From Technology Readiness Levels (TRL) to demonstrating Demand Response in Blocks of Buildings: Upgrading technical and social systems

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Abstract:

Electricity networks base their stability on the balance between electricity usage and generation. Unbalance in the electricity network results in blackouts and can escalate to systems disruption at national and multinational level. The National grids, Transmission Network Operators (TNOs) and Distribution Network Operators (DSOs) ensure the electricity grid remains within safe operational threshold. Demand Response (DR) is a series of the mechanisms intended to procure that the electricity grid stays stable when a peak demand period is forecasted. A demand response action aims at alleviating grid stress or constrains making use of the flexibility that some users have on their electricity use at specific periods. This flexibility is agreed through contracts between companies acting as aggregators and the National grid in the case of the UK for the current DR programs. These aggregators need to acquire flexibility from the qualified users (industry and large energy consumers mainly) in order to be able to manage the assets at disposal to response to the grid's requests to increase or the reduce energy consumption or generation. The Demand Response as a means to balancing electricity grid stress over peak demand periods has long been a matter of research.

Currently DR is largely the reserve of large industrial consumers. It is now widely agreed that DR must become more attractive to smaller energy consumers enabling the aggregation of the energy assets of those customers to increase the amount of flexibility available for DR. This paper presents a detailed discussion of a pilot at a UK University campus of a DR energy management solution developed as part of the DR BoB EU project. This paper also highlights the need for complex social interactions within buildings to be integrated with the technical upgrades when implementing DR solutions.

Keywords: Demand Response - Blocks of Buildings – Energy efficiency in buildings – Technology Readiness Levels – User interaction – Building Management Systems (BMS)

1. INTRODUCTION

Demand Response (DR) programs are mechanisms intended to ensure that the electricity grid remains stable during times of peak demand. They involve but are not limited two variable tariffs - such as traditional Critical Peak Pricing (CPP), Real-Time Pricing (RTP), Time of Use Pricing (TOUP), Two-Tier Pricing (2TP) and various combinations thereof. They prompt DR actions that alleviate grid stress or constrains by leveraging the flexibility that users have in their electricity consumption at specific times of the day (Crosbie et al., 2017). In some DR programmes, this flexibility is agreed through contracts between companies acting as aggregators and the TSO or DSO. These aggregators acquire flexibility from users (mainly large industrial consumers) that manage their assets in response to the grid's requests to increase/reduce energy consumption/generation (Sisinni et al., 2017).

Due to the increasing penetration of distributed renewable electricity generation and the need for the efficient utilisation of existing assets to ease capacity constraints on distribution networks, DR is becoming increasingly significant to electricity networks (US DOE, 2006; Grünewald and Torriti, 2013; Crosbie et al., 2017). It is now widely agreed that DR must become more attractive to smaller energy consumers enabling the energy assets of those customers to be aggregated together to increase the amount of flexibility available for DR (US DOE, 2006; Grünewald and Torriti, 2013; Crosbie et al., 2017). However, there is a lack of integrated tools supporting optimization, planning and control/management of supply side equipment (Olivares et al., 2014; Crosbie et al., 2018). As such, the majority of demand response implementations aimed at small or medium scale customers have failed to meet their expected potential (Olivares et al., 2014; Crosbie et al., 2018).

To address this a project called "Demand Response in Blocks of Buildings" (DR-BoB: www.dr-bob.eu) has integrated existing technologies into a scalable cloud based solution for DR in blocks of buildings. "*The degree to which the DR-BoB energy management solution can increase the ability of any given site to participate in DR is dependent upon its current energy systems i.e. the energy metering, the telemetry and control technologies in building management systems, and the existence/capacity of local power generation and storage plant*". Earlier work in the project has outlined Demand Response Technology Readiness levels DRTRLs (Crosbie et al., 2018), to provide building owners and facilities managers with a method of assessing and validating the technology readiness of their buildings and associated energy assets to participate in DR programmes.

This paper presents a detailed discussion of the implementation of a DR solution developed as part of the DR BoB EU project at Teesside University Campus. This paper also highlights the need to consider the behaviour of building occupants and systems users within the implementation of DR solutions, an aspect that has commonly been under looked (ENERNOC, 2011).

