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ORIGINAL PAPER

A semantic service-oriented platform for energy efficient buildings

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Abstract The construction industry is under pressure to increase the sustainability of its practices to meet UK commitments for reducing energy consumption and alleviating climate change. The research uses a mixed-method approach drawn from recent studies to explore the readiness, maturity and level of engagement of construction stakeholders in adopting the UK government sustainability agenda. Limited positive energy practices and sustainability regulatory awareness, combined with information provision deficiencies, form some of the key barriers to sustainable construction faced by industry. A service-oriented platform that provides integrated access to sustainability resources in the form of interactive, dynamic and user-oriented services that fully exploit latest advances in computing technologies is proposed to address these barriers. In this paper, we specifically elaborate on how a service-oriented system can be efficiently used for performing (near) real-time energy optimisation in buildings, greatly contributing to engaging construction stakeholders with sustainability practices. The solution disseminates energy efficient practices and provides support for building managers in implementing energy efficient optimisation plans. The solution is tested and validated through a number of energy efficiency scenarios developed as part of the EU FP7 SportE2 project.

Keywords Sustainability · Energy efficiency · Service-oriented computing · Construction · Buildings · Energy optimisation

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Introduction

Political and economic attention to climate change has led the UK government, particularly during its presidency of the European Union in 2005 and the G8, to strive to meet EU commitments to achieve an 80 % cut in CO_2 emissions by 2050 (Low-Carbon Report 2011). Studies indicate that our built environment is responsible for some of the most serious global and local environmental change (EU Platform 2005; UKDEnergy Statistics 2008; Clarke et al. 2008). Creation and operation of the built environment account for at least 50 % of all energy consumption in Europe (Martinaitis 2006), and in the UK, more than 50 % of all carbon emissions can be attributed to energy use in buildings (The Concrete Centre 2011). Consequently, the construction industry is under pressure to increase the sustainability of its energy practices, the implication of which is a requirement on the industry's behalf to understand the demands both from society and its clients and its sense of corporate responsibility, which in turn implies major changes in its working practices (Rezgui et al. 2010a, b; Rezgui and Miles 2011). The UK government aspires to achieve construction of zero carbon homes from 2016, public sector buildings from 2018 and all other non-domestic buildings from 2019 (BSRIA 2011). The UK building regulations have already undergone a number of amendments; the next, with the target CO_2 reductions embedded, are expected in 2015. Wales, which forms the focus of the research, has set aspirations for zero carbon for new buildings earlier than proposed in the rest of the UK (WAG 2011).

Public awareness of climate change acknowledges the main causes and concerns (DEFRA 2002), and scientific evidence highlights the significance of the human factor in reducing the impact of climate change (IPCC 2001, 2007; Schellnhuber et al. 2006). However, only a minority engage with effective measures to reduce their lifestyle impacts on the environment (Norton and Leaman 2004). The literature indicates significant discrepancies between public awareness about climate change and natural resource depletion on the one hand and behavioural change on the other (Lorenzoni et al. 2007; Whitmarsh et al. 2011), suggesting complex interactions of psychological, social and environmental factors influencing behaviour (Vliet et al. 2005).

The UK government's aspiration for energy and CO_2 reduction requires widespread social change (Lorenzoni et al. 2007); although considerable moves have been made towards regulating the energy and construction sectors, there is less systematic evidence regarding construction industry stakeholders' responses to whole-system transformations, and how such transformations are likely to be experienced, enacted and negotiated in terms of everyday practice. Building on existing literature, this paper explores the constraints and factors that influence individual stakeholders to adopt sustainable energy practices at work including changing their own behaviour, the reasons underlying these perceived constraints and proposes an advanced collaborative web-based environment to address the situation. The paper draws upon findings of recent mixed-method studies conducted across Europe and in the UK (Wales).

In this paper, we present the sustainable construction service platform (SCRIPT), a service orientated platform developed to solve the key issue of knowledge dissemination in, and organisations engagement with, sustainable construction. Within the approach, we combine a number of different technologies such as semantic web, social networks and mobile applications, towards a knowledge representation paradigm concerned with maintaining (potentially complex) information sources, practices and semantic models related to sustainability in construction. Section 1 discusses the problem of sustainability in the construction industry, with a focus on building energy practices. Section 2 presents the background of our work. Section 3 explains the methodology that underpins the research as well as the requirements that guided the development of the SCRIPT solution. Section 4 expands on the technical development process. Sections 5 and 6 are dedicated to the validation of the approach. Section 7 provides concluding remarks and directions for future work.

Background research

The literature indicates that the socio-technical practices that impact on sustainability are embedded in the everyday; that is, they are intangible and largely taken for granted (Burgess and Nye 2008). As a consequence, construction industry practitioners, who predominantly work for small and medium-sized enterprises (SME), are unlikely to be fully aware of the daily practice implications resulting from transformations within current policy and regulatory environments (Rezgui et al. 2010a, b). The construction industry is characterised by a complex socio-cultural and organisational environment reflected by its endemic resistance to change (Vakola and Wilson 2004) and the requirement for different management strategies due to contradictory interests of owners, contractors and craftsmen (Lill 2009); indeed, it is perceived as 'unique' when compared with other sectors (Egemen and Mohamed 2005). In developing the regulatory environment to meet carbon and energy reduction targets, it is essential to enable long-term changes in individual attitudes and behaviours while promoting positive engagement. Lorenzoni et al. (2007) suggest that engagement concurrently involves cognitive, affective and behavioural aspects at an individual level to embrace wider values embedded within the organisational culture. Whitmarsh et al. (2009) discuss the convergence of findings from the work around public engagement with climate change and the work on learning about climate change and carbon, and argue that the literature demonstrates that both individual and institutional dimensions of engagement are vital to understanding barriers to adoption of low-carbon lifestyles. Furthermore, they highlight the need to understand the 'situated' meanings associated with carbon, i.e. how individuals translate and apply knowledge about carbon and climate change to their daily lives through processes of objectification and anchoring (Florian et al. 2014; Saidur and Mahlia 2011).

Engagement may therefore be seen as both an individual and collective phenomenon reflected in the team and project-based nature of the construction industry. Stern (2000) argues that in addition to attitudinal factors, behaviours are influenced by contextual forces, personal capabilities and habits. This is in line with related literature drawn from environmental psychology which highlights the influences of past behaviour, knowledge, experiences, feelings, social networks, and institutional trust on individual attitudes and behaviour towards environmental issues (Blake 2001; Kollmuss and Agyeman 2002).

