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Demand Response Technology Readiness Levels for Energy Management in Blocks of Buildings

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Abstract: Fossil fuels deliver most of the flexibility in contemporary electricity systems. The pressing need to reduce CO_2 emissions requires new methods to provide this flexibility. Demand response (DR) offers consumers a significant role in the delivery of flexibility by reducing or shifting their electricity usage during periods of stress or constraint. Blocks of buildings offer more flexibility in the timing and use of energy than single buildings, however, and a lack of relevant scalable ICT tools hampers DR in blocks of buildings. To ameliorate this problem, a current innovation 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 plants. To encourage the owners and managers of blocks of buildings to participate in DR, a method of assessing and validating the technological readiness to participate in DR energy management solutions at any given site is required. This paper describes the DR-BoB energy management solution and outlines what we have called the demand response technology readiness levels (DRTRLs) for the implementation of such a solution in blocks of buildings.

Keywords: demand response (DR); block of buildings; technology readiness level (TRL)

1. Introduction

Fossil fuels deliver most of the flexibility in contemporary energy systems [1]. As the percentage of renewable energy sources in the energy generation mix increases, it is becoming increasingly difficult to balance energy flows on electricity networks. This is because many of these technologies (i.e., wind and solar) are variable and largely uncontrollable. Therefore, flexibility from storage and demand response is necessary to accommodate renewable intermittency [1]. The loss of system inertia and the need to replace generator reserves with storage and demand response resulting from the removal of fossil fuels from the energy generation mix are well-studied [1]. If we are to further increase the amount of renewable energy in the energy mix, flexibility from storage and demand response is necessary to accommodate renewable intermittency [1–5].

DR offers consumers a significant role in the delivery of flexibility by reducing or shifting their electricity usage during periods of stress or constraint: as such is one method of delivering the flexibility required [1–3,5]. Traditionally DR refers to "changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" [2]. Recent DR schemes not only involve changes in electric energy use but also the optimisation of local power generation and storage [3,4]. In the context of smart grids and increasing renewable energy sources in the generation mix, DR is becoming increasingly attractive as a cost-effective way of meeting peak energy demand [1,2,5]. It may fulfil a number of potential roles:

- More efficient utilisation of network, generator and consumer assets
- Supporting the increased penetration of renewable energy on national energy grids
- Easing capacity constraints on distribution networks and facilitating the further uptake of distributed generation
- Reducing required generator margins and the costs of calling on traditional spinning reserve
- Improving environmental credentials by reducing emissions

It seems intuitive that blocks of buildings offer more flexibility in the timing and use of energy than single buildings [6,7]. As such, current work is considering how blocks of buildings can operate collectively to provide DR within energy networks [8,9]. However, metering instrumentation, automation/control and information/communication technologies tools are a pre-requisite of participation in many DR services requiring guaranteed and fast response from commercial buildings [8–11]. This is especially apparent when considering DR in emerging markets such as frequency control [10]. However, even in the short term operating reserve (STOR) programme, the largest explicit turn-down DR programme in the UK, 85% of assets are found to respond within 10 min despite a nominal 4 hour response time [11]. To enable the exploitation of the potential flexibility in the timing and use of energy in blocks of buildings, an ongoing innovation project called Demand Response in Blocks of Buildings (DR-BoB) has upgraded existing technologies and integrated them into a scalable cloud-based solution for DR in blocks of buildings [8]. The solution is being piloted at four sites in France, Italy, Romania and the UK.

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 the pre-existing energy systems, i.e., the energy metering, telemetry and control systems, and local power generation and storage plant [8]. The value proposition for the DR-BoB solution is obviously dependent on the available revenue sources, which are discussed in detail elsewhere [9]. The work presented here outlines a method of assessing four levels of technology readiness (0—no capability, 1—limited manual capability, 2—limited automated capability, 3—full capability) related to the technologies required for consumers' facility managers, buildings and the local energy infrastructure to participate in the DR-BoB energy management solution at any given site. The approach adopted borrows from the concept of technology readiness level (TRL), developed by NASA, in the early 70s to assess whether an emerging technology was suitable for space exploration [12].