2. DR-BOB solution

The DR-BoB energy management solution (see Figure 1) consists of the integration of the following components:

- A Market Emulator (ME), developed by Nobatek, in collaboration with Teesside University, in charge of the Critical Peak Price Black Box (CPPBB). It replicates market signals for the existing and non-existing trade-offs in the different countries piloting the solution. Market Emulator in figure 1;
- A Decentralized Energy Management System provided by Siemens DEMS®, appearing as Demand Response Management System (DRMS) in figure 1;
- A Local Energy Manager (LEM) developed by Teesside University as product of the IDEAS project (Short et al., 2013);
- A Consumer Portal provided by GridPocket.

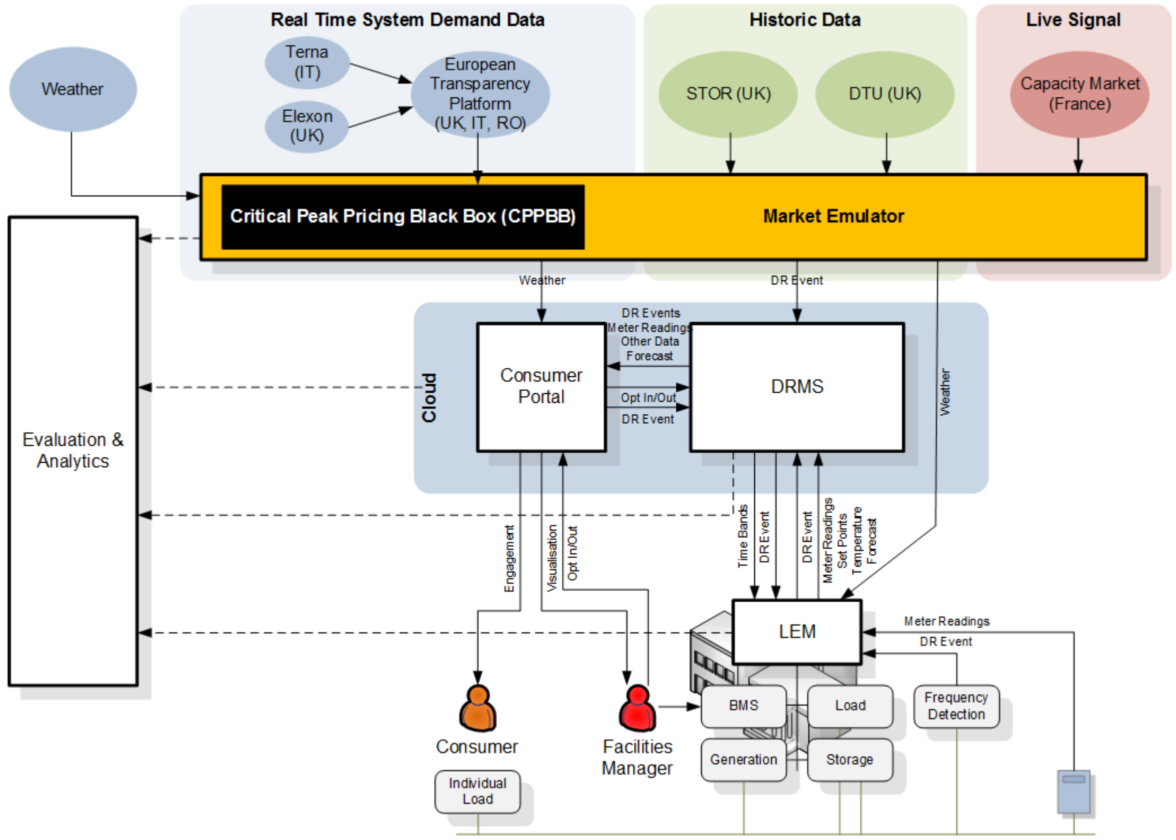

Figure 1. DR-BOB system architecture. DR-BoB consortium®.

