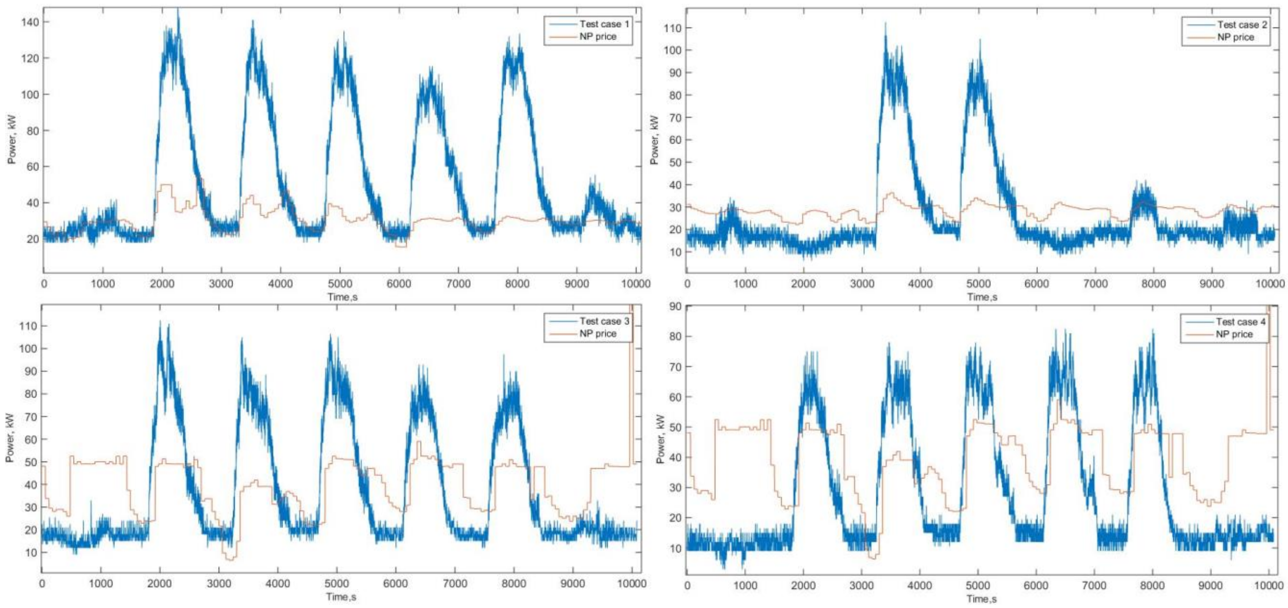

Figure 11: Building base consumption for each test case

The observed test cases represent the historical information about the following dates:

- Test case 1: 18-Feb-2017 : 25-Feb-2017;
- Test case 2: 29-Apr-2017 : 06-May-2017;
- Test case 3: 10-Jun-2017 : 17-Jun-2017;
- Test case 4: 12-Aug-2017 : 19-Aug-2017.

Each set of test case contains the week data that are starting from Sunday. All test cases with flexible load, storage algorithms and storage capacity rate also contain these four basic weeks. Different price and power capacity rate under these test cases allow to overview EMS setup potential and define positive and negative scenarios for EMS implementation. The common consumption and peak loads rates for each test case are given in Table 2.

Table 1: Test case consumption analysis

	Test case 1	Test case 2	Test case 3	Test case 4
Average working day consumption, kWh	1486	709.2	1077	839
Average working day peak load, kW	134.7	61	102.9	79.2

The Table 2 data show that average day consumption during summer time is lower; however, the price during this period in Latvian NP zone will be higher. This can be explained with HPP cascade that are one of the main generation units in Latvia and their potential during summer time is low. The peak load information provided in Table 2 shows that with consumption rate increasing the peak load also increases. During the test cases with different combinations authors do not pay attention to peak load decreasing and all algorithms will be aimed to increase savings in payment. Load decreasing in peaks is not a paramount task because transformer that is connected to the object that is tested can hold 1 MW of load.

b. Load shifting

Figure 12 shows the load change after the shifted load, triggered shifting loads, price during the week and total load before (without) shifting.