Following this introduction, Section 2 of this paper outlines the DR-BoB energy management solution and the demonstration sites at which the solution is being piloted. Section 3 of the paper discusses the installed technology required to exploit the DR potential of the DR-BoB solution. This section presents the initial version of the DRTRLs developed to measure the capacity to implement the DR-BoB energy management solution at any given site. A short case study to illustrate a test demand response event at the highest DRTRL level at one of the pilot sites of the DR-BoB project is then discussed. This case study helps to illustrate the level of automated control during DR events which can be achieved when the technology is at an appropriate readiness level. The paper concludes with a discussion of the different applications of DRTRLs and the potential for their further development and application beyond consideration of the DR-BoB solution.

2. DR-BoB Demand Response Solution

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

- A Decentralized Energy Management System provided by Siemens DEMS® [13];
- A Local Energy Manager (LEM) developed by Teesside University from an IDEAS project product [14];
- A Consumer Portal provided by GridPocket.

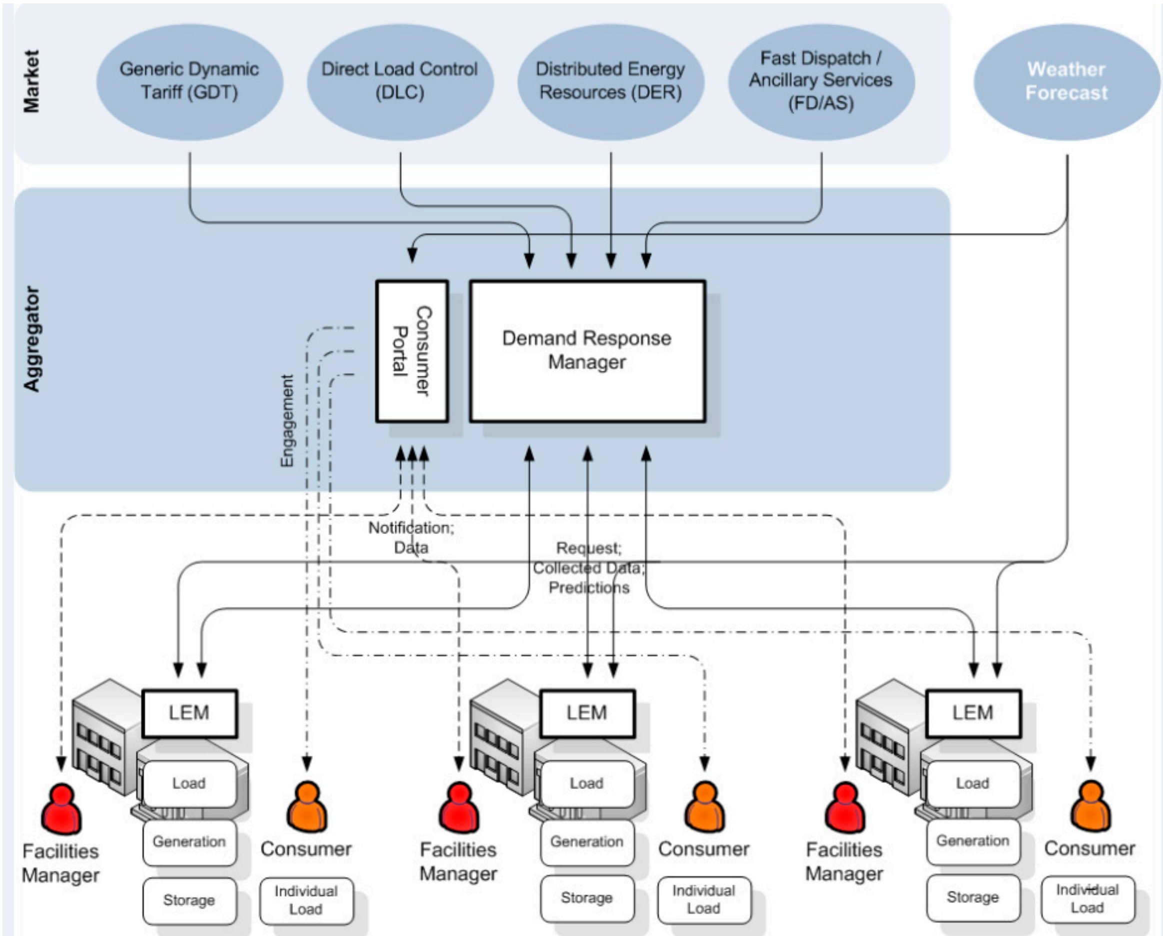

Figure 1. DR-BoB Energy Management Solution.