Whitmarsh et al. (2009) define the concept of carbon capability as 'The ability to make informed judgments and to take effective decisions regarding the use and management of carbon, through both individual behaviour change and collective action'. Three core dimensions of carbon capability are identified (Whitmarsh et al. 2011): (a) decision-making (knowledge, skills, motivations and judgments), (b) individual behaviour or 'practices' (e.g. energy conservation) and (c) broader engagement with systems of provision and governance (e.g. lobbying, voting, protesting, creating alternative social infrastructures of provision). While this addresses larger public concerns, there is a gap in similar understanding of organisations across the construction value chain, which is addressed by the paper.

Methodology

Evidence from behavioural decision research indicates that people do not come to unfamiliar or complex technological issues with fully formed views but nevertheless can be supported in the construction of their preferences through systematic elicitation and deliberative procedures (Morgan et al. 2002; Lichtenstein and Slovic 2006). The research methodology therefore utilises a mixed-method approach involving studies incorporating qualitative and quantitative methods to elicit construction industry stakeholders' requirements and prototyping for the development and testing of the proposed solution. The research is located within theoretical traditions that take socio-technical systems as the focal unit of analysis (Rip and Kemp 1998). This perspective provides a robust foundation for analysing whole built environment sustainability systems understood as linked processes of social and technological practices (Smith et al. 2005).

The requirements gathering studies employed extensive consultations including: an online Europe-wide survey (February–April 2009) from which 252 responses were received; construction industry consultations in Wales comprising firstly three workshops (c70 participants in total) and a series of 15 semi-structured interviews with key industry representatives (May–September 2009) and secondly two workshops and 13 focus meetings (a mix of one to one and small group consultations) (February–November 2010).

Table 1 Perceived barriers to engagement with sustainable construction

Individual perceived barriers	Context
Lack of knowledge	Knowledge about sustainable construction, including practices and principles; availability/accessibility; information overload.
Uncertainty and scepticism	The necessity for and effectiveness of sustainable construction practices (both industry stakeholders and end-users).
Distrust in information sources	Including consistency, validity, authority and timeliness.
Reliance on technology	Including new technologies for sustainability and for information retrieval.
Resistance to lifestyle change	Perceived threats include changes in living standards, inconvenience, cost.
Organisational perceived barriers	Context
Lack of enabling initiatives	Information and knowledge sources are fragmented, diverse, unstructured, non-integrated.
Lack of training	Including understanding the skills need; raising the demand for skills; understanding how to up-skill the workforce.
Work overload and priority to expedite current tasks and activities	Including within tight financial margins.
Lack of information/knowledge sharing	Including commercial imperative, costs, trust.
Wider Industry perceived barriers	Context
Lack of government action	To initiate and promote energy positive behavioural change.
Government focus on regulation	In an industry which suffers from poor stakeholder education.

Limited sustainability best practice, regulation awareness and information provision deficiencies were emerged as key themes from the initial survey. The subsequent combined consultations explored stakeholders' knowledge, understanding, attitudes, values and behaviours and helped identify key barriers to sustainability engagement in Wales. The identified barriers were discussed and debated from a variety of socio-technical perspectives. A total of 27 stakeholder organisations took part in the consultations including: construction companies and practitioners, advisory groups, umbrella professional organisations, consultants, policy makers and education and training bodies.

The identified barriers led to user requirements for the proposed collaborative web-based environment. In developing a complex advanced technology to innovatively address the emergent challenges that face the construction industry stakeholders' engagement with sustainability, a waterfall model of development was not seen as appropriate as this involves completion of analysis before moving onto design, and all design being completed before moving onto implementation. The alternative approach of prototyping or 'design and creation' was chosen, wherein a prototype system is analysed, designed, implemented and tested, the understanding from the validation then being used to modify the analysis and design models and create a revised system prototype. This approach is advantageous as it is not necessary to fully understand a problem before exploring tentative solutions (Oates 2006). Vaishnavi and Kuechler (2011) note that design and creation employs an iterative process involving five steps: awareness, suggestion, development, evaluation and conclusion; the steps are not followed in a rigid, step-wise fashion; rather they form a more fluid, iterative cycle.

The perceived barriers to engagement

While many of our participants are aware that employees have moral responsibilities to deliver environmentally friendly buildings this does not systematically translate into sustainable practices and engagement. The studies highlight possible reasons for this disparity between awareness and concern and a pro-active level of engagement with sustainable construction. Consistent with Lorenzoni et al.'s (2007) position that the various barriers that function to limit engagement can be interpreted either as principally personal or social; we analysed perceived barriers at the individual, organisational and wider industry levels. Table 1 presents a summary achieved by review and amalgamation of the triangulated findings from the studies.

At the individual level, a lack of 'actionable' knowledge about sustainable construction emerges as a significant perceived barrier to engagement including: (a) lack of knowledge pertaining to best practices; (b) the accessibility to existing relevant codified knowledge and (c) the perception of information overload. This lack of knowledge, or abundance of ill-structured knowledge, may be a factor in creating uncertainty and scepticism about the necessity and effectiveness of sustainable construction; practitioners indicate an urgent need for clarity. Additionally, distrust in information sources exacerbates disengagement because individuals feel that contradictions exist between information sources. The respondents also believe that commercial considerations bias the information available to them, and there is a desire for reliable neutrality. The studies indicated that web portals are a primary channel for accessing information by stakeholders; however, there is widespread dissatisfaction with this method of retrieval, not least in terms of trust. Resistance to changes in lifestyle emerged as a significant perceived barrier to engagement in sustainable construction. This is reflected in the literature indicating that while recent energy price increases have made people more aware of their behaviour, barriers that prevent householders from going further include: disbelief in the putative savings, savings being too small to overcome the disruption involved, concerns over the health and comfort effects of air-tightness and over-heating, and the fact that some householders just are not interested.

At the organisational level, there is a perceived lack of initiatives that enable sustainability information and knowledge nurturing. Participants emphasised the negative effect to engagement induced by the diversity of information they are faced with and the resulting information overload. Currently available web-based information portals tend to focus on informational needs of individuals, while the environment in which such information is provided is often overlooked, a situation exacerbated by limited collaboration mechanisms across the supply chain and throughout the construction lifecycle. Another constraint explicitly identified by a wide cross section of participants was an immediate requirement for training throughout the industry, which is in line with the literature (e.g. Cardoso Teixeira et al. 2006; Vakola and Wilson 2004). This barrier is perceived to be extensive as it includes not only the 'general' and low-skilled workforce that is a perennial characteristic of the industry but also the huge gaps in understanding in the public sector and the need to educate clients. Finally, although participants on the whole recognised information/knowledge sharing as a cornerstone to the promotion of construction stakeholders' engagement with sustainability, while it occurs within teams and organisations, there is a reluctance to share 'outside' due to commercial interests.