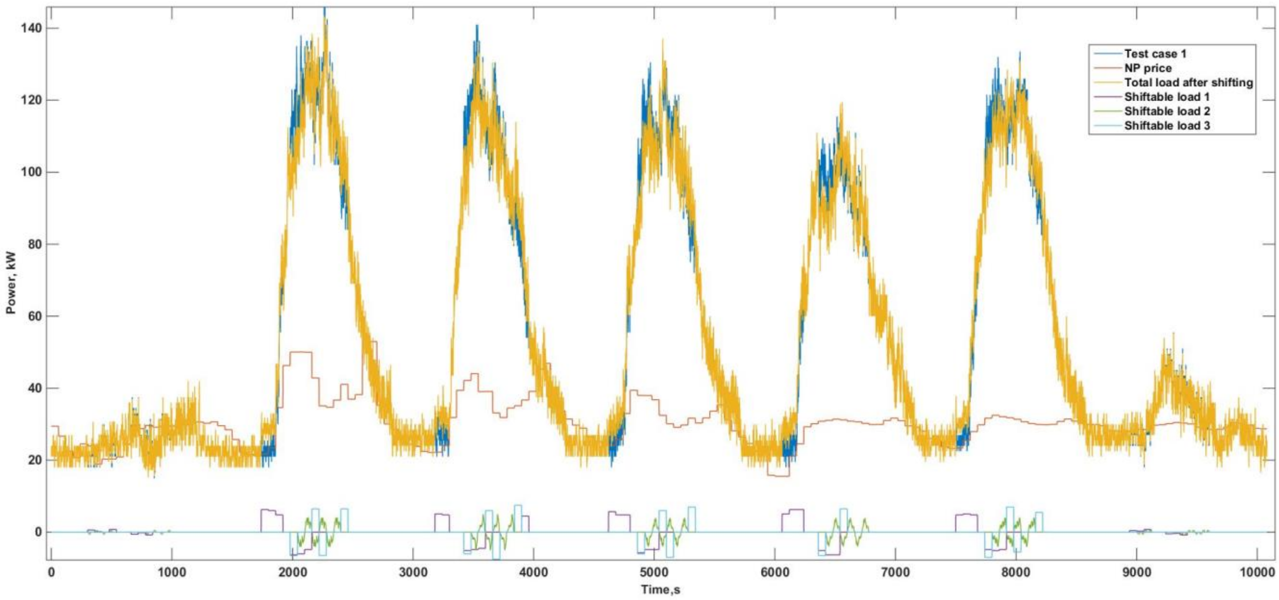

Figure 12: Test case 4 results after the shifted load

The results of shifted load in energy flow and peak load change are provided in Table 3 below. The available load for shifting is used as historical power flow taken for one week and implemented to each test case with the same behaviour, to analyse possible income at different total load and price rates. During the third and fourth test cases the amount of shiftable load is increasing, because the price rates when the algorithm can operate become wider.

Table 2: Shifted load consumption analysis

	Test case 1	Test case 2	Test case 3	Test case 4
Average working day consumption, kWh	1486	709.2	1077	839
Average working day shifted load amount , kWh	79.2	80.1	84.8	87.3
Shifted load amount from total in %	5.32	11.3	7.87	10.44
Average working day peak load, kW	134.7	61	102.9	79.2
Average working day peak load after shifting, kW	133.44	60.6	104.16	82.32

c. Load shifting and storage implementation with one charge/discharge rate

In Figure 13 shown the total load behaviour before shifting, total load behaviour with flexible load shifting and storage with 75 kW rate use and NP prices.

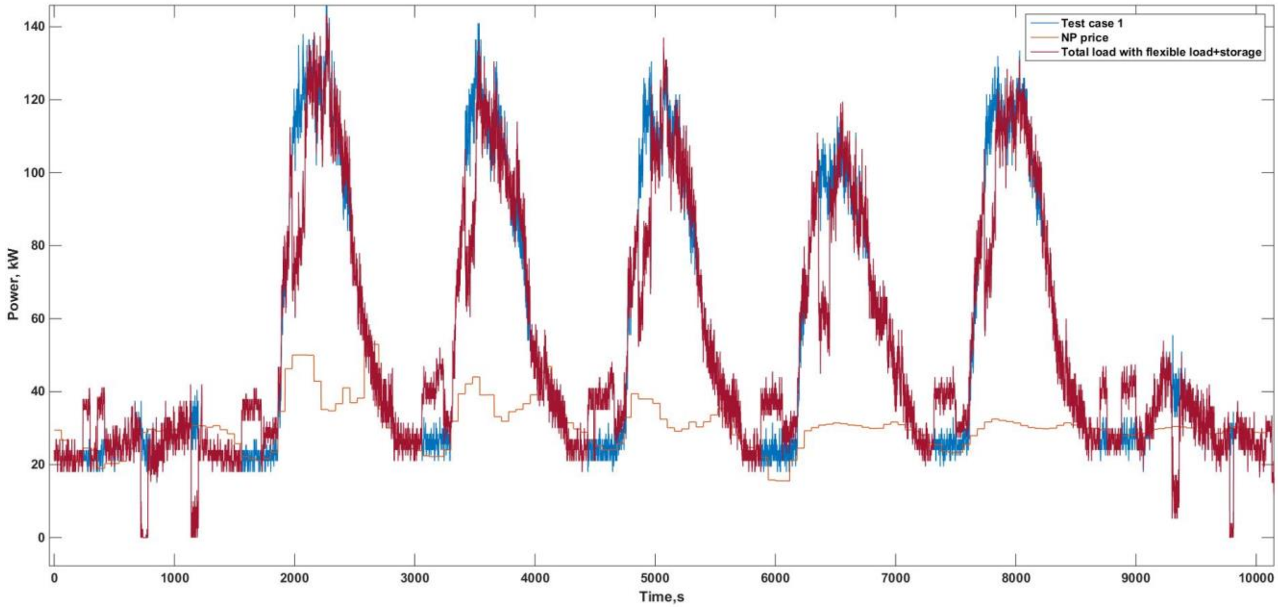

Figure 13: Test case 1 with flexible load and storage 75 kW rate (one charge-discharge/day)

Figure 13 shows one of the test cases with 75 kW capacity rate of storage system. Storage algorithm is implemented with 1 charge/discharge rate per day. The other test cases with different storage capacity rate are described in Table 4.

The simulation results show that the increased impact has the storage system with 50 kW capacity rate in comparison with storage of higher capacity rate. The efficiency calculation is done as follows: average energy use from storage during the day to total storage capacity rate.