Together these tools provide an innovative scalable cloud based central energy management system for single and multiple blocks of buildings applicable to all voltage levels. The DR-BoB energy management solution is directly applicable to the low/medium voltage networks managed by distribution service operators (DSO) and to low voltages networks at the building level (Crosbie et al., 2018). However, many DR requests are sourced from the transmission network operator (TSO) so it can also indirectly provide services to high voltage (HV) networks. The solution is intelligent and can automatically adapt to fluctuations in energy demand or production, subject to dynamic price tariffs where applicable, and changing weather conditions. In the solution, the Market Emulator (ME) replicates and echoes the signals that would trigger DR requests from the grid. The LEM communicates with individual building management systems (BMS) and generation/storage equipment within a block of buildings and as such provides optimised micro-level energy management. The CPPBB module generates signals used to generate events based on grid historical demand data and weather forecast for the day ahead. The LEM enables the real-time optimisation of local energy production, consumption and storage, which can lead to reductions up to 20% in peak demand. The criteria for the optimisation can be set to fit user preferences and thresholds, i.e. to maximise economic profit or to minimise CO_2 emissions. The DRMS provides macro-level optimised energy management, which enables the optimisation of the DR potential of numerous blocks of buildings. The Customer Portal provides the user interfaces required for energy management and community engagement.

The configuration of the DR-BoB energy management solution enables facility managers, building managers and ESCos involved in energy management in blocks of buildings to provide varying levels of control, ranging from the centralised (macro-view) through to local control of the energy systems at the building level (the micro-view). The solution utilises existing standards such as BACnet, ModBus and OpenADR and an open architecture that enables the addition of new adaptors to support new future standards. As such, it allows access to most generation, storage and load assets. DR-BoB energy management solution provides open connectivity to both supervisory control and data acquisition (SCADA)/utility communications and customer side advanced metering infrastructures. The decentralised approach allows the hierarchical optimisation of supply side DR in blocks of buildings and wider energy infrastructures, with automatic distribution of control via building management systems—removing some of the burden and alleviating the complexities involved in individual customer or resident participation

3 Piloting the Solution

The DR-BoB solution is currently being piloted at four demonstration sites. Theses pilots began in October 2017. The pilot sites include two public university campuses, one in the UK and one in Romania, a technology park in France and a hospital block in Italy. This paper concerns the UK pilot at Middlesbrough University Campus (see figure 2). All of the elements of the DR BoB solution in figure 1 are locally deployed at the pilot site. The Market Emulator generates demand response signals to test the DR-BoB solution. As such, it emulates the demand response products of a Transmission System Operator (TSO), Distribution System Operator (DSO) or an aggregator. The DEMS allocates these requests to the LEM, while the Consumer Portal manages interactions with the facilities manager and building occupants.

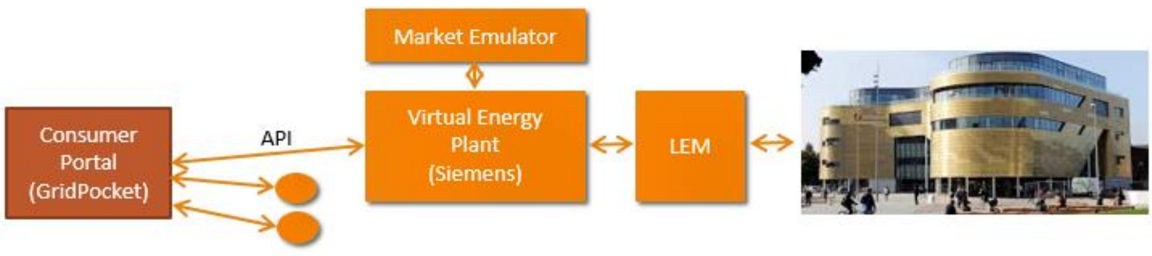

Figure 2. DR-BOB architecture implemented at the UK pilot sites

The buildings at the pilot site are governed by a single owner, and managed with a centralized BMS (Satchwell Sigma legacy), although as discussed later in this paper the metering and billing systems are disparate and complex. The buildings involved in the pilot have a total area of 37.238 m2, the involved power capacity is 764 kW and the occupants involved within these buildings are around 6240 (see Table 1 for details).

Table 1. UK demonstration site buildings

Building	Gross Internal Area (m2)	EUI (kWh/m2/yr)	Consumption (kWh/yr)	Occupants (people)
Middlesbrough Tower	11398.95	137.31	3130278.00	1500
Constantine	4875.01	172.62	841523.00	1100
Clarendon Building	8562.63	182.71	1564494.00	1040
Phoenix Building	4296.00	173.19	744026.00	1050

Stephenson building	8106.00	178.80	1449239.00	1500
Middlesbrough Tower EV chargers	100	62.63	6263.00	20
Total	37238.00	107.36	8768529.22	6240

All manually controlled assets will require that the CP will provide the notification in an appropriate manner to the Facility managers, and the end users of equipment in the scenarios that consider the occupant as an active part of the solution.