From the wider industry perspective, the responsibility was firmly placed back on the government. Firstly, there is a perceived lack of government action to initiate and promote energy positive behavioural change. The implicit assumption is that the government was responsible for the original targets and aspirations but relied on an initially largely un-knowledgeable industry to achieve them, there should be therefore be far greater government support to aid the industry. Secondly and closely related to this first barrier is the perception that the government's primary focus is on regulation without recognising the depth of the increased challenges faced by an industry that is suffering from poor stakeholder awareness and education.

System requirements

The results from our consultations and the exploration of the key perceived barriers identified and established the need to create circles of impacts that bind building professionals, energy administrations and citizens in a shared sustainability experience to address a number of issues including:

- Lack of sharing, exploitation and reuse of isolated sustainable practices and principles acquired through practice across the industry.
- Lack of education and awareness across key construction stakeholders and building end-users.
- Lack of easy access to structured sustainability information and knowledge.
- Unclear links between sustainability principles and current construction regulations and standards.
- Uncertainty about the cost of sustainable solutions/technologies.

Different actors have built various repositories, organised events, etc., in an effort to fully understand the changing construction landscape, but with little or no coordination or awareness of what one another is doing. We recognised from the results that a socio-technical 'knowledge solution' may address the issues outlined above. This led to the development of a service-oriented platform. The major themes that emerge are summarised as recommendations for the proposed solution in terms of information requirements and functionality/services as follows:

Information requirements

- *Categorise information* Various different information types and topics need to be catered for including regulations, legislation, research and innovation, etc.
- *Dedicated and focused best practice information* Currently much of this information is very 'high level'.
- *Information and knowledge management and sharing* There is a need to transform 'information' into knowledge, which requires advanced content management and contextualisation of new concepts.
- *Real data provision* There is currently a lack of empirical data for Wales, including costs data, which need to be collected and disseminated across the sector.
- *Provide avenues of marketing or connectors* Data and information regarding supply chain, products, etc. are required.

Functionality/service requirements

- *Smart searching facilities* Current searching methods are unsatisfactory and limited, treating documents as 'black boxes' and lacking filtering mechanisms.
- *Create and implement a sustainable construction ontology* This will be a requirement to ensure smart searching functionality.
- *User profiling* This service will empower users and increase satisfaction in terms of Knowledge management and will enable enrichment of other services.
- *News service(s)* Linked, relevant RSS feed(s).
- *Calendar of events* This will amalgamate the various disparate events that are advertised via various media in a single place. Events include both information and training and enable professional networking.
- *Bi-directional channels for information sharing and enrichment* Incorporating e-Forums and professional networking capability. This will rely on both the ontology and user profiling.
- *Interface for shared tools/services* Free to use tools and potential for paid tools possibly on a rental basis. Also potentially include a tools register and/or tools market watch.
- *CPD facilities* To potentially include educational tools such as live and/or interactive case studies and with clear information on access to skills training programmes, educational courses, etc.

Developing the service-oriented platform

The platform was designed and developed taking into account the validation and testing results. A service-oriented architecture (SOA) was used to organise data and information from engineering into deliverable services that can be consumed based on various provision schemes. It was also concluded that these services must be specified at a level of granularity that allows maximum flexibility in use, while minimising the effort required to access specific functionality at an application level. In addition, the received feedback and consultation verified the necessity of an ontology that provides the functionality required to make resources from the engineering sector available to the platform services.

We have designed an architectural model organised on different levels, each level providing an intended functionality for users.

Levels of services

The platform is developed on the basis of the service-oriented model. SOA works with a set of principles and methodologies for designing and developing software in the form of interoperable services. These services represent well-defined business functionalities that are built as software components (discrete pieces of code and/or data structures) that can be reused for different purposes. The architectural model (Fig. 1) illustrates a set of discrete services that can be provided independently to the platform or within the platform brokered by kernel.