Table 3: Building consumption analysis with integrated storage system (one cycle of charge/discharge)

	Test case 1	Test case 2	Test case 3	Test case 4
Average working day consumption, kWh	1486	709.2	1077	839
Average energy used from storage, (50 kW) kWh	32.58	28.1	40.21	37.64
Average energy used from storage, (75 kW) kWh	42.56	35.03	49.28	44.8
Average energy used from storage, (150 kW) kWh	76.06	58.6	86.89	72.47
Average working day peak load, kW	134.7	61	102.9	79.2
Average working day peak load after shifting (50 kW), kW	133.44	64.99	104.6	82.32
Average working day peak load after shifting (75 kW), kW	133.44	65.69	104.16	82.32
Average working day peak load after shifting (150 kW), kW	133.44	74.74	84.82	87.82

d. Storage with one charge/discharge economic analysis

Table 5 provides the economic analysis of profit in different test cases: flexible loads, different storage capacity rates and different prices during the week. The main conclusion for the flexible load impact on savings is that flexible loads provide low saving possibility. Even with 10-15 % of available flexible loads from total load the used amount during one day will be only 2%. However, the flexible load amount was defined by user comfort level to ensure that the user working process will not be affected. In case of maximum savings the used flexible load can be increased.

From the storage capacity rate and their impact analysis can be conclude that most profitable storage system stays 50 kW capacity rate storage.

Table 4: The economic analysis of EM strategies impact with one cycle of storage charge/discharge

Case/EUR Consumption type	1	2	3	4	TOTAL
Regular	**250.42**	**130.43**	**213.03**	**191.22**	**785.1**
With flexible loads	**249.43**	**129.73**	**211.04**	**187.58**	**777.77**
Profit	**0.99**	**0.70**	**1.99**	**3.64**	**7.33**
Flexible & storage **(150)**	240.56	128.49	198.85	170.19	738.09
Savings in storage	0.57	2.06	1.64	1.58	5.85
End cost	**239.98**	**126.44**	**197.21**	**168.61**	**732.23**
Profit	**10.44**	**3.99**	**15.82**	**22.61**	**52.87**
Flexible & storage **(75)**	244.72	127.92	204.74	177.37	754.75
Savings in storage	0.27	0.44	0.94	1.06	2.71
End cost	**244.45**	**127.48**	**203.79**	**176.32**	**752.04**
Profit	**5.97**	**2.95**	**9.23**	**14.90**	**33.06**
Flexible & storage **(50)**	246.10	128.19	205.89	179.23	759.41
Savings in storage	0.27	0.29	0.64	0.97	2.17
End cost	**245.83**	**127.89**	**205.25**	**178.26**	**757.24**
Profit	**4.59**	**2.54**	**7.78**	**12.96**	**27.86**

Figures 14 and 15 show the storage system comparison based on the data presented in the table above. The impact of 50 kW storage to 150 kW storage system is 1.3-1.8 times more.

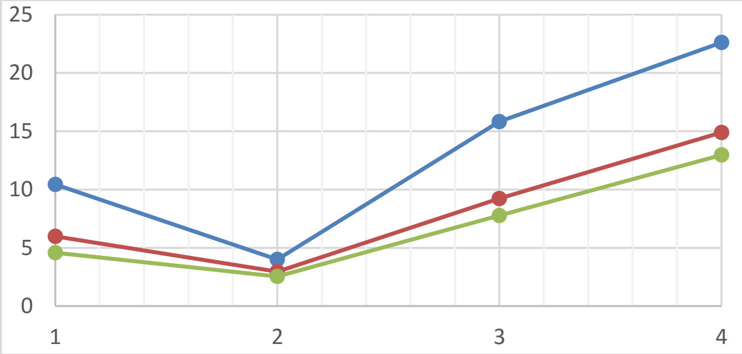

Figure 14: Profit in EUR per case with 150 kWh (blue), 75 kWh (red) and 50 kWh (green) storage.

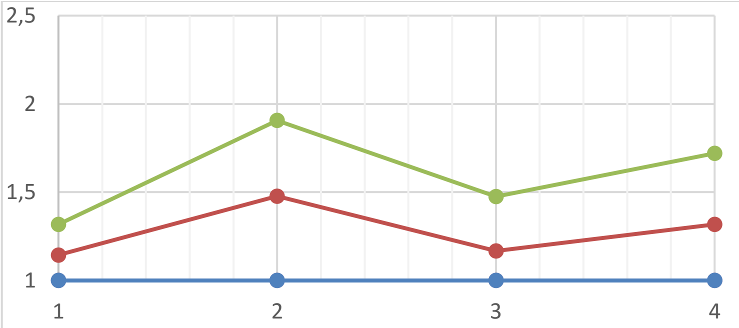

Figure 15: Profit multiplier per case based on most expensive storage, 150 kWh (blue), 75 kWh (red) and 50 kWh (green) storage.

e. Load shifting and storage implementation with two charge/discharge rate

Figure 16 illustrates load behaviour using different storage control algorithms. The algorithm with two cycle of charge/discharge per day works almost in the same hour due to price criteria, but provides one more charge if the price for charge are lower than prices for discharge. In this case second charging are searching after 8-9 a.m. when the first discharge comes (first discharge comes in the morning peak of price 6-9 a.m.). However, the statistic data show that mainly prices after 12-13 a.m. are lower that prices in range of 8-12 a.m. and therefore second charge/discharge process for the storage is not starting every day.