For control and monitoring, the individual assets are defined as 'Virtual Assets', this term simply refers to a single asset[1], or group of assets that are treated as a single unit in terms of DR management. This is because controlling individual assets is not always the best approach and can lead to inefficient BMS systems operation. For example in the case of HVAC units, any independent control signal could cause conflict with the other elements of the BMS. Grouping these types of asset as a single unit (virtual asset) mitigates potential control and communication channel dysfunction.

The LEM is deployed centrally to act as a controller across all assets, whether they will be controlled automatically or manually by users or Facility managers during a demand response event. The LEM is deployed alongside the BMS on the BACnet LAN, which will allow the LEM to read and write set points as needed to control the assets under the control of the BMS. Where the DR action makes use of automation the LEM is used to control the assets if opted in from FM to the event generated by the Market Emulator (ME). The virtual assets are listed in the table 2. below. These virtual assets are fed by different meter and temperature readings, forecast values and simulated values provided by the LEM's different functionalities. The meter readings are retrieved using two different sources: the BACnet /IP connection to the BMS using new and existing temperature and electricity metering points. The second source of meter readings values comes from the centralized Meter Reading Service. The data is acquired at the Gateway PC, where the LEM is hosted for the UK site.

Table 2. Assets and control method within DR-BoB project at UK site

Location/Premise	**Virtual Asset**	**Control Manual/ Auto**
Middlesbrough Tower	Electricity Import	None
	Total Electricity Consumption	Manual
	Backup power UPS	Automatic
	CHP	Automatic
Stephenson Building	Total Electricity Consumption	Manual
Clarendon Building	General Area Chillers	Automatic
	Users Electricity	Manual
Constantine Building	Total Electricity Consumption	Automatic
	Constantine Heat	Automatic
The Tower Car Park	Electric Vehicle Chargers	Manual
Phoenix Building	Total Electricity Consumption	Manual
	RIS Office Electricity	Manual
Main Site	Main Site Electricity	None

3.1 Configuring the BMS

Meter data is supplied by a cloud connection to a 3rd party remote metering service that gathers meter readings over a 3G/4G connection and the central BMS, from which the LEM retrieves the data through Modbus and BACnet/IP. The BMS required an upgrade to allow BACnet/IP control of HVAC assets to respond to the DR requests and new meters were required to monitor the controlled assets. Migration from the existing Satchwell sigma BMS system to Schneider StruxureWare BMS was required to enable the BMS to operate automated DR actions within the system architecture. The server uploads meter readings every 15 minutes, as csv files, to a FTPS server locally established to enable processing by the LEM.

Due to requirements for the LEM to be able to control the assets and override set-points, the Clarendon building

[1] Item of property owned by a person or company, regarded as having value to conduct DR, i.e. is automatically or manually controllable and consumes gas or electric energy.

will substitute the Stephenson building. This is due to impossibility to add the necessary control points to the HVAC layout in the Stephenson building. The new control equipment for this project is housed in the existing Clarendon building control room. A Schneider Electric fully licenced StruxureWare Enterprise server on a Workstation Pro is used. The Existing Sigma system has been fully transitioned into the StruxureWare Enterprise server. The transition enables the Sigma BMS system to be available via BACnet/IP, amongst other features. This is enabled by the StruxureWare Automation Server 24 (ASB24) Controller installed in the Mechanical Control Panel (CP1). The controller acts as the BACnet gateway between the LEM and the StruxureWare/Sigma BMS.

There are four Air Handling Units (AHU) in the Clarendon Building which are fitted with two stage DX Cooling coils and serve various locations in the building. The AHU software has not been altered as part of this project. The AHU's are enabled on demand from their own individual time schedules.

3.2 DR-BoB Plant / Environmental Conditions Monitoring

Various existing, and new room temperature calculation points (Highest, Lowest and Average temperature for each quadrant) are monitored by the LEM System. For example, a (BACnet Analog Input Value) in the LEM System is connected via BACnet/IP to a (BACnet Analog Value) in the StruxureWare ASB24 controller. The ASB24 BACnet Analog Value is bound to the existing points via the global values bindings table in the StruxureWare Enterprise server PC. These values are read only and do not affect the control of the Sigma System.