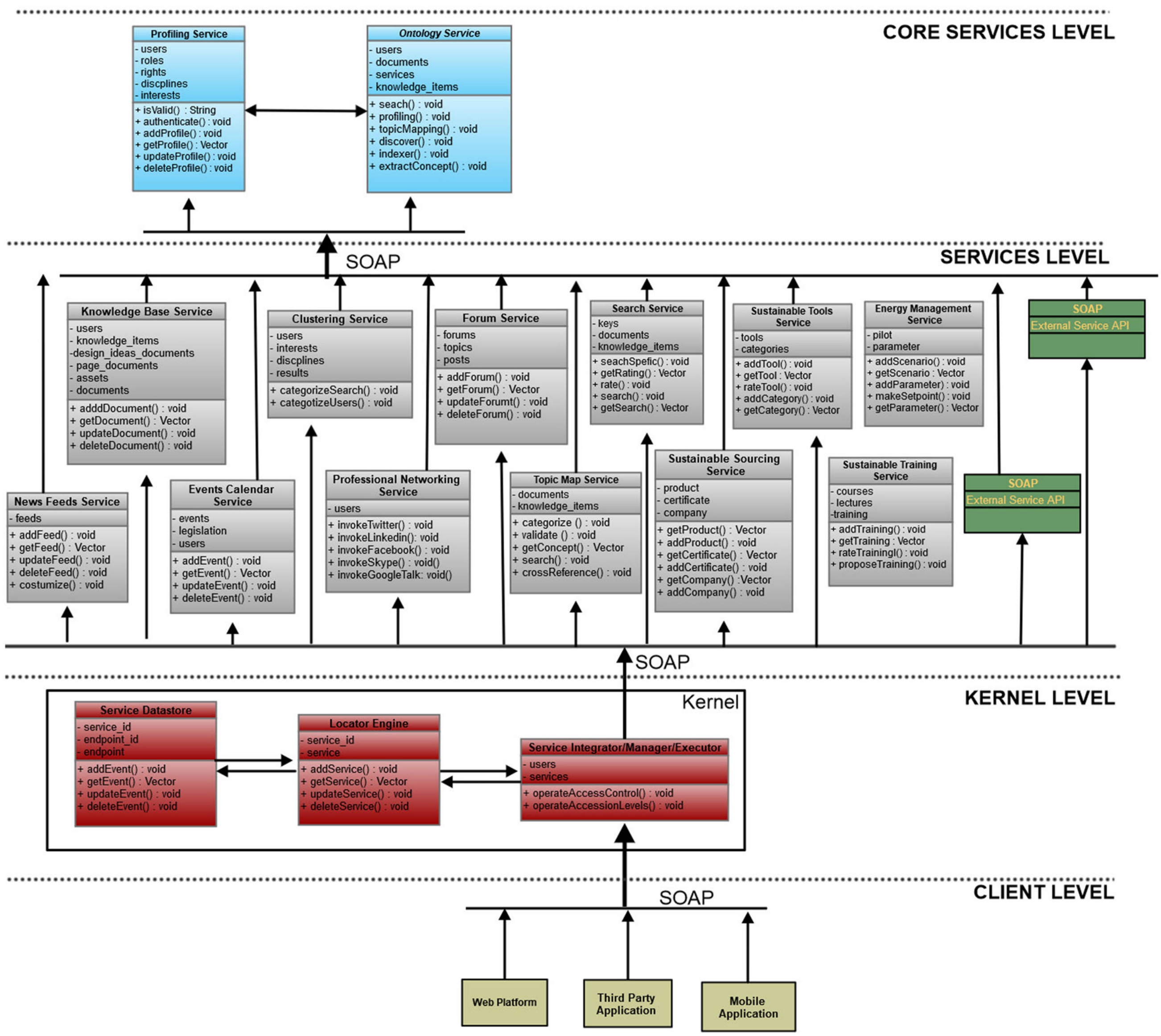

Fig. 1 The architectural model

In this context, we identify two types of provision that can be implied:

– Direct provision of services is performed outside the platform, each service being delivered as a separate discrete service. This type of provision uses the standard of WSDL (Web Service Description Language) specification where each service has a number of description tags for active methods and related parameters. It is important to note that in the context of direct provision, the association of services in terms of functionality is disabled.
– Indirect provision of services occurs within the platform where mixed-service functionality is enabled. With this provision mechanism, each service invocation is mediated by kernel.

Each service has an associated Application programming interface (API) which serves as a description for possible access requests. The associated API defines a set of methods that a service can offer and a set of associated parameters. These services are specified with a certain level of granularity in order to ensure maximum flexibility in use and minimising the effort of accessing specific functionality at an application level. The set of core services provided within the system are at four levels:

The client level identifies the user interface which allows users to submit requests and retrieve results. At the client level, various parsing mechanisms are implemented for ensuring a proper format of the results.

The kernel level facilitates the communication between the client level and related levels of the platform. The kernel acts as a broker and controls the access to the service repository. In terms of architecture, the kernel is developed on three dimensions:

– *Service integrator/Manager/Executor* receives requests from the client level, analyses the request and sends a query to the service locator. After the service locator identifies the service, SI/M/E (Service integrator/Manager/Executor) forwards the query by invoking the locator of services.
– *Service locator* receives a request from SI/M/E and sends queries to the service data store. After identifying the associated endpoint, the Service Locator sends a response to SI/M/E.
– *Service data store* represents a repository of endpoints with services deployed on the platform. Each time a user accesses a resource within the system, the kernel invokes the associated service endpoint of that resource.

The services level identifies a set of services managing the content and to enhance the collaboration within the platform.

– *The topic map service* provides an interactive representation of semantics where users can observe and choose various terms for customising their search. The topic map service facilitates smart access to platform resources and helps users to retrieve accurate information. This service is a graphical representation of the ontology offering means for users to visualise ontological concepts and to improve their searching session by enriching the query with various semantic elements. This service is triggered each time a user types a search query generating sets of semantic elements in relation with the search input.
– *The knowledge base service* contains a corpus of related guides, regulations and various existing documentation related to sustainability in construction. These resources are the archive of documents that have been collected in the course of development of the SCRIPT platform. These documents are generally: (a) Documents that have already been submitted and validated for inclusion within the platform and hence made available to users; (b) Documents that have been located by crawling a set of relevant and reviewed (trusted/vetted) sustainable construction related websites.
– *The clustering service* provides means to produce ontological full text indexing of each knowledge item within the system. It is also used to regulate and rank searching results.
– *The professional networking service* enables users to collaborate using social networks such as LinkedIn and Twitter aggregating associated data. This service also allows users to search for partners and colleagues and identify the corresponding networking profiles based on a set of interests and disciplines. An illustration of the associated interface of the professional networking service is provided in Fig. 2.
– *The events calendar service* is a reminder of the important events from the engineering community. Users can subscribe and synchronise these events relating to sustainability with their personal calendar.
– *The news feeds service* provides useful aggregated information and updated news related to sustainability in relation with users' interests and discipline(s). This service allows users to add new sources according to their field of expertise.
– *The forum service* allows users to interact by sharing data and information within the platform.
– *The sustainable sourcing service* allows users to lookup products (based on their current location) from certified suppliers. Figure 3 illustrates the associated interface of the sustainable sourcing service identifying the results obtained when searching for certified timber suppliers within Wales.
– *The energy management service* facilitates users to undertake energy optimisation plans and to adopt optimisation scenario based on an API interface. Within this service, building facilitates are evaluated, and relevant optimisation scenarios are identified with the ultimate objective of reducing energy consumption and costs. A more elaborated use case is presented in Sect. 5 and Sect. 6.
– *The sustainable design tools service* providing a number of web-based tools addressing various aspects of sustainability such as carbon emissions, energy simulation, etc.
– *The sustainability training service* enabling users to identify courses and lectures related to sustainability in construction from various institutions such as universities, research organisations, governments agencies, etc.

The core services level provides semantic means of the content and ensures a certain hierarchy of the results.

– *The ontology service* provides the functionality required to make engineering knowledge items available on the system. The ontology service is developed on the basis of semantic vectors ensuring the required level of intelligence for the platform. The ontology aims to enrich and expand the content and current domain specification with additional concepts and

Fig. 2 Professional networking service

facets extracted from: (i) Document repository specific to the engineering area, (ii) The data structures that underpin industry calculation, simulation and compliance checking tools. The ontology uses the established term frequency-inverse document frequency (tf–idf) and metric clusters techniques to identify relevant ontological concepts from the document base repository and their relationships with concepts from engineering. In more detail, for each identified concept and facet, we quantify the degree of importance (in terms of semantics) over the document and over the entire gathered documentary corpus. For ensuring the relevance of relationships between concepts, a mechanism that factors the number of co-occurrences of concepts with their proximity in the text is adopted. This clustering algorithm proceeds by factoring the distance between two terms in the computation of their correlation factor. The ontology service allows the querying of the ontology and the expansion of terms along their relationships. This functionality allows other areas of the platform to leverage the knowledge contained within the ontology. For example, issuing the query command on ‘Solar power’ would look-up any individuals within the ontology named either ‘solar’, ‘power’ or ‘solar power’. Then calling expand on any of these individuals will return a list of all other individuals related to the input, additional variants of this method also exist to allow tighter filtering based on relationship type (Fig. 4).