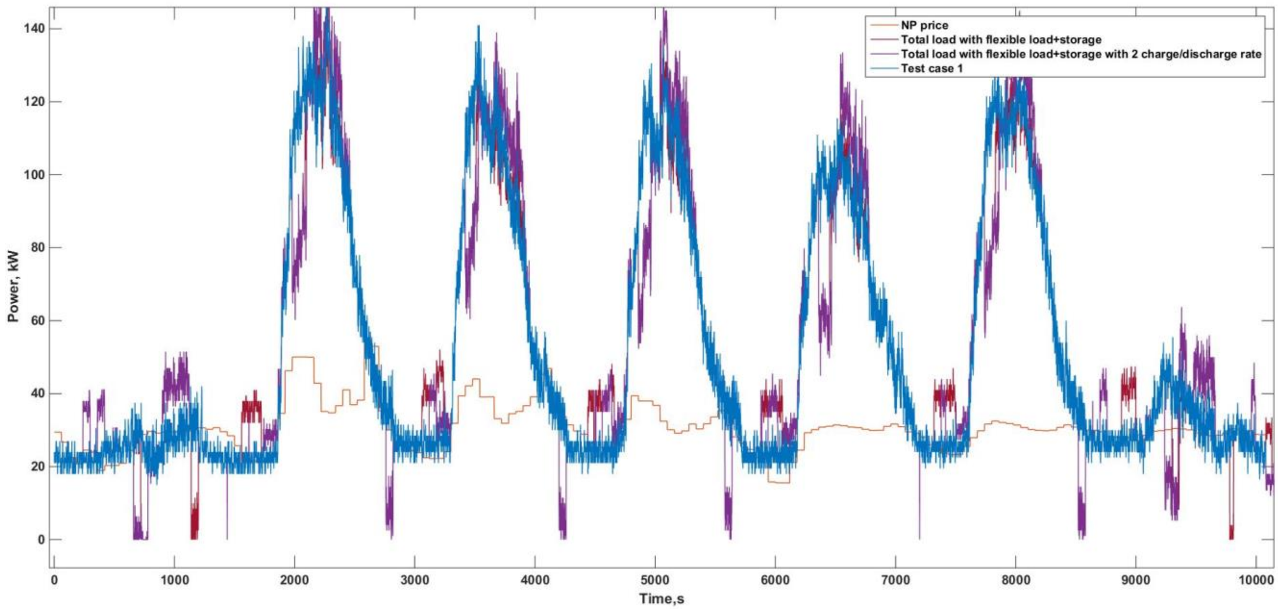

Figure 16: Load behavior with different type of storage control implementation (75 kW storage's)

In Table 6, there are combined consumption analysis of test cases for user savings. The table stores information about different capacity storage's with different price levels. The same conclusion as with algorithm with 1 charge/discharge process could be done for the algorithm with two charge/discharge process. The average use of energy to storage capacity rate is higher to 50 kW capacity rate storage. Also, it should be mentioned that peak load is higher in the two charge/discharge algorithm, but as it was mentioned before, peak load decreasing is not the first order task due to high capacity rate of transformer.

Table 5: Building consumption analysis with integrated storage system (two cycle of charge/discharge)

	Test case 1	Test case 2	Test case 3	Test case 4
Average working day consumption, kWh	1486	709.2	1077	839
Average energy used from storage, (50 kWh) kWh	45.76	24.52	34.53	32.38
Average energy used from storage, (75 kWh) kWh	68.36	32.99	49	46.62
Average energy used from storage, (150 kWh) kWh	130.5	54.55	91.88	86.52
Average working day peak load, kW	134.7	61	102.9	79.2
Average working day peak load after shifting (50 kWh), kW	140.9	64.09	103.83	82.3
Average working day peak load after shifting (75 kWh), kW	145.1	65.35	104.16	82.3
Average working day peak load after shifting (150 kWh), kW	159.2	74.74	104.84	82.3

f. Storage with two charge/discharge economic analysis

The profit from different test cases using storage system with two charge/discharge cycle algorithm is summarized in Table 7. As it was mentioned previously, the impact of 50 kW storage system is higher. At the same time, by analysing two different methods of storage control it can be concluded that 1 cycle charge/discharge process is more effective. The main discussion of this will be provided in conclusions.

Table 6: The economic analysis of EM strategies impact with two cycle of storage charge/discharge

Case/EUR Consumption type	1	2	3	4	TOTAL
Regular	**250.42**	**130.43**	**213.03**	**191.22**	**785.1**
With flexible loads	**249.43**	**129.73**	**211.04**	**187.58**	**777.77**
Profit	**0.99**	**0.70**	**1.99**	**3.64**	**7.33**
Flexible & storage **(150)**	247.35	125.46	199.08	177.03	748.92
Savings in storage	2.68	2.07	1.69	1.41	7.84
End cost	**244.67**	**123.39**	**197.39**	**175.62**	**741.08**
Profit	**5.75**	**7.04**	**15.64**	**15.6**	**44.02**
Flexible & storage **(75)**	248.15	126.16	205.09	182.13	761.53
Savings in storage	2.68	0.44	1.04	0.99	5.15
End cost	**245.47**	**125.72**	**204.05**	**181.14**	**756.38**
Profit	**4.95**	**4.71**	**8.98**	**10.08**	**28.72**
Flexible & storage **(50)**	248.57	127.2	206.63	183.86	766.26
Savings in storage	2.68	0.29	0.48	0.58	4.04
End cost	**245.89**	**126.91**	**206.15**	**183.28**	**762.22**
Profit	**4.53**	**3.52**	**6.88**	**7.94**	**22.88**

From Figures 17 and 18, the impact of storage system capacity could be compared. For the two cycle of charge/discharge rate the 50 kW capacity storage is even more effective, however, it provides lower savings than with previous algorithm.