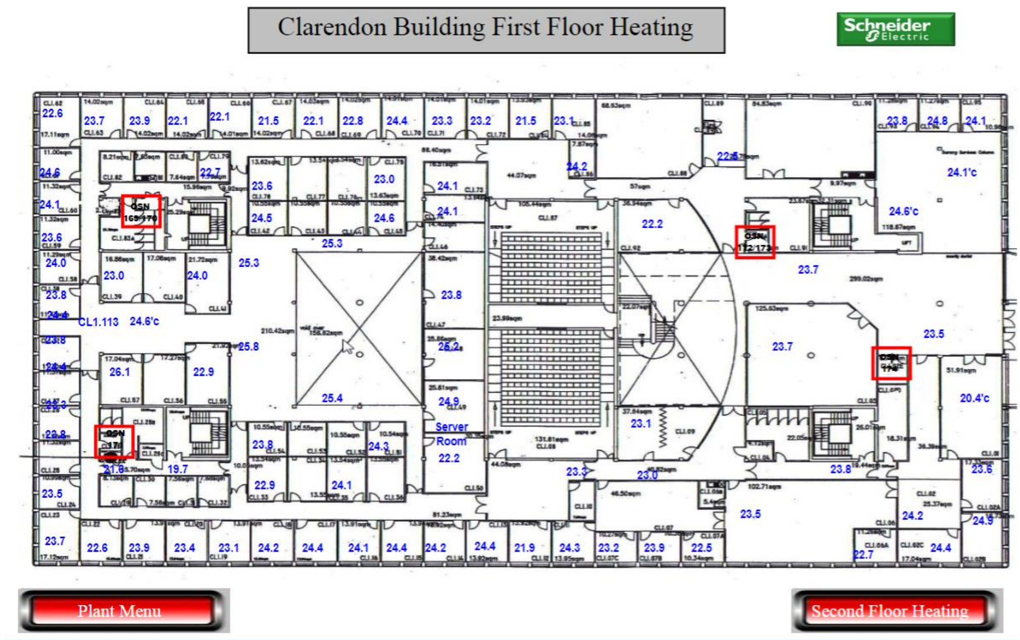

Figure 1. Teesside University StruxureWare Sigma interface. Clarendon building real time temperature monitoring and control access.

Identifying Specific Areas for DR-BoB control in Clarendon Building

As mentioned before, the existing layout of Stephenson building hampered the implementation of the requested upgrading to support DR-BoB technologies and enable overriding of the chillers within the Stephenson building assets. In search of a substitute, the Clarendon building was found suitable for this adaptation, due to its current configuration, although some improvements on the metering system were required. Within the Clarendon building the chillers have been identified as controllable, as well as the FCUs and the heat pumps.

There are two chillers on the roof of the Clarendon Building which serve fan coil units in various locations on the first and second floor. The Chiller software has not been altered as part of this project. The Chillers are enabled on emand from temperature conditions and time schedule. If the Chiller time schedule is on, the outside air temperature is greater than or equal to 9°C, and the maximum value of the following average zone room temperatures is greater than 20°C, then the Chillers will be enabled.

When a DR request is received from the ME to the LEM, the scenario starts running. When a scenario is initiated, and the FM has opted in, the LEM sends a request and via BACnet/IP to the StruxureWare ASB24 controller, housed in CP1. The ASB24 BACnet Values are bound to the new Sigma points via the global bindings table in the StruxureWare Enterprise server PC.

The DR-BoB control overrides each individual existing FCU Cooling set point to REM (remote reference point condition). The REM is referenced to the new “DR-BoB setpoint”. On initial demand the setpoint will be 20°C (adjustable) for the first 30 minutes. This is considered the “shedding period” which translates in a “pre-cooling strategy to be able to reduce HVAC related energy during the actual event period. After this pre-cooling the setpoint is raised to 26°C (adjustable) and hence, there will now indirectly be no demand to the chiller and the rooms should hold their temperature. This is named as the” Low power period”. Once the power is restored the LEM system will disable the “DR-BoB control” and the BMS will be back to automated.

To simplify the operation of the system, during the heating season, the strategy will consist of using the opposite the set-points. 26°C (adjustable) as for the pre-heating period, and 20°C “Low power period” for the DR event. The adjustable values and time for pre-cooling and pre-heating periods will be modifiable as part of the optimization strategy to conciliate users’ comfort and DR effectiveness.