– *The profiling service* manages the identities of users and controls the access to the platform. Each user has a set of associated interests and disciplines which are used as input data for other services such as searching, professional networking or news feeds.

It is important to note that the interaction between levels is mediated by simple object access protocol (SOAP). In particular, the system offers facilities for integrating third parties services. Rather than having to understand the data structures of each system to integrate or write application-to-application integration code, a web service layer is added around legacy systems that expose necessary information functionality in a standard way. Therefore, the integration represents an effort to orchestrate business processes by enabling web services calls rather than retooling measures. This is realised using interface description languages and services that allow distributed objects to be located, combined and invoked. These technologies have also been used to encapsulate the heterogeneity of legacy systems and applications within standard wrappers. It was identified that service-oriented middleware solutions present high flexibility in solving the integration of legacy systems.

Communication and service descriptors

The communication within the platform is ensured by SOAP. SOAP is an XML-based messaging protocol

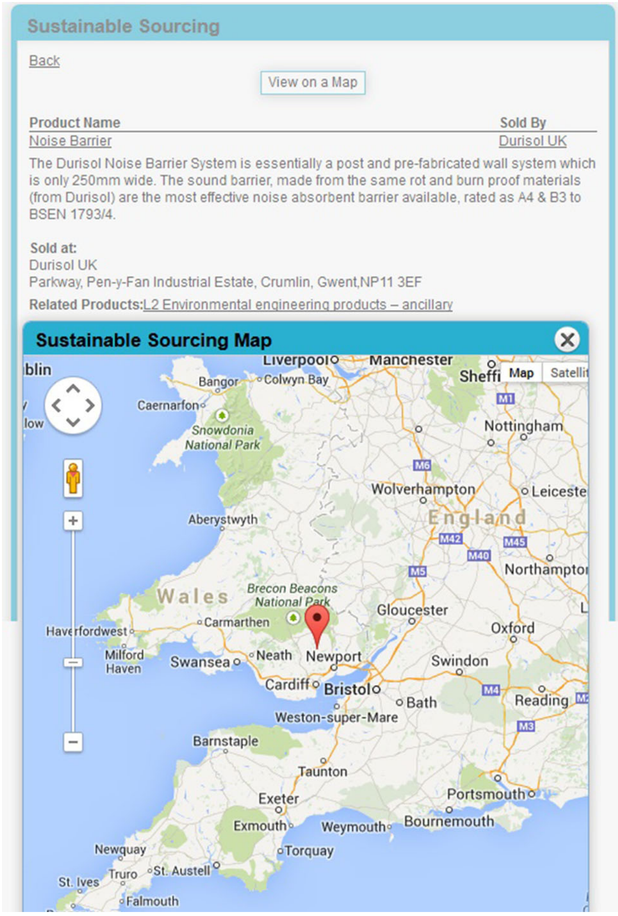

Fig. 3 Sustainable sourcing service

defining a set of rules for structuring messages that can be used for simple one-way messaging. SOAP is particularly useful when performing RPC-style (Remote Procedure Call) request-response dialogues. We use SOAP as a protocol for facilitating the communication within the platform because SOAP works independently to any particular transport protocol or to any particular operating system or programming language. In addition, the clients and servers can be running on any platform and written in any language as long as they can formulate and understand SOAP messages. SOAP represents an important building block for developing distributed applications that exploit functionality published as services over an intranet or the Internet. In our platform, the communication can take place between various services from the same level as well as a communication can take place between different levels. Each service is described in a web services description language (WSDL) format. Therefore, from the perspective of an external call, third parties can use all the services without requiring any reference to the conceptual model of the system. Each service invoked by the kernel identifies an associated method operating on a set of parameters.

Method 4.1 illustrates a kernel transmission of an operation with related parameters over SOAP. At each request, the kernel issues a call to a service containing the name of the requested method and associated parameters.

Method 4.1

Method: Send
Input parameters: None
Output parameters: result
Parameters: serviceName, methods, parameters
(1) createOptionsType();
(2) setEnpointReference();
(3) createService();
(4) setServiceOption();
(5) FOR i=0 TO paratemersSize
(6) addMethodParameters();
(7) createResult();
(8)getResultoMethod();

Method 4.2 explains how services are called by the kernel and how the result is returned. When invoked, each service is identified with a unique endpoint reference and implies a set of associated parameters.

Method 4.2
Method: Run
Input parameters: serviceName, method, parameters, token
Output parameters: result
Parameters: serviceName, methods, parameters
(1) createResultList();
(2) TRY
(3) initialiseResult();
(4) selectUrl FOR serviceName
(5) IF (selectiUrl)
(6) link=serviceUrl;
(7) createKernelTransmissionfForService();
(8) addServiceMethod();
(9) addServiceParameter();
(10) addServiceToken();
(11) TRY
(12) sendConfiguredService();
(13) getResultOfSend();
(14) WHILE (serviceHasNext)
(15) addToResult();
(16) ELSE
(17) closeService();
(18) returnResultToArray();

Method run takes a number of associated parameters such *as serviceStr, function, param* and *token* and returns an array of strings containing service endpoint with the corresponding kernel address. It is important to note that the actual implementation of a service may be realised within the platform or by an external third party with the details of its implementation being of no concern as long as the API is adhered to. In our system, each service is deployed on a separate virtual instance in order to ensure high performance and an appropriate level of tolerance. Each instance uses apache axis 2 as web server for deploying the service with a unique port. The benefits of web services include the decoupling of service interfaces