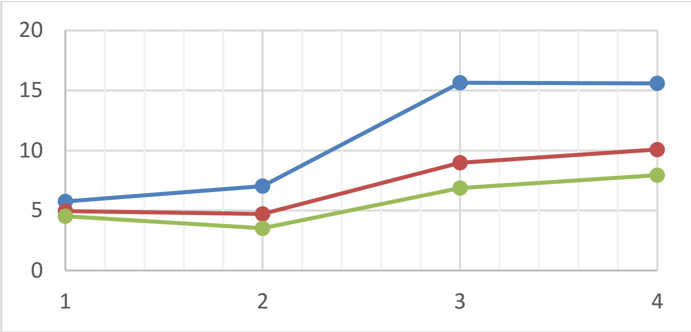

Figure 17: Profit in EUR per case with 150 kWh (blue), 75 kWh (red) and 50 kWh (green) storage.

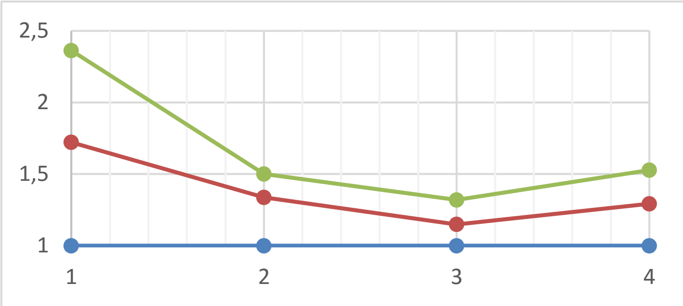

Figure 18: Profit multiplier per case based on most expensive storage, 150 kWh (blue),75 kWh (red) and 50 kWh (green) storage.

Conclusions

The simulated test cases enabled us to analyse and correct the developed - EMS algorithms and approaches before its physical realisation. Implementation of flexible load control for the commercial type building shows that within the LV price zone the low flexible loads, which can be used only for several hours per day, are ineffective. For the commercial type building, the EMS flexible loads should be higher in comparison to its total load. In this case it can be achieved by two approaches: by selecting high consumption flexible load or increasing the amount of flexible loads with mid capacity rate.

Figure 19 depicts the average price in LV price zone per hour in 2017. To provide more reliable price distribution the data during weekends are not taken into account in this graph. From the graph, it can be observed that during workdays in LV price zone there are two price peaks - between 8-11 a.m. and 4-7 p.m. However, the evening price peaks are higher than morning ones and therefore two cycles of charge/discharge storage algorithm have lower efficiency rate. At the same time, two charge/discharge rate for storage decreases the lifecycle of potential storage system.

To increase the profit from the storage system, the potential charge and discharge process should be started only if the difference between prices is higher than some appropriate constant value. This value should be set from the price of the storage system. The test cases with 50 kW storage system show that potential gain during the year can reach up to 350 EUR, but the trigger when to charge/discharge storage system for decrease in storage payback time should be studied further.

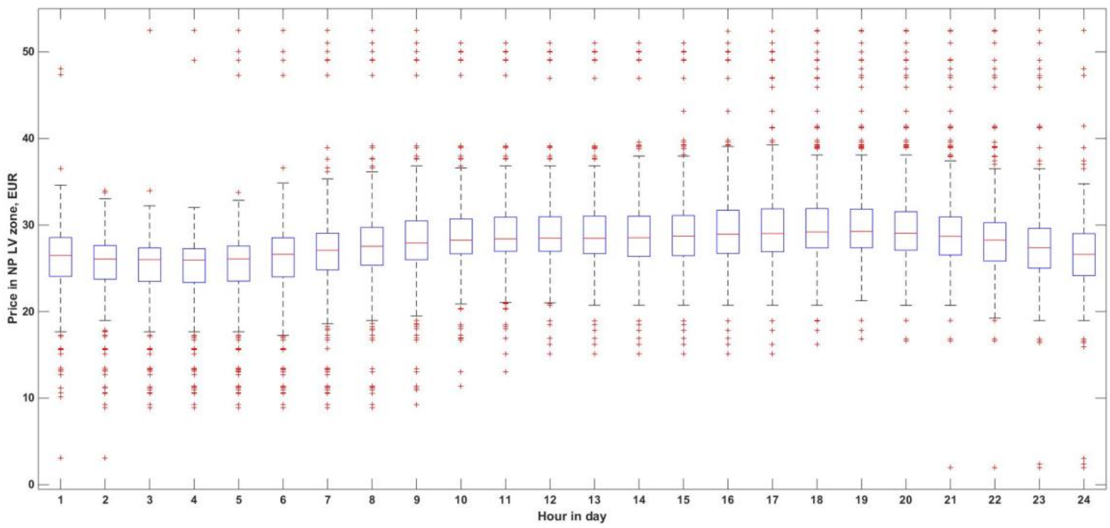

Figure 19: The historical distribution of prices for each our of working day in LV zone (for 2017)

In Figure 20, the visualisation of potential gain from one smart socket can be seen. The amount of possible savings in EUR depends on the load capacity connected to the socket together with the average gain from flexible load algorithms. The peak savings can reach up to 70-80 EUR per year, but for this to be possible the average savings from shifted load should be around 70 EUR/MWh, but from the figure above we can assume that the average savings between different hours are smaller than the peak.

