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PROCESS CENTRIC BUILDING ENERGY MANAGEMENT-AS-A- SERVICE

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ABSTRACT Business operations are an inseparable part of overall business services and energy consumption. Multiple levels of information regarding building components (architectural, electrical and mechanical), environmental conditions (outdoor and indoor) and occupant behaviour patterns, mostly driven by everyday business processes (schedules, loads, specific business episodes related to occupancy patterns and building operations), are considered necessary for effective and efficient modelling of building energy performance. Given the trend towards low energy consumption, actively engaging occupants during the building operation is critical to achieve high energy efficiency without scarifying end users comfort. The aim of this paper is to report the design and development of an innovative energy management framework to enable the alignment of fine-grain building energy use data to the organizational operational activities, allowing thus for a holistic view over the organizational energy performance. The main principle for the proposed framework is about linking Business Process Modeling (BPM) with Occupant Behaviour patterns and Building Information Modelling (BIM), the model that contains information for the building spaces and resources in terms of material and equipment. The exchange of information among these models is essential towards energy efficient buildings. By linking core operational aspects (equipment usage) and environmental conditions (temperature, humidity and luminance) to occupants' behaviours underlying business processes and organizational structures, the aim is to enhance the comprehensiveness and easy interpretation of building energy performance metrics within an extended enterprise performance evaluation framework.

1. Introduction

Energy efficiency is considered to be a key component of the European energy policy underlying the fundamental objectives of the European Union (EU) 2020 strategy. Buildings represent a major constituent of the urban ecosystem accounting for almost 40% of the overall energy demand in Europe. Most of the energy usage and consumption in buildings occurs during their operational phase accounting for 80% of overall consumption (Kamat *et al*., 2013). Within this percentage, at least 70% is caused by the occupants' behaviour and real-time control decisions, also within the context of business operations executed in the building.

With the focus on business processes, several approaches have been proposed towards identifying and modelling activities in an enterprise environment. As of today, modelling technologies are used in various areas, such as process management, business modelling, software development, security, etc. In the most recent research work, Carrara *et al*. (2009) present a human behaviour simulation model to enhance workspace wellbeing and productivity. By incorporating BIM related parameters in an ontological model, a semantically enriched model is defined to address the need for detailed behavioural performance analysis in an enterprise environment. Tagliabue *et al*. (2016) indicate the importance of behavioural modelling in building performance simulation by providing a probabilistic framework for a more accurate incorporation of business activity related parameters in an energy management framework. Moreover, Lopes *et al*. (2012) investigate the way that behaviour understanding represents a significant untapped potential for the increase of end-use energy efficiency in buildings.

Business operations (process organization and management) are an inseparable part of overall business services and energy consumption. Ideally, energy consumption should be tracked back to spatiotemporal aspects of business operations. Martin-Gomez *et al*. (2014) define an innovative framework towards modelling business activities on the way of optimizing simulation-based building energy performance. At the same direction, Truong *et al*. (2013) define a framework for business activity tracking and management towards energy efficiency in a residential environment. Nguyen and Aiello (2013) provide an overview of the most relevant research work in the field of behavioural and activity modelling with a hierarchical taxonomy of the different approaches towards energy efficiency. The common denominator of the different approaches is the focus on modelling business activities for enterprise management applications and, therefore, the perspective is towards the exhaustive and detailed modelling of the different business steps.

Within the context of an energy management framework, a behaviour-oriented approach should be considered for modelling different business processes. Towards this direction, a quite sophisticated approach for simulating human behaviour in buildings has been presented by Tabak *et al*. (2010). In this study, the authors have categorized activities in three different ways depending on i) the business nature of activities, ii) the number of occupants involved resulting in solo or group activities, and iii) the type of activities, such as planned or unplanned. The approach to the human activity behaviour simulation was based on the definition of activity schedules.

In this study, an inclusive energy management framework is proposed, incorporating business behavioural and energy related parameters, which is presented in section 2. The design framework is further transformed in a software tool and described in section 3 while a simulation-based evaluation analysis is briefly reported in section 4.

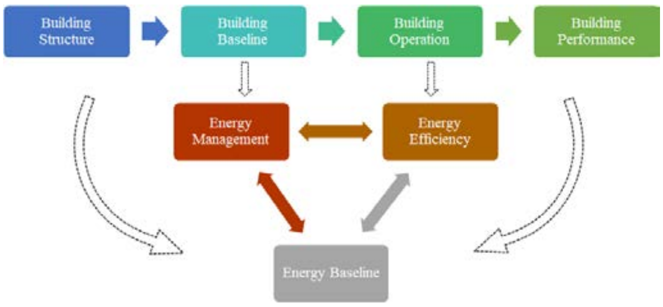
2. Energy management framework

The integrated methodological framework is characterized by three functional components closely linked to each other (Figure 1):

- Energy status capturing: It is the baseline stage of capturing the energy status of a building, mapping structural features and an "ex-ante / post" energy demand assessment.
- Building energy management: It is the stage of the real-time energy status capturing of a building in the operational phase, with the calculation of the key energy indices.
- Energy saving: It is the stage of extracting knowledge from the installation operation and further activating end-users for energy saving.

The partial analysis of the different stages of the methodological framework in the tertiary sector is presented in the following sections.

Figure 1 Framework methodology components



2.1 Energy status capturing

The initial stage of the methodological approach defines the context of the research problem. The individual subsystems and procedures are described in the subsections below.

2.1.1 Capturing building static characteristics

With the aim of developing an advanced energy management methodology and its implementation in the tertiary sector, the first step is the modelling of primary information. Building Information Modelling (BIM) is the digital representation of the physical and functional characteristics of a building and constitutes a source of knowledge and information, forming a reliable basis for decision-making during building life cycle, from the original conception of the project to its demolition. In this direction, the XML protocol, used to record information in buildings, has been developed. The information is written in XML format and the objective is to facilitate the transfer of building design information to energy simulation software. The protocol is widely accepted by the leading design software manufacturers, e.g., Autodesk, Archicad, and others (Wang *et al.*, 2014; Ham *et al*., 2015).

In this study, the XML model is extended to take into account the individual functional characteristics of a building installation (e.g., modelling features of individual devices) and also to design a wrapper to capture the important information for energy simulation. Therefore, the model is a converter of multi-layer information, as imprinted in XML, to relational information while acting as a facilitator for energy management based on the human-centered operation of the individual energy consumption devices.

The individual steps of this process are the following:

1. Study of the building installation and modelling of the information in the XML template.

2. Semantic enhancement of XML with additional information (e.g., typical device operating features).

3. Transfer of XML information on an Entity-Relationship (ER) information model.

On the basis of the XML scheme, where the stationary information with structural features is captured, fields related to the operational/business role of the installation are added, namely: devices with their functional characteristics, building zones based on environmental conditions, end users and how they operate at a functional level. The semantic enrichment of the building model and the mapping of relational structures is the basis for the proposed methodology.

2.1.2 Energy savings measurement and verification

Regarding the methodological approach, the development of standardized procedures for measurement and valuation of savings is an important task. In this respect, the framework adopts the International Performance Measurement and Verification Protocol (IPMVP) methodology, the most standardized methodology for energy capture (European Committee, 2001; Waltz, 2007). IPMVP provides four options for determining savings which are:

- Option (A): Retrofit Isolation and Key Parameter Measurement

Parameters not being actually measured are valuated through estimation. Estimates can be based on historical data, manufacturer specifications, or engineering judgment. Documentation of the source or justification of the estimated parameter is required.

- Option (B) Retrofit Isolation and all Parameter Measurement

Energy savings are determined by field measurement of all key performance parameters that define the energy usage of the affected system.

- Option (C) Whole Facility Measurement

Savings are determined by measuring energy use at the whole facility or sub-facility level. This approach is likely to require a regression analysis or similar one to account for independent variables, such as outdoor air temperature.

- Option (D) Calibrated Simulation

Savings are determined through energy use simulation of the whole facility or a sub-facility. Simulation routines are validated to adequately reflect the actual energy performance measured in the facility.

The novelty of the proposed approach is that, apart from the formulation of individual static methods, a dynamic, time-based methodology for plotting the energy status of an installation is proposed. The proposed methodology for redevelopment of each step/method based on data availability for calibration and valuation of energy consumption is presented in Figure 2.

Figure 2 Energy savings measurement and verification

2.1.3 Key Performance Indicators

A holistic assessment framework is adopted for defining Key Performance Indicators (KPIs) with an emphasis on the energy efficiency of each business operation. The KPIs focus on serving the optimization of the energy performance of buildings providing, for instance, low energy consumption, high business utilization, and satisfactory comfort for end users. The classification of performance indicators is:

- KPIs describing energy efficiency aspects, e.g., energy consumption, CO2 emissions or heat loss (Table 1).
- KPIs that describe business performance aspects, e.g., total run time of a business process, total activity time per room, etc. (Table 2).
- KPIs that describe the comfort of living in the building, e.g., lighting, temperature (Table 3).

Table 1 Energy efficiency KPIs

KPI	Description	Calculation
Energy consumption	Calculation of total consumption by each individual component (BIM element)	Sum (DER_Consumption)
Energy cost	Calculation of total consumption costs	Consumption * Price
Emissions	Calculation of total emissions	Consumption * CO2 emissions rate

Table 2 Business performance KPIs

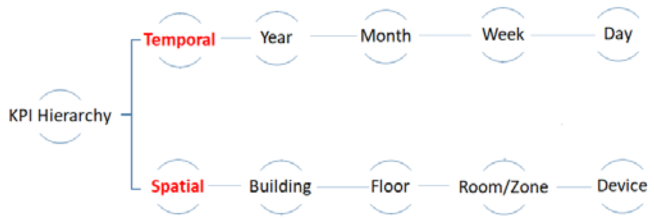
KPI	Description	Calculation
Consumption per process	Total energy consumption per process (total / per minute)	Sum (DER Consumption)
Equipment utilization rate	Time that selected equipment is in use or idle (in selected processes and depending on the scenario)	Actual BP Consumption / Estimated BP Consumption
Time of process cycle completion	Average completion time in selected processes. The system must be able to calculate any deviations based on this indicator	End Time BP - Start Time BP

Table 3 Environmental conditions KPIs

KPI	Description	Calculation
Visual comfort	Room brightness status	Average (Lum.) per process / zone / user etc.
Thermal comfort	Room temperature status	Average (Temp.) per process / zone / user etc.

The dynamic framework of a building footprint is defined as the composition of energy, environmental and business features. For the KPIs calculation, a spatiotemporal hierarchical structure is adopted (Figure 3).

Figure 3 KPIs hierarchy



2.2 Energy management status

2.2.1 Data analysis modelling and integration

The advancement of this research is related to (a) the incorporation of additional metering data (environmental data) and correlation with the operation of individual devices and (b) the adoption of a simulation-based operation approach where data are correlated with the operating modes of the individual loads. This approach allows a detailed perception and extraction of useful insights from the actual operating mode. The individual steps of the algorithmic process are the following:

A. Metering data collection: It is the first step in the analysis where data are collected from heterogeneous sources (the physical measurement systems in a building facility and historical data).

B. Model training: Metering data are correlated with individual device operating models, based on knowledge available from existing research (Kamgarpour *et al*., 2013; Caicedo *et al*., 2014;Hu *et al*., 2015;Hreinsson *et al*. 2017), with the aim of extracting knowledge about the operation of each individual installation, by using regression and fitting models.

C. Simulation-based data analysis: The real-time correlation of the metering data with the data extracted from the trained models (Step B) is used in the simulation-based building energy analysis.

D. Data analysis: In addition to the simulation-based data analysis presented above, time-series are used to provide additional data analysis of the building model.

Both data from simulation-based and time-series analysis become then available as system knowledge for further processing in later stages.

2.2.2 Unified energy management framework

A Business Process is a collection of associated structural activities that produce desirable results for the business (Hassen *et al*., 2017). The term "Business Process Management" refers to the approach that supports organizations and companies in managing their processes efficiently, reducing their costs, becoming more productive, and adding value to their work in general.

The integration of business processes into an energy management environment is the basic advancement of this methodological approach. The individual steps of the methodology are the following:

1. Recording: This first step involves the recording of the individual organization processes (main and secondary) with emphasis on the interconnection with the organizational level and the operation of individual equipment (resource level) in the building.

2. Redesign: The collected information is used for the Skeleton processes extraction. Skeleton processes are considered as the hierarchical synthesis of individual detailed (main and secondary) processes (based on the organization workflow) which are related to human behaviour and the activities in buildings. Examples of skeleton activities include meeting attendance, conducting administrative tasks, handling complaints, and communicating with clients.

3. Processes modelling: The stage involves the representation of business processes using business process model and notation techniques (Business Process Modelling Notation, 2007).

2.2.3 Business processes and energy management integration

An enhanced Entity-Relationship model is defined for matching processes with individual loads (and consumptions). Each individual device load (Device Model) is associated with a building space (BIM Representation) where a particular process is performed by a specific user (BPM Representation) in a corresponding time period. In the case of multiple operational processes in one zone, the load participation per process is defined. On the basis of the above analysis, the depiction of the semantic model of a building layout is illustrated in Figure 4.

2.3 Energy saving status

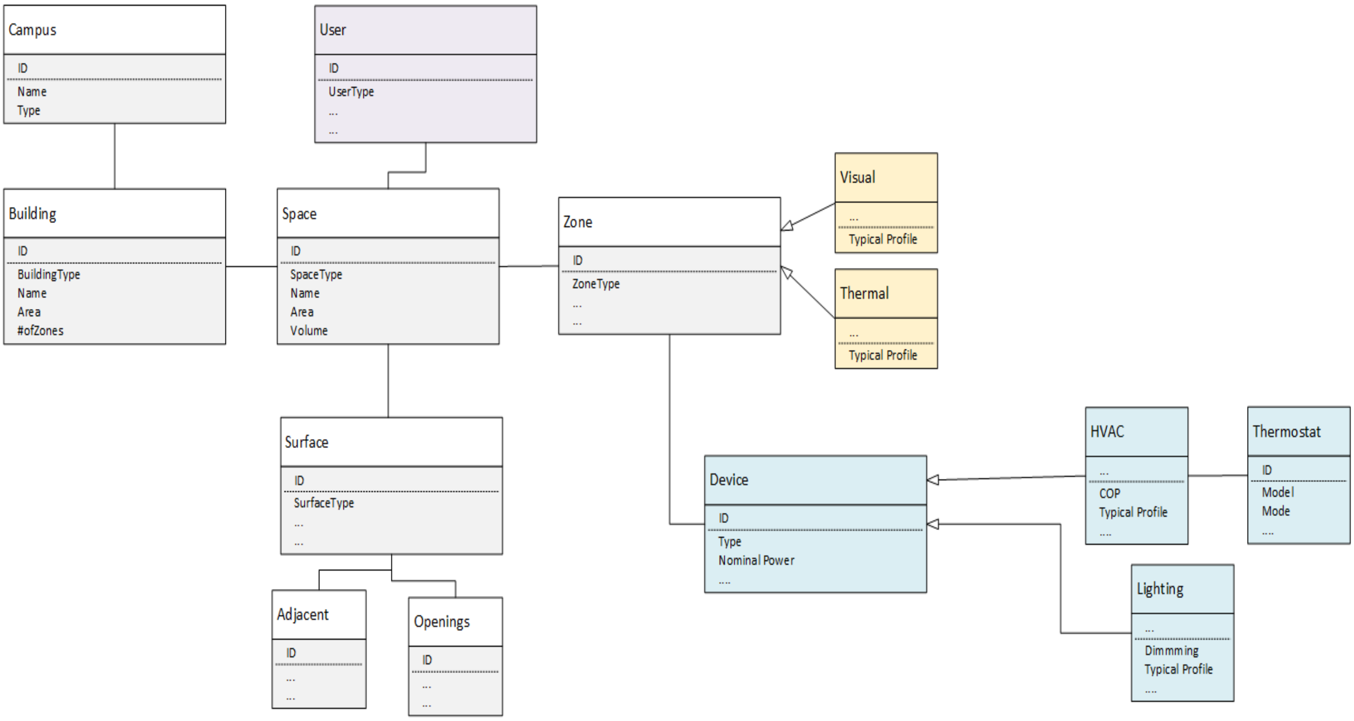
Burger *et al*. (2015) present a variety of factors for behavioural changes of end users on the basis of their active engagement in energy consumption efficiency (in consideration of different parameters associated with psychology, economics, consumer behaviour, science, business, sociology and political science). Indicative factors may be knowledge, perception of social norms, values, emotions, etc. A hybrid approach is adopted in this work and the individual factors that make up the holistic semantic context towards the inducement of end users are recorded:

-Information: Information increases the knowledge of the person being addressed. It is the simplest yet most effective activation method for changing behaviour.

- Feedback: With feedback, a characterization is added to the provided information. For example, information about end user energy consumption is converted into red or green feedback. In this way, the consumer is faced with assessing his or her behaviour, judging it as negative or positive. Feedback can be given in the forms of gamification or competition.

- Recommendations: In addition to the interventions mentioned above for adjusting behaviour, recommendations should also be given to consumers, e.g., references for behaviour change.

Figure 4 : Entity-Relationship Model



- Remarks: Remarks include a variety of interventions, which are generally considered to be useful strategies for triggering behavioural changes in this context; they appear to be a promising approach for promoting the concept of sustainable consumption behaviour (Lehner *et al.*, 2016).

The methodological approach for selecting the appropriate activation mechanisms is the basis for repository of knowledge used for sending personalized messages to end users.

3. Information system architecture

The design process of the system architecture should take into account important architectural concepts and design principles to reflect high-level basic elements and their interrelationships in the final structure. The modular architecture of the system is considered as the synthesis of many architectural structures, including software components, their interconnection and the connection with the end user. This section describes the various components of the system architecture and the way they interact to perform the required functions for the final synthesis of the IT system.

The high-level structure shown in Figure 5 represents the conceptual logic of the system functionality, by splitting the architectural approach into three levels. The basic conceptual elements of the system architecture are described in the following sections.

3.1 Database

The database is placed on a horizontal level with the primary responsibility of storing and providing access to heterogeneous information (semantic data models) used by other subsystems.

3.2 Semantic Middleware

The Semantic Middleware element provides the necessary interconnections for device control and stores the metering data from sensors. The middleware system creates an open, united, and homogeneous layer that can integrate all the building measurement and control components (e.g., sensors, air conditioning systems, room lighting, etc).

In addition, the proposed system provides all the necessary tools for integrating devices into the system as virtual elements (semantically enriched elements), incorporating the necessary semantic components (ontologies and rules) for efficient grouping and coordinated management of the various devices. More specifically, the intermediate software level consists of Device Managers, allowing a wide range of devices to be integrated into the system, and Ontology Managers that handle all the interactions between user profiles and building spaces.

3.3 Data Processing tools

The Data Processing tools element provides the ability to export user and device profiles. The user profile and space usage environment are based on real-time analysis of all data related to the environmental conditions inside the building and on user preferences in relation to business processes.

Figure 5 Information system architecture

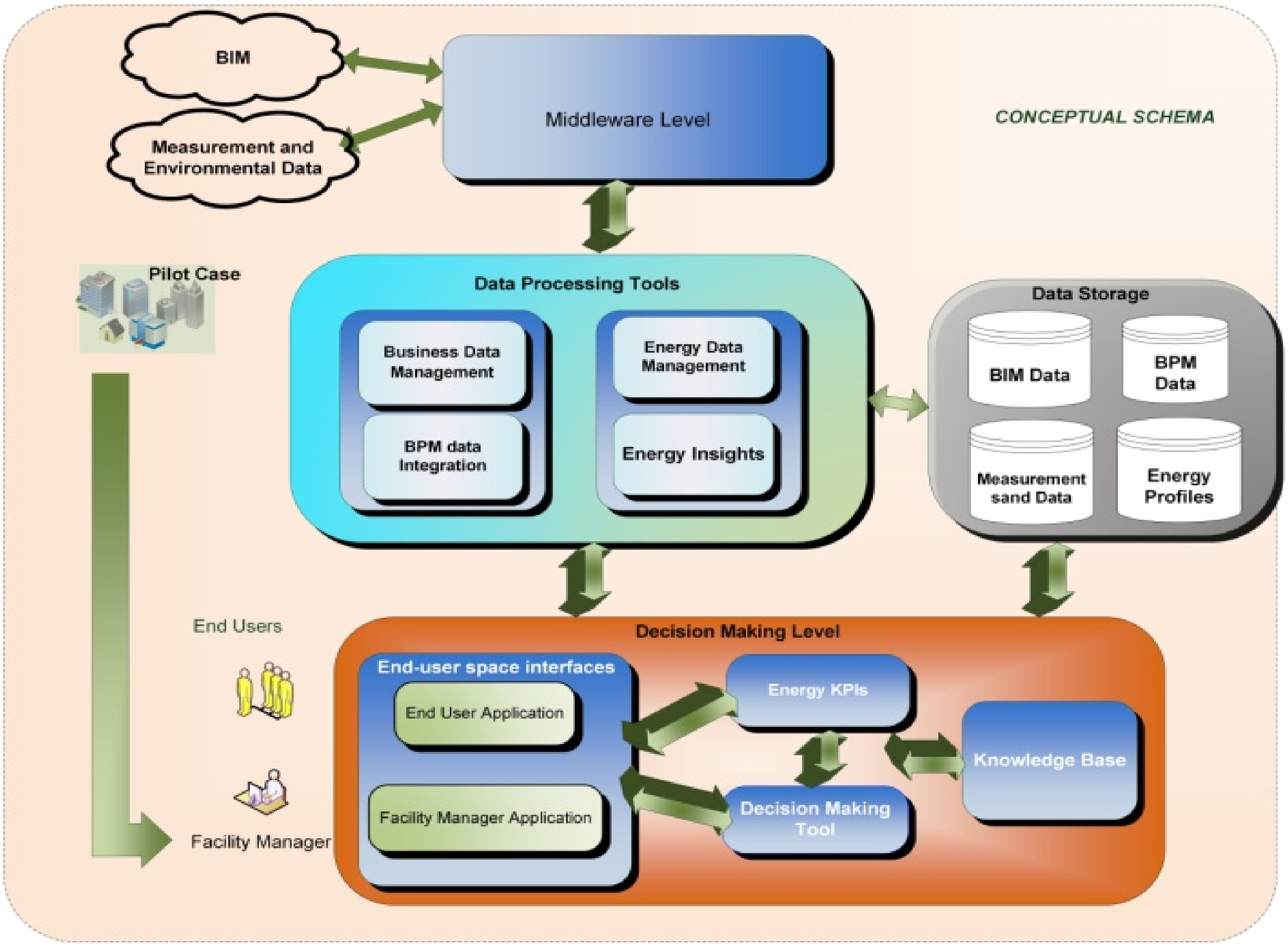