Data Handling

Different logging-data frequency intervals were tested to analyse data and infer conclusions for the research team. The frequency available for data logging is 1 min interval. The interval required by LEM to operate is 15 min for the UK site (and could be taken to a 60 min frequency if more than 3 buildings were involved with different contracts and BMS in place). This interval should be sufficient to analyse data in terms of energy consumption, DR evaluation and Environmental conditions analysis.

In terms of the optimisation, some adjustments needed to be done. A series of testing were carried out after setting the logging data frequency to 1 min interval, hence being able to analyse the actual pattern in the correlation of the different integers, if existing.

To have enough data to determine the correlation trends, the team has run a test for the assets in Clarendon building in which for 2 hours the assets run with nominal set-point (24C), after that, they run for 3 hours with low set-point (20C) and after that, they run for 3 hours with high set-point (26C).

Data Visualisation Requirements

After having determined the different logging points and time interval for the data logs the decision is to determine the different trends and charts needed to examine and analyse the data. In the StruxureWare interface, different charts aim to do so.The charts can be adapted to different timescales, include other logging trends, isolate or discard logging trends, and change the refresh window period.

4. The human factor. Team leader and staff engagement

In one of the DR scenarios being run will generate a Triad Warning use the LEM’s forecasting algorithm and the Rolling System Demand from National Grid to predict when a Triad period is likely. The event will be activated in DEMS via REST API. The ME will gather Rolling System Demand data, pass this to forecasting routine and create any predicted events in the VEP.

Triad charges are levied on all UK customers with half-hourly metering (100kW peak demand) and come into action during the winter in late afternoon and early evening. Warnings are given a day in advance which allows time for more distributed interventions that require communication and manual input. Examples of these would be individually turning off laboratory equipment or deactivating electric vehicle (EV) charging points

Within DR-BoB, the scenario describing the Triads or TNUoS (National Grid, 2016) is one of the most important scenarios to be deployed in the UK demonstration site, involves 6 different buildings and multiple stakeholders need to be aware and provide support to the DR-BoB team. This scenario is aimed at reducing demand during the Triad periods. As these periods are not known in advanced, they require a combination of predictive capabilities as well as flexibility as to be able to reschedule or shift activities across the day or even moving them to another weekday. To do so, collaboration and coordination with responsible staff of the equipment which generates the load remains vital.

A complex interaction process has been defined to enable participation of a block of buildings making use of the different technical components. This complex interaction is depicted in figure 9 and involves more than 200 people changing their behaviour to shift or reduce energy consumption during the DR event.