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. 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. 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 LEM enables the real-time optimisation of local energy production, consumption and storage. The criteria for the optimisation can be set to fit user preferences and thresholds, i.e., it can be set to economic profit or to minimise CO_2 emissions according to the requirements of the user. The DRM 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. Demand Response Technology Readiness Level

The applicability of the DR-BoB energy management solution to any given block of buildings depends on the technologies deployed in the buildings and their building management systems, the controllable assets within the buildings (including energy generation/storage), and the availability of wider communications interfaces to enable telemetry and telecontrol signals with the DR sponsor (DSO, TSO, DR aggregator etc. offering the demand response product). To enable building owners and managers to assess the applicability of the DR-BoB energy management solution to their buildings, a method of assessing and validating the technology readiness of building stock to participate in the DR-BoB energy management solution at any given site is under development. This work is in harmony with other ongoing initiatives within Europe. This includes a current project supported by the European Commission's Directorate-General for Energy looking at smart readiness indicators for buildings [15] as well as two French initiatives called Ready2Grids [16] and "Recommendations for Smart Grid Ready Buildings" [17].

The concept of a Demand Response Technology Readiness Level, or DRTRL, is to measure the technological readiness of a block of buildings to participate in a building-stock oriented DR program such as the DR-BoB energy management solution. The proposed DRTRL borrows from the TRL concept developed by NASA in the early 70s. Essentially, TRLs provide a "discipline-independent, program figure of merit (FOM) to allow more effective assessment of, and communication regarding the maturity of new technologies" [12]. In the case of DRTRLs we are looking to provide a scale which a facilities manager or a building owner can use to conduct a technology readiness assessment (TRA) of the current energy and communications systems at their site, or sites, to support their decision to implement the DR-BoB energy management solution or similar solution.

The concept of DRTRLs for blocks of buildings is operationalised in the following way:

- Technology refers to the building/site energy and communication systems which include metering and telemetry, flexible load, local energy generation and energy storage plant etc.;
- Readiness refers to time, specifically it means ready for operations at the present time;
- Level refers to the extent of the capability of a block of buildings to take part in the DR-BoB energy management solution.
- Block of buildings refers to a group of buildings that may or may not be in proximity to each other if under common governance.

The DR-BoB project aims to provide and validate a method of assessing levels of technology readiness related to the technologies required for consumers' facilities managers, buildings and the local energy infrastructure to participate in the DR energy management solution at any given site [8]. Currently the following four technology readiness levels are defined:

- DRTRL-0: no capability, which is defined as a building/site that does not have the technical capacity to enable the implementation of the DR-BoB solution;
- DRTRL-1: manual capability, which is defined as a building/site that has flexibility that can be controlled in a manual capacity by facility managers, or end consumers, making a direct intervention to apply control signals, typically based on a recommendation notification such as an email;
- DRTRL-2: partially automated capability, which is defined as a building/site that has the minimum technology required to partially enable some of the automated functioning of the DR-BoB energy management solution by directly responding to tele-command signals without manual intervention, but will still require manual intervention for some functionality;
- DRTRL-3: full capability, which is defined as a building/site that has the technologies required to fully enable all of the automated functioning of the DR-BoB energy management solution through tele-command signals, without requiring manual application of control.

To achieve DRTRL-1, a building/site must have:

- Consumption assets that can be deactivated for a short period by manual direct control without deleterious consequences;
- Wide Area Network (WAN) communications (dedicated network connection or relevant ports open in firewall for OpenVPN);
- Occupants with access to notification services such as email, twitter, intranet pop-ups etc.

At DRTRL-1, the DR-BoB solution is able to pass recommendations for asset control and requests for demand response to occupants. The signal for these requests can be from a third party (TSO/DSO/Aggregator) or from the DR-BoB solution itself when configured with time varying energy/power prices. For instance, at the UK site the DR-BoB solution will analyse real time national grid consumption data, supplied by Elexon (Elexon is a limited company that provides payment and settlement services within the UK's electricity industry), and notify staff to reduce consumption during peak periods likely to be designated for Transmission Use of System (TUoS) charges. This is informally known as "Triad avoidance".