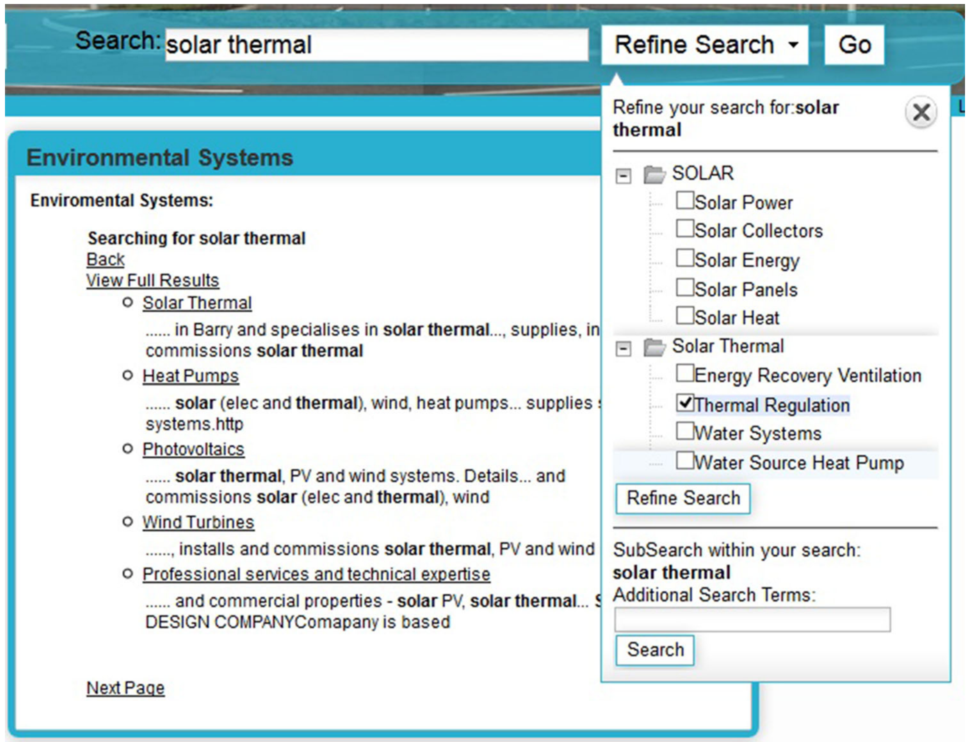

Fig. 4 Keyword and relationships suggestions within the SCRIPT platform

from implementation and platform considerations, the support of dynamic service binding and an increase on cross language and cross platform interoperability.

Validation for real-time energy optimisation

We have used the platform presented in this paper for conducting energy optimisation on the FP7 EU project SportE2.[1] The platform is configured to satisfy the requirements identified in the context of energy optimisation. We have used a modular approach where a module corresponds to specific pilots that are used as testing building facilities. We have pilots in Rome (Italy)–FIDIA, Bilbao (Spain)–EMTE and Portugal-SELF (see Fig. 5). Each model that is associated with the pilot can be customised as required by embedding into existing software solutions for ensuring real-time energy optimisation. By using the platform, organizations (pilot owners) can familiarise themselves with relevant energy efficiency practices and can undertake optimisation plans based on a number of optimisation scenarios, while have access to thematic and context-based knowledge provided by the SCRIPT platform.

Each sport facility is equipped with sensors and actuators for monitoring, control and optimisation of energy use. The building has metering capability to determine consumption of electricity, gas, biomass, water and thermal energy. This data can be accessed through a specialist interface and recorded for analysis. The sub-metering of thermal and electrical consumption within grouped zones are also provided along with ‘comfort’ monitoring by functional area: gym, fitness room and swimming pool. In these areas, the Predicted Mean Vote (PMV) index (which measures the average response of a group of people to a thermal sensation scale—such as hot, warm to cool and cold—it is one of the most widely recognised thermal comfort models) is measured as a function of the activity performed within a particular part of the building. The occupancy is also monitored in the gym, fitness room and around the swimming pool area. The structure of the facility does not allow the direct measurement of the total value of occupancy for the pilot, so the occupancy of the whole facility is provided as sum of number of people. Figure 6 explains how the optimisation input is retrieved in real-time from the deployed sensors in the pilot. In this case, the values associated with all the variables are retrieved from the FIDIA pilot via the automation server and displayed in the form corresponding to the optimisation scenario.

Figure 7 presents how the results are being illustrated. After the optimisation is completed, subject to an interval of time dependent on the latest sensors readings, the results

[1] SportE2 is a research project co-financed by the European Commission in FP7 under the domain of Information Communication Technologies and Energy Efficient Buildings. In this project, we develop energy efficient products and services dedicated to needs and unique characteristics of sport facilities, www.sporte2.eu.