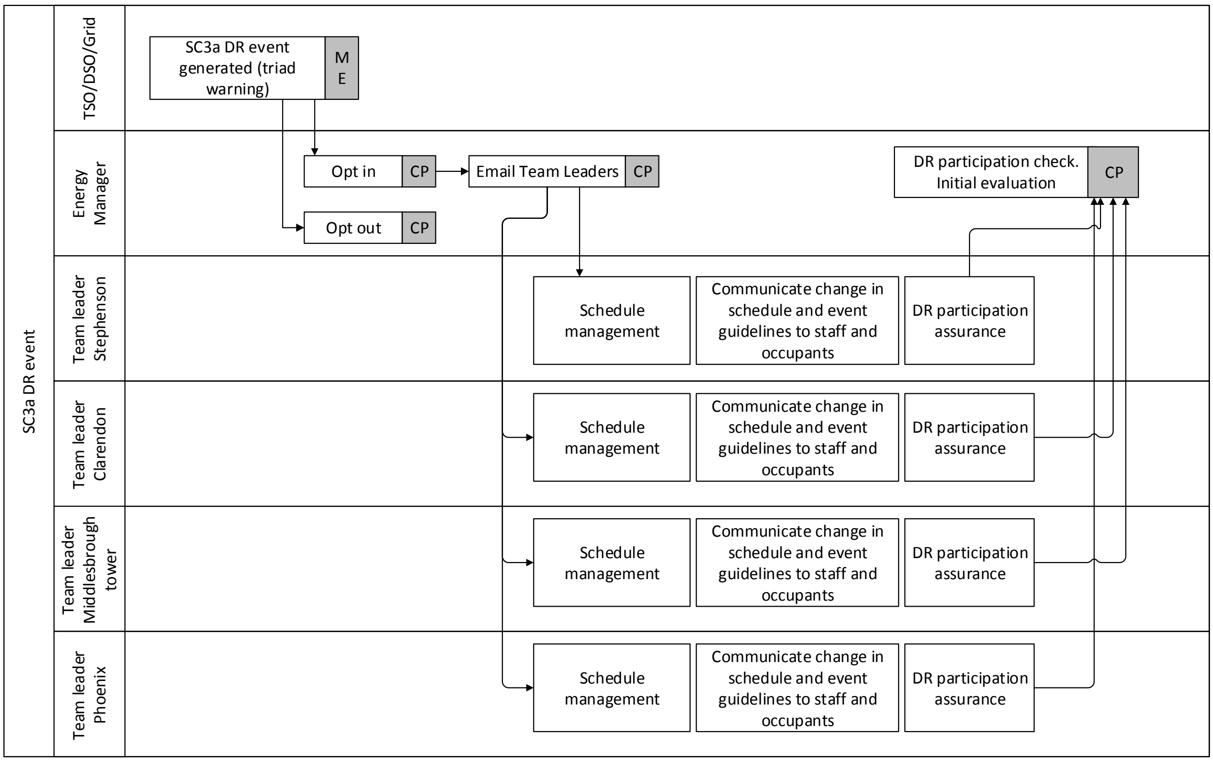

Figure 9. BPMN flow diagram depicting the human interaction within the SC3a DR event

Science Laboratory Areas – Middlesbrough Tower

As part of this scenario, two laboratories, located in the 9th and 8th floor within the Middlesbrough tower will be involved. These laboratories experience an intense activity and hence, responding to the DR request is not an easy task. Coordination with the DR-BoB team will ease the process, and identification of the laboratory principal managers is crucial. In this case, responsible of the Chemistry and Biology laboratory, and Food and Nutrition laboratory respectively, have been nominated as team leaders for this scenario.

Electrical Laboratory Areas – Stephenson Building

A similar approach has been defined within Stephenson building. The technician Team Leader at the electrical Laboratory areas will be responsible for conducting; guiding; and making sure that demand from the assets within this laboratory are switched off during the triad alarms, or alternatively to shift the schedule to accommodate these tests outside the DR event timeframe.

General Areas - Clarendon Building

The enrolment of the team leaders at the Clarendon building is paramount, as the of likelihood of discomfort issues and complaints is the greatest within this building than in the rest of the buildings in the demonstration. The triad DR event will require the automated override of temperature set points by the LEM as explained in the section 2 and 3, but also the request for the staff to modify, if possible, their behaviour in order to reduce energy demand within the building. The team leaders (TLs) at the Clarendon building, were recruited to act as liaison with the staff in the building, and gather complaints (if any), doubts, and requests from the users involved (aware or not of the DR event taking place). They will also actively participate in defining the scenario, e.g. highlighting overlooked aspects, as rooms that should not participate in DR (e.g. server rooms), and elaborating an inventory of ancillary equipment that could be part of the disconnected assets during the “triad” periods.

The TLs will participate in the cascading of emails to the personnel and students at the Clarendon building (1st and 2nd floor) within this event. A e-calendar event will be sent to the involved staff members, to give timely notice and explanation of the event.

A list of personnel at the different offices involved within the spatial constrain of the DR event, and a selection of the representatives for the occupant panel has been done.

Phoenix Building

Within the Phoenix building, two offices and their equipment are enrolled in the “triads” scenario (figure 11). Research personnel will act as TL within these spaces and keep communication with the team to act as liaison before, during and after the triad periods and scenario runs.

5. CONCLUSIONS

Training of Building Managers and Occupants

Training activities have been scheduled to enable the soft and coordinated participation in the DR events for the "triads" scenario, the most complex one for the UK site demonstration. Participation of staff and students is crucial for the success of the DR event, but also for the evaluation and feedback. Consideration of the DRTRL is crucial, but it has been noted that coordination, user expectations, and subjective factors influence the success of DR in BoB a great deal. Therefore a new category for DRTRL is needed, involving the user behaviour and coordination of enrolled people (organisational category).

This paper discussed the upgrading of the BMS and metering carried out to enable the implementation of the DR-BoB energy management solution at Teesside University Campus. It also discussed the integration of these with the different elements of the solution. The discussions presented clearly illustrate that DR requires more than the upgrading of building management systems and metering and the implementation of a technical solution. It also requires complex interactions between different stakeholders to be in place, which can be understood as the social system for DR.

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