To reach DRTRL-2, a building/site must additionally have:

- Automated energy metering at the building level (high frequency, <1 h) able to export data with low latency, <1 h;
- Controllable assets, either dispatchable behind the meter (BTM) generation or turn-down demand, whose schedule can be altered for a short period by without deleterious consequences;
- HVAC assets controlled by BMS accessible via an open or standard protocol;

These additional capabilities allow the DR-BoB solution to optimise HVAC asset dispatch under supervisory control, such as temperature set points. Participation can also be demonstrated quantitatively in high resolution meter readings. DR-BoB will display such data to energy managers and building occupants directly in the Consumer Portal to enhance engagement and understanding of DR.

To reach DRTRL-3, a building/site must additionally have:

- Automated, low-latency (<15 min), high-frequency (<half-hourly) asset-specific energy metering;
- HVAC assets under direct control via an open or standard or BMS protocol;
- Temperature sensors in areas served by HVAC assets under direct control.
- Energy storage assets (electrical, thermal).

If the building/site under control has temperature sensors and close to real time energy metering then more effective optimisation is possible with feedback to the DR-BoB solution platform. The full capability of the DR-BoB solution is enabled if this is also coupled to energy storage assets that can be incorporated into dispatch schedules.

4. DRTRL Exemplified by the DR-BoB Project Demonstration Sites

The DR-BOB energy management solution is currently being implemented at four pilot sites and will be demonstrated over a period of twelve months from September 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 (see Figure 2). The buildings at each of these sites have different uses, physical forms, market and climatic contexts (see Figure 2). In addition to the DR-BoB DR solution, a market emulator is being implemented at each of the pilot sites. It is necessary to emulate the different types of DR products on the market to test the efficacy of the DR-BoB energy management solution, as within the timeframe of a three-year project it is not possible to change the current energy contracts at the pilot sites.

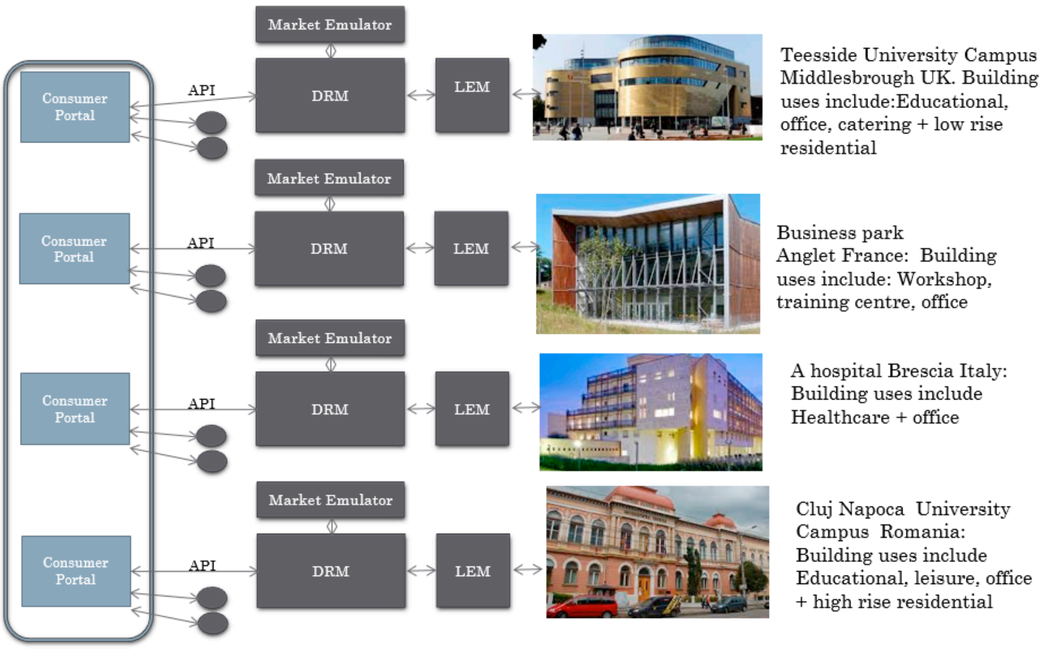

Figure 2. DR-BoB architecture implemented at four pilot sites.

Prior to the implementation of the DR-BOB solution at each pilot site, each of the blocks of buildings involved in the pilots had a unique configuration of assets, metering and management largely at DRTRL 1. As such, all sites required some degree of investment, predominantly in metering, to be able to fully deliver the DR-BoB functionality and measure the quantitative impact of the solution (see Table 1 below).