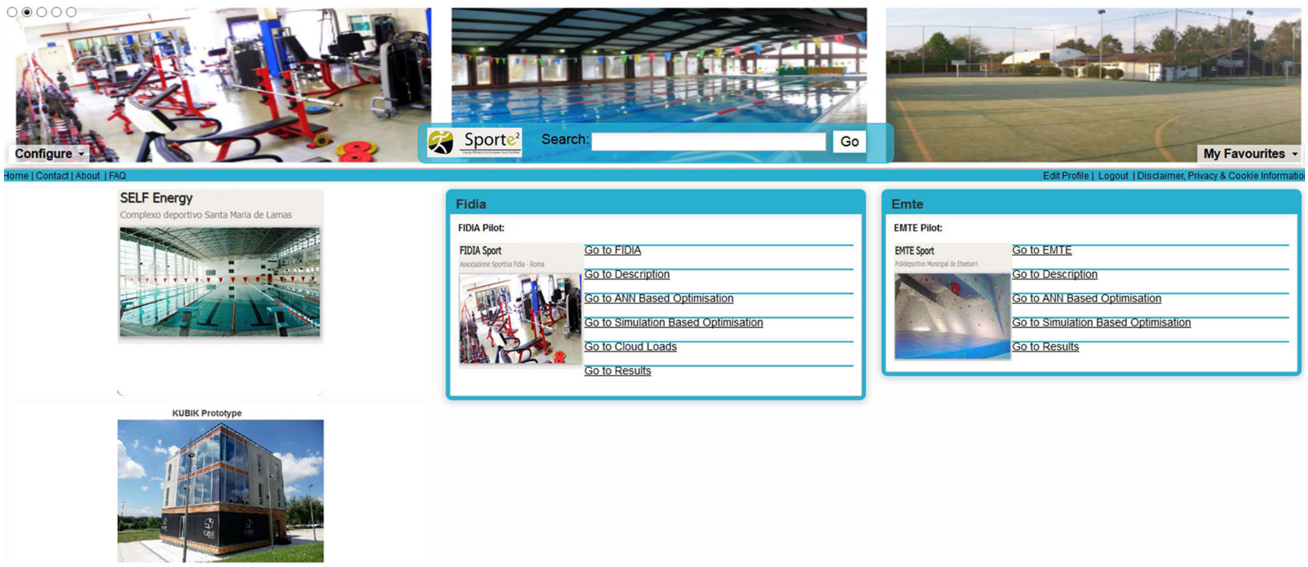

Fig. 5 Energy optimisation platform

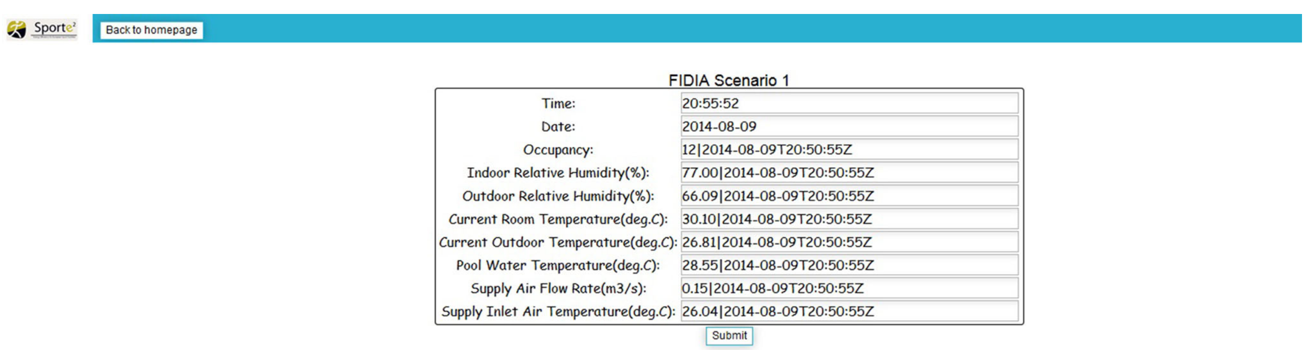

Fig. 6 FIDIA ANN optimisation

and the optimised set-points are displayed on the interface. The user is informed with the new set-point value being implemented. Also the user is provided with a historical trend of the energy consumption on (i) Predicted energy consumption and (ii) Optimised energy consumption.

After the graphical illustration of results the user is also informed with a predicted energy savings that is likely to happen with the future interval based on historical recorded optimisation results. In addition to the ANN-based optimisation, one user has the option to run a simulation-based optimisation using Energyplus as an application and HTCondor as a computing management system.

Figure 8 illustrates an interface corresponding to simulation-based optimisation for FIDIA pilot. For the optimisation duration depicted on the OX axis, optimised values are recorded at each stage. The user can dynamically modify the input and observe how the optimisation evolves over time. This optimisation module facilitates users to test out various scenarios and analyse results.

Energy efficiency validation

In this section, we evaluate the impact of our service-oriented platform when used for conducting optimisation plan and measure how much energy can one of the SportE2 project pilots called FIDIA can save over time. We have recorded the 'real energy consumption' as identified in the FIDIA pilot over a period of 24 h and compared with the results obtained when running the optimisation within service-oriented platform optimisation methodology. It must be noted that the optimisation process was conducted based on real input data recorded from the pilot to which we have applied an Energyplus optimisation process deployed on our computing infrastructure.

In our evaluation cases, we compare the optimisation undertaken via our service-oriented platform, as identified in this paper, with traditional optimisation techniques as existing in the pilot. A traditional optimisation technique refers to a number of operations that pilot personnel are