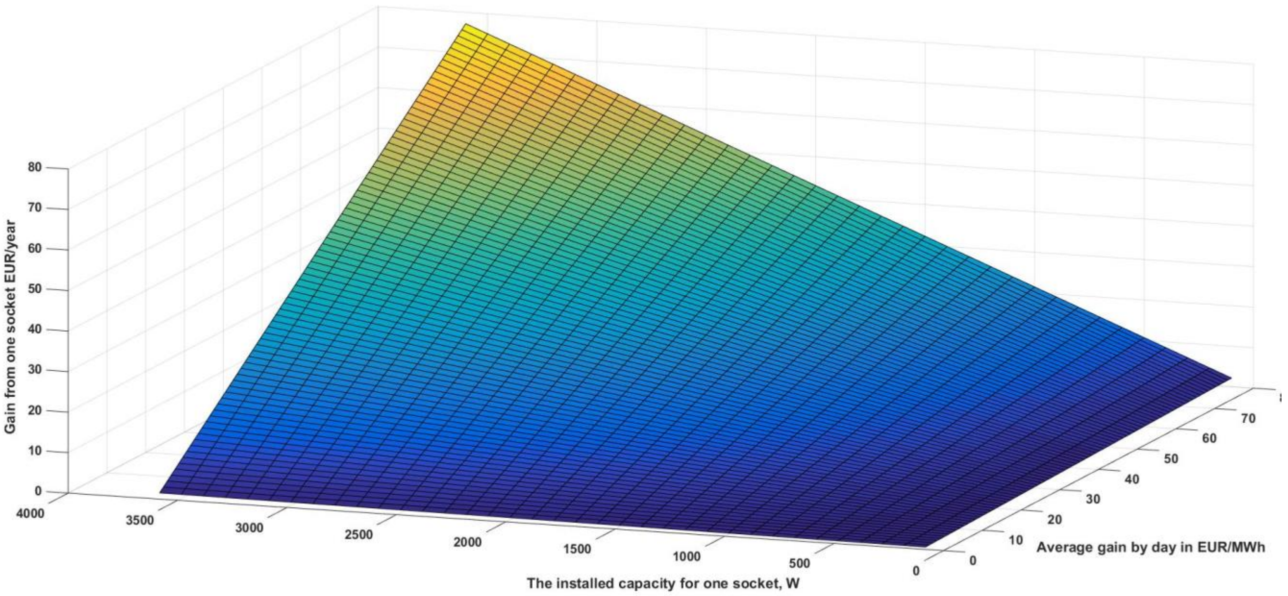

Figure 20: Possible savings during the year from one smart socket

The technical implementation of developed smart sockets can hold up to 16A of current flow. From this it can be concluded that the total power that can be held and therefore shifted by the socket is up to 3600 W. The average gain by each load type is shown in Figure 21.

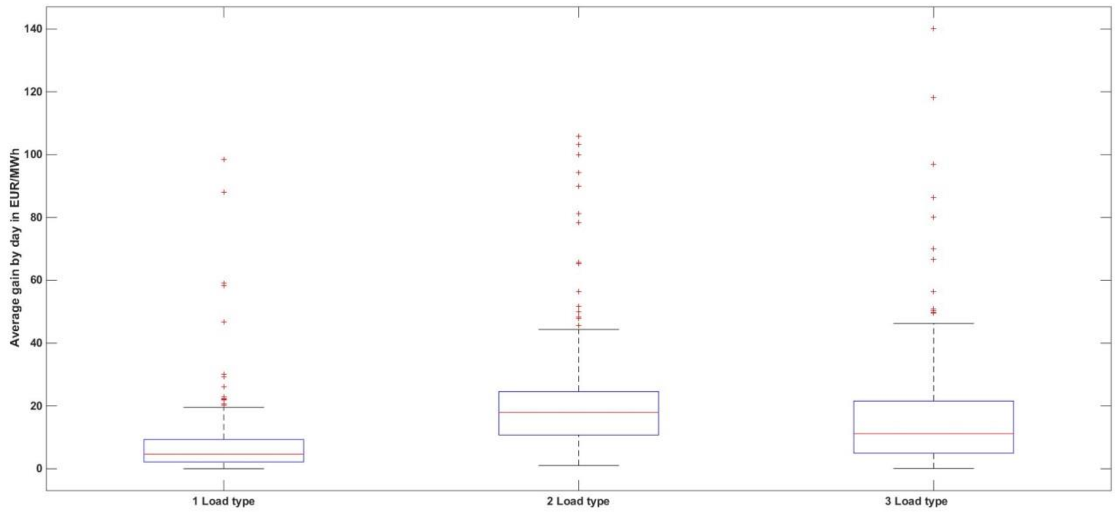

Figure 21: Average savings in EUR/MWh using different load shifting algorithms

The mean gain in EUR/MWh for the first load type is 4.65 EUR/MWh, while the 25 and 75 percent of distribution borders are 2.1 and 9.3 EUR/MWh respectively. For the second load type the mean gain value is 18.9 with 25 and 75 percent of distribution borders that are 10.7 and 24.8 EUR/MWh. The last third load type mean gain during the day is 11.75 EUR/MWh and the 25 and 75 percent of borders are 4.9 and 21.5 EUR/MWh. Analysis of each load type possible impact is provided in Table 8.