Table 1. DR-BoB pilot sites their uses controllable assets and DRTRLs.

Site & Building Use	Controllable Assets	Initial DRTRL	Implemented DRTRL
Teesside University, UK, Educational facilities, offices, catering & low rise residential	Chilled water system, fan coil units, electric vehicle (EV) charging stations, combined heat and power (CHP), backup generator & uninterruptible power supply (UPS)	1—Half hourly automated meters report to data server with one day delay. BMS with temperature sensors & assets accessible only over proprietary protocol.	3—Existing half hourly metering system upgraded to reduce latency to <15 min, BMS upgraded to enable direct control over standard (BACnet) protocol & data gathering from room temperature sensors.
Business Park, Anglet, France, Workshop, training centre, & offices	Microgrid, heat pumps, renewable energy systems (PV), electrical storage	1—Multiple metering systems & BMS within buildings. No metering of wood consumption. Open IP communication present but not configured.	3—Metering & BMS data export established & configured at high frequency (15 min). One additional meter required at carpentry workshop. Existing direct control hardware configured.
Fondazione Poliambulanza Hospital, Italy, healthcare & offices	Chilled water system, combined cooling, heat and power (CCHP), food carts, laptops	1—Metering system at building scale not asset scale. Low temporal resolution (daily). Sophisticated BMS with multiple assets & sensors.	2—Metering system upgraded to improve resolution to 15 min & reduce latency to <15 min. Hardware available for direct control but manual implementation at building manager's request.
Technical University of Cluj-Napoca, Romania; Educational facilities, leisure, offices & high rise residential	Chilled water system, washing machines, swimming pool pumps	1—Isolated manual meters & control systems on assets.	2—Building Energy & Management System required to enable control over standard protocols & export of data at <15 min latency, 15 min resolution.

5. Case Study: DTRL-3 at UK Pilot Site

As discussed in the preceding section, the DR-BOB energy management solution has been implemented at four pilot sites and is being demonstrated over a period of twelve months from September 2017. The UK pilot site is capable of achieving DRTRL-3, i.e., full capability to fully enable all of the automated functioning of the DR-BoB energy management solution through tele-command signals without requiring manual application of control. To illustrate the functionality of the solution in action, this section describes some initial test data which has been obtained for one of the four test scenarios chosen to be implemented at the site. The scenario in question is a short term operating reserve (STOR) capability. In a STOR event, a request to curtail demand for a specified period (maximum 4 h notice, minimum 15 min notice, duration 2 h or more) is received by the aggregator from the wider market (see Figure 1). The DR Manager (DNO) then forwards the request to the LEM located at the UK pilot site via the secure OpenADR connection.

As shown in Figure 3, at the pilot site itself, the LEM then disables the chiller (Air Source Heat Pump—ASHP) via the BACNet interface to the building energy management system (BEM). Figures 4 and 5 display the chiller return air temperature (in °C) and chiller electricity consumption (in kWh) during a test request of a STOR event. The event was scheduled to start at 12:30 and last for a duration of three hours. As illustrated in Figure 4, prior to 12:30 the air temperature fluctuates as the chiller cycles around its set-point; during the STOR event, the chiller is automatically held in the OFF state and the air temperature starts to rise to the ambient (outdoor) temperature. At the end of the STOR event, the air temperature is brought back down to its set-point and normal cycling resumes. As can be seen in Figure 5, the electricity consumption for the corresponding STOR period is curtailed (as desired), indicated by the flat line occurring between 13:30 and 15:30. Prior to the STOR event, the electricity consumption is driven by the cycling of the unit.

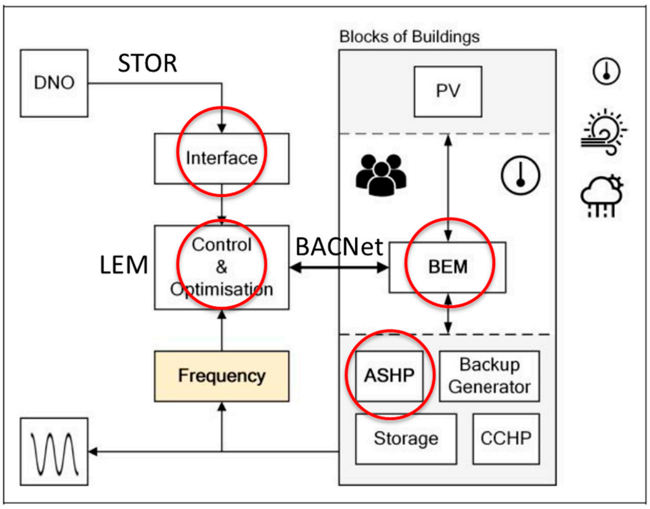

Figure 3. Control concept for handling STOR event at the UK pilot site.