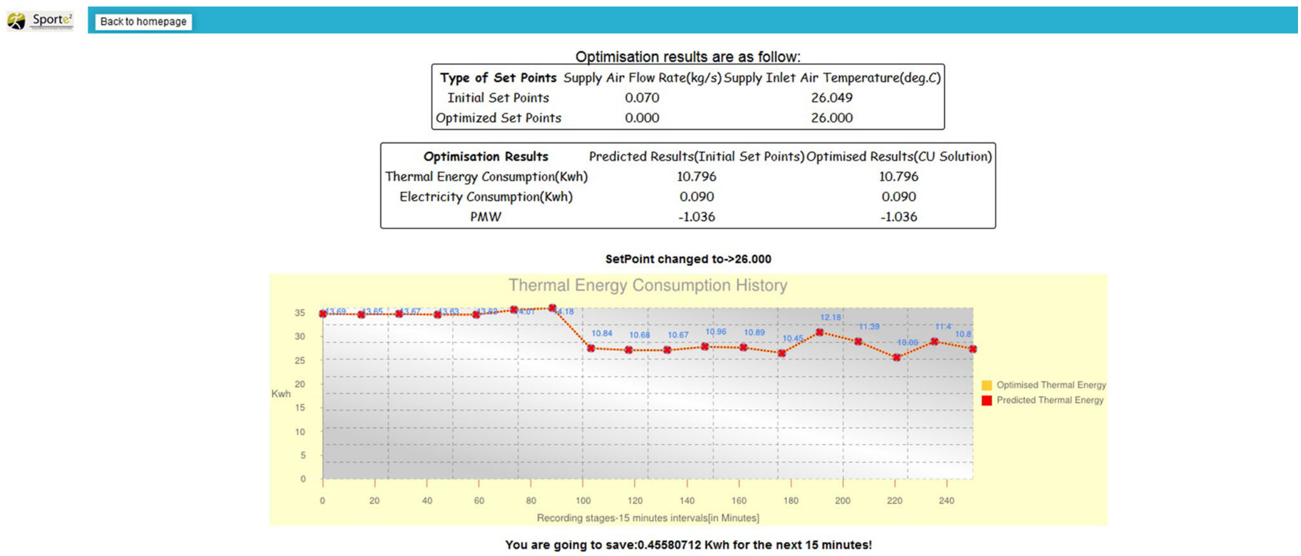

Fig. 7 FIDIA ANN optimisation results

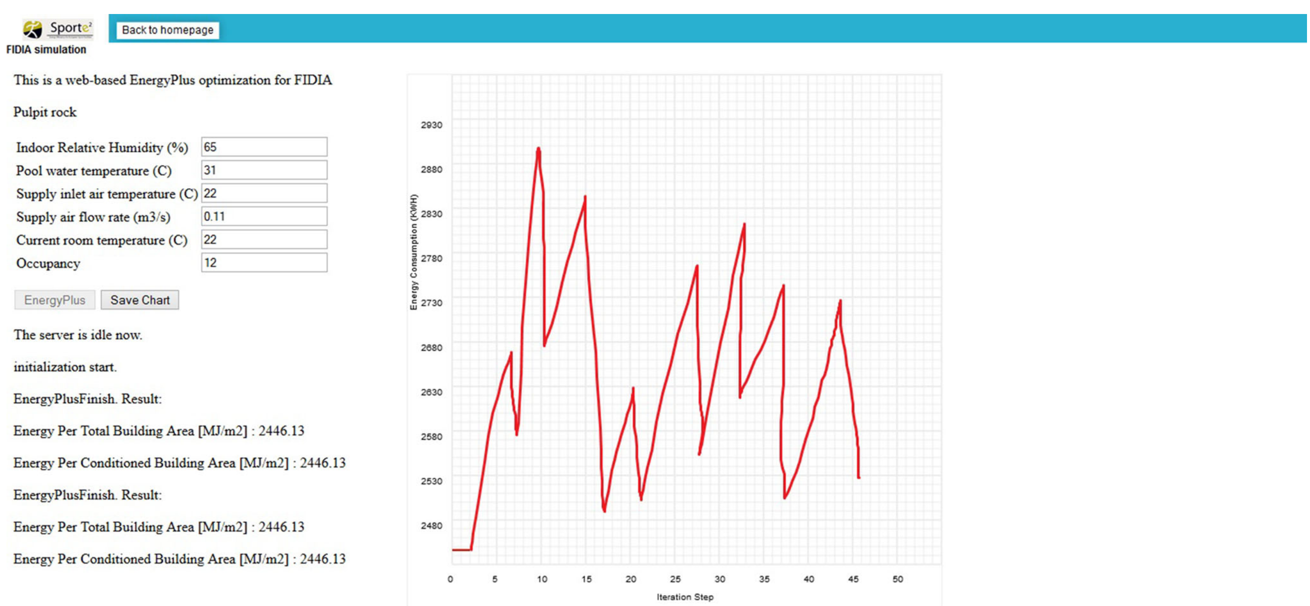

Fig. 8 User interface: real-time simulation-based optimisation

adopting for reducing energy. All these operations are manually applied (i.e. switching off the boiler, the air fans, the lighting system, etc.) and have no automated implementation or consistent decision-making process. Our solution, on the other hand, is based on a number of optimisation techniques and is related to a set of input parameters and generates optimised values according to which setpoints within the building are automatically adjusted.

Figure 9 illustrates how energy consumption evolves in FIDIA over a monitored period of 1 day (24 h). It can be observed that the energy consumption, as recorded in the pilot and undertaken with traditional optimisation methods, fluctuates between 0 and 100 kWh with a peak value of 300 kWh. For the online optimisation, the energy consumption fluctuates over the interval of [0–38] kwh. We can immediately conclude that online optimisation imposes a uniformity over the energy consumption.

From Fig. 9, it can also be identified two consumption schedules: (i) Day schedule ([0–20] recording stages and [50–100] stages) and (ii) Night schedules ([20–50] recording stages). Whereas during the day schedule, the energy consumption is high, over night the consumption is minimum. However, as traditional optimisation technique

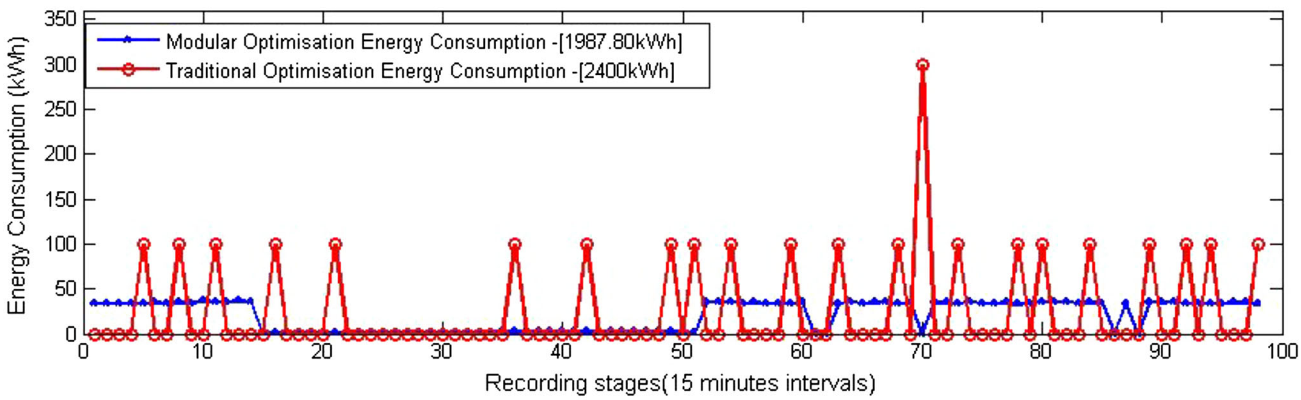

Fig. 9 Energy efficiency results

has no intelligent decision-making process for some night schedule intervals, energy consumption is still high. Our service-based optimisation assumes a continuous adaptation based on the values read from sensors. This process of continuous adaptation associated with an intelligent optimisation mechanism facilitates significant energy savings. For a monitor period of 1 day (24 h), the saving obtained using service-based optimisation is of 412.20 kWh equivalent with a saving percentage of approximately 39 %.

Conclusion

The paper presents how a service-oriented platform can be developed and used to ensure engagement with sustainable construction and energy efficiency practices. This research revealed a set of perceived barriers to engagement at individual, organisational and wider industry levels. Based on the research results, it was found that a socio-technical solution that provides integrated access to sustainability resources (knowledge, expertise, best practice, and software tools and applications) in the form of interactive, dynamic and user-oriented services that fully exploit latest advances in computing technologies may address these barriers.

We have presented the design and implementation of a service-oriented platform and experimentally evaluated a number of energy optimisation scenarios emphasising the savings in terms of energy consumption. From the results, we can conclude that the platform provides a number of advantages regarding to energy savings such as uniformity over consumption intervals, balance between optimisation objectives and greatly assisting building managers to employ efficient decisions.

Overall, the paper makes two main contributions:

- It provides a comprehensive analysis of construction sustainable practices regarding energy efficiency;
- It proposes a service-oriented platform to federate the plethora of existing information to provide an integrated and content-based access to the knowledge related to sustainability in construction.

The authors believe that the proposed web portal (a) has the potential to engage further practitioners in delivering sustainable interventions as inferred through our portal validation work and (b) contributes to the ongoing process of educating the organizations in the process of adopting energy efficient practices.

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