Table 7: The algorithm types impact under different scenarios

	Load 1	Load 2	Load 3
Gain with mean load, EUR/year	1.98	8.92	5.94
Gain with worth load, (75%), EUR/year	6.6	18.4	15.47
Gain with low load, (25%), EUR/year	0.76	2.8	1.26

Table 8 shows the conditional outcomes during one year period for one smart socket that implements concrete algorithm approach with different possible device capacities. First load type provides the shift for boiler type load, the mean saving value for this load is 1.98 EUR/year, however, the boilers savings can reach up to 3-4 EUR/year depending on their capacity rate. The second load type works with low level loads with known behaviours; in this case its savings impact is lower and the possible savings amount can be less than 2 EUR/MWh.

The common conclusion for all load types and their possible savings is that the device for load shifting should be chosen using the following criteria: flexibility, consumption rate and user comfort level. At this time, the smart socket price that was developed and described before would cost around 16-18 EUR. The possibly high consumption rate devices such as entertainment system could not be connected due to the negative impact on user comfort level. The list of possible flexible devices that could be connected to the smart sockets and controlled should be overviewed. The low consumption devices cannot pay off the smart socket price, however the connected devices can participate in the incentive based DR programmes. The saving possibilities with incentive based together with price based program should be analysed.

Open Issues and Suggestions for Improvements

- Before the practical implementation of the EMS the study of possible flexible load with their capacity rate should be provided. From the conclusions of test cases was noticed that devices that are connected to the smart socket using some appropriate algorithm should have high enough consumption rate to provide profit faster, due to the price of one smart socket;
- The storage system use pattern should be taken in to account. Eventhough with storage technology price is decreasing, they are still expensive and may not pay off during lifecycle. In this case if the possible profit for the next day is too low the storage system should not start charge/discharge process. Without forecasting price in NP this option will be sometimes unprofitable if in the D+2 the price will be higher;
- For the long term implementation the forecasting algorithms should be realized to increase the income from the EMS;
- Human action variable must be taken in mind, implementing alternative scenarios if previous setup is unavailable or in use by users.

5 Dissemination Planning

- ERIGrid project outcomes will be published in international conference / jornal by IPE team as EMS / DSM topic;
- The gained experience can be used for bachelor or master topics creation for the next academic year with IPE team who are involved in the teaching process;
- The proposed project outcomes will be firstly presented at local events of CloudGrid project that will be interesting for project participants and gained experience will be used as added value for CloudGrid WP5 – Ancillary Services and Energy Management.

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7 Annex A

7.1 List of Figures

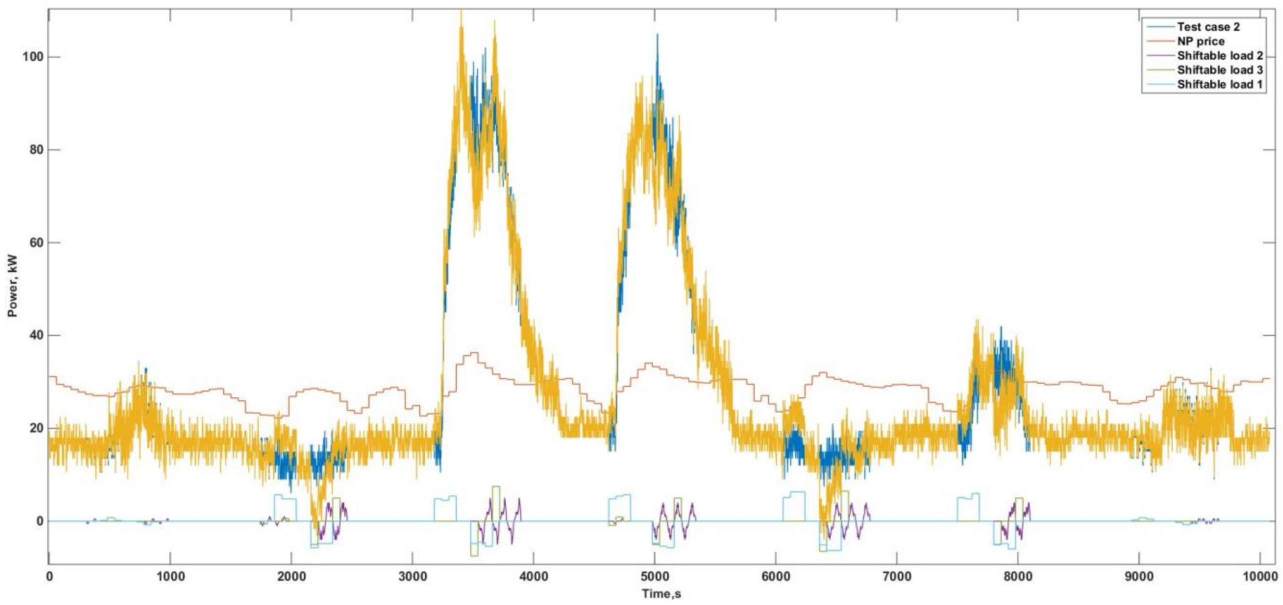

Figure 22:Test case 2 results after the shifted load

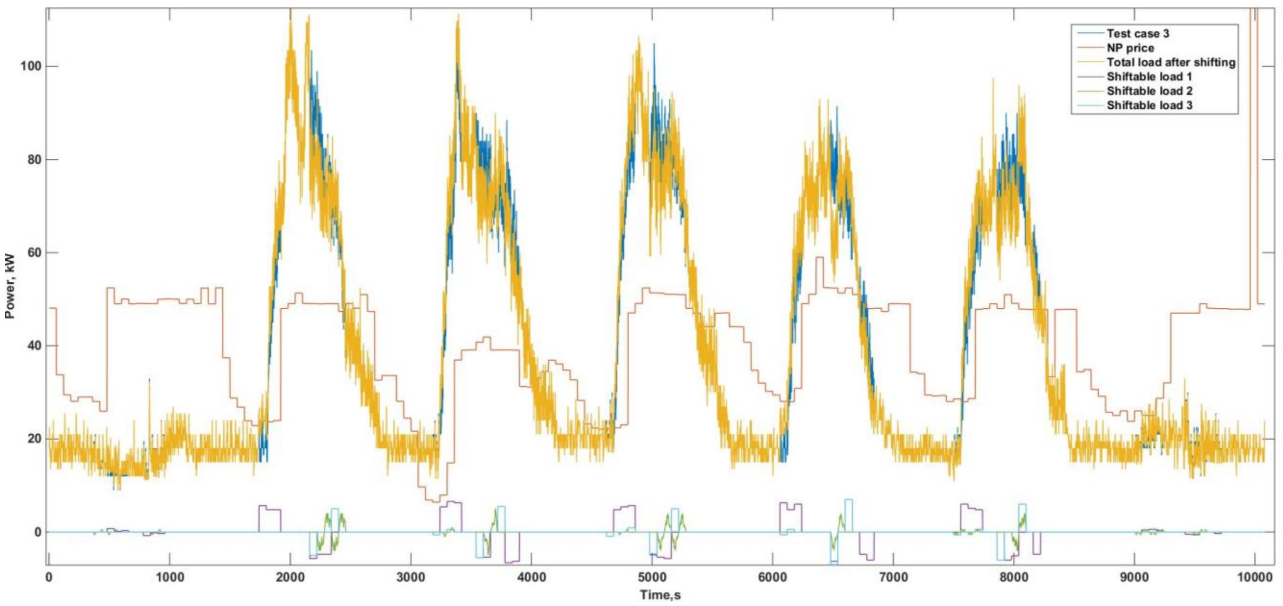

Figure 23: Test case 3 results after the shifted load

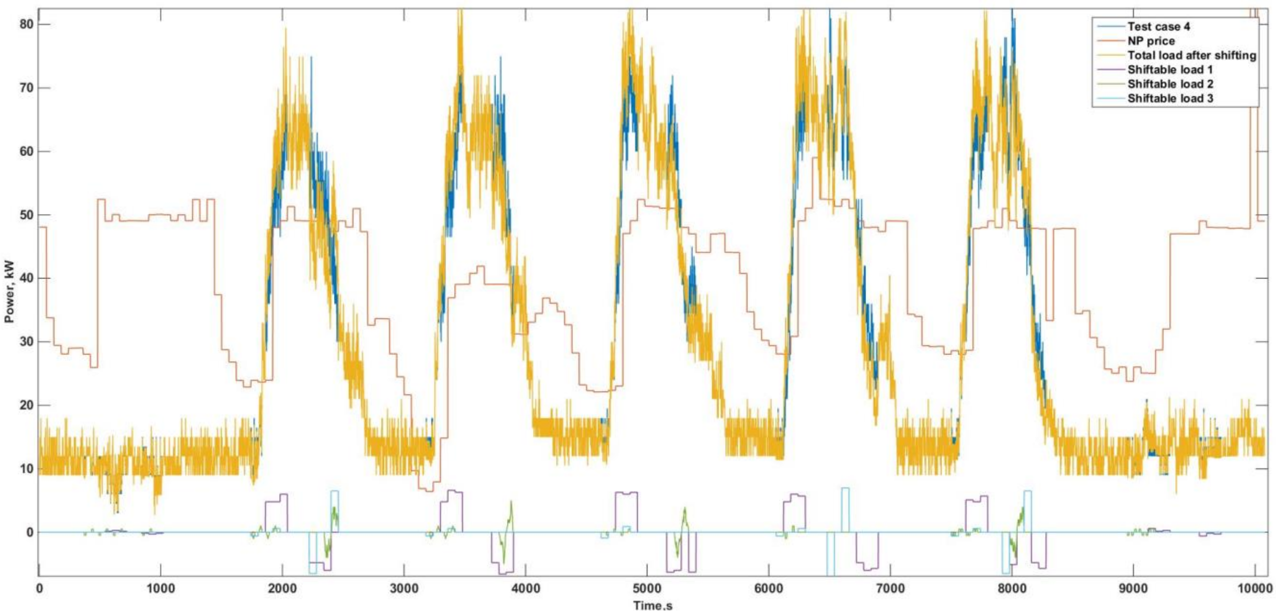

Figure 24: Test case 4 results after the shifted load