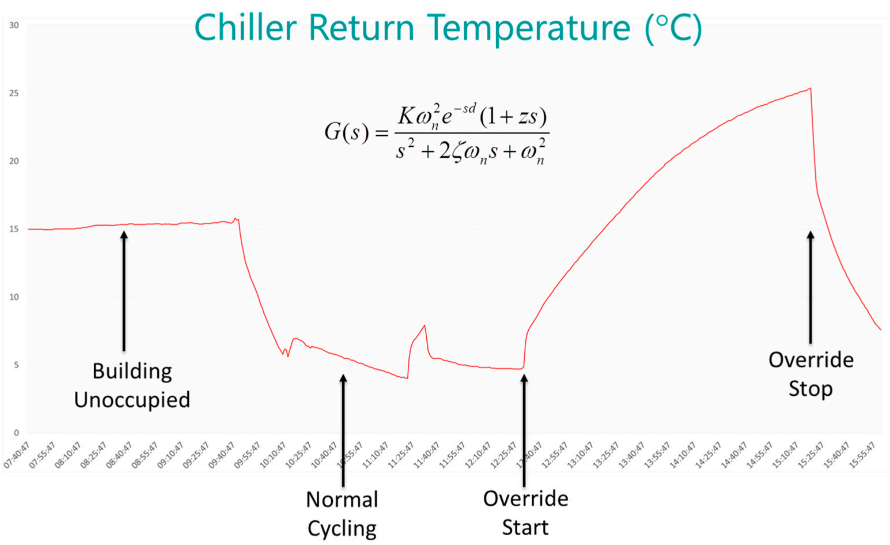

Figure 4. Measured chiller return temperature (°C).

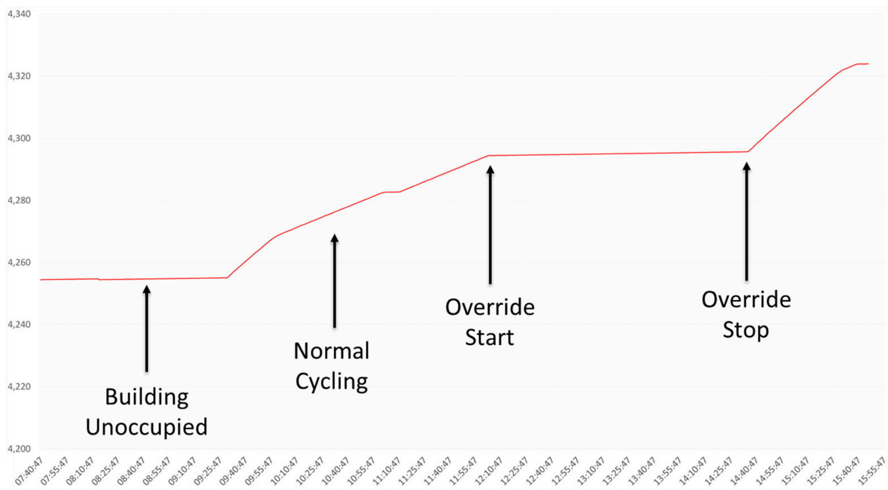

Figure 5. Measured chiller electricity consumption (KWh).

Clearly there is a trade-off between the level of comfort of users of the chiller and the amount of electricity curtailment; the development and implementation of an appropriate optimal control algorithm for this purpose are part of the ongoing work of the DR-BOB project. However, this case study helps to illustrate that at DRTRL-3, the potential for a fully automated DR solution exists at the UK pilot site.

6. Discussion and Conclusions

The DRTRL scale discussed in this paper is applicable to the assessment of the technical readiness of a block of buildings for the implementation of the DR-BoB energy management solution. It does not consider the maturity of the market in any given context or the potential financial value for a building owner/manager of participating in DR in general. Rather, the DRTRL begins to provide a method of assessing the technical readiness of blocks of buildings to take part in DR. Indeed, high-resolution metering data, available at DRTRL 2 or higher, is required to provide a reliable assessment of a specific building's, or BoB's, load profile and potential for DR. Although not advisable, it is perfectly possible for manual participation in DR actions without prior knowledge of potential value to the end user. Further, the DRTRL approach is agnostic to building use, be it residential, commercial or industrial; rather, it specifies the interactive and data gathering capabilities that are required for different types of DR participation. The assets under control and demand profiles of occupants are an important but separate feature of the block of buildings.

At the most basic level, a building energy manager is able to act on demand response requests if it can receive these requests and reschedule an energy-consuming asset's operation. However, such interventions would not scale well, particularly when a commercial building may have tens of such assets. Through the initial stages of deployment at its demonstration sites, the DR-BoB project has found that a lack of low-latency automated metering, instrumentation and control equipment are the most common reasons for low DRTRL. Whilst the DR-BoB solution could operate in a manual mode, the scale and latency of DR response would be substantially impaired. Other DR solutions may wish to include such integrated metering and other technologies to enable deployment to sites with lower DRTRL. Implicit DR programmes, such as time-of-use tariffs, may be addressed without automated metering and other sensor data visible to the building occupants and control equipment, although opportunities for enhanced control, optimisation and feedback will be impaired. However, demonstration of sensing and control capability for entry and high-resolution meter data for settlement post DR-events, necessitate this capability for explicit DR programmes. A clear advantage of explicit DR over implicit schemes like time-of-use (TOU) pricing is that unexpected events occurring on the wider grid (e.g., loss of generation) can be compensated in a pro-active/reactive manner. Having the required low-latency automated metering, instrumentation and control equipment in place is a pre-requisite for emerging dynamic demand control [18,19].

It was also noted that some sophisticated building management systems may not allow third party integration, impairing the ability of the DR-BoB solution to coordinate a response. This is unlikely to be solved by DR solution providers in general given the proprietary nature of such BMS firmware and software. There may therefore be a role for regulatory bodies, e.g., through subsidiary policies to the Energy Performance in Buildings Directive (EPBD) and relevant national building codes, to facilitate the wider involvement of the built environment in energy system management through standardising the interoperability of infrastructure. Such regulation would reduce future transaction costs and increase the scope and scale for participation in DR programmes as they are developed by electrical system operators.

The authorities involved in urban planning also have the potential to facilitate DR in blocks of buildings by mandating or favourably considering developments incorporating the technical capabilities outlined above. For instance in the UK, the so-called "Merton Rule", requiring developments over 1000 m^2 to provide at least 10% of energy demand from on-site renewables, has already proved influential far beyond the local authority's boundaries [18]. Indeed, since 2013

Ealing Council have required major developments to show how they will verify post-construction energy performance through automated monitoring [20].

The concept of DRTRLs presented here maybe expanded, to offer a useful, common way to measure the maturity of a buildings energy systems for DR. This is particularly interesting in the light of the European Commission's 2016 proposal to amend the EPBD. One of the aims of this proposal is to supplement the existing EPBD with a definition of a "smartness indicator" and with the conditions under which the smartness indicator would be provided as additional information to prospective new tenants or buyers. The proposal states that "*[t]he smartness indicator shall cover flexibility features, enhanced functionalities and capabilities resulting from more interconnected and built-in intelligent devices being integrated into the conventional technical building systems*" [21]. It goes on to state "*[t]he features shall enhance the ability of occupants and the building itself to react to comfort or operational requirements, take part in demand response and contribute to the optimum, smooth and safe operation of the various energy systems and district infrastructures to which the building is connected*" [21]. Therefore, it would seem that this new smartness indicator will need to account for the DR potential of a building. In this sense, the DRTRLs presented here provide valuable information to inform the development of building regulations and directives.

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Author Contributions: Tracey Crosbie lead the production of this paper structuring the arguments and concept of DRTRLs presented. John Broderick lead the implementation of the DR-BoB solution at the UK pilot site and is largely responsible for the work underpinning the details of the DRTRLs in Sections 3 and 4. Michael Short is largely responsible for the discussion presented in Section 5 Muneeb Dawood and Richard Charlesworth commented on the content of this paper and substantially contributed to the development of the DR-BoB solution and to the thinking underpinning the work on DRTRLs presented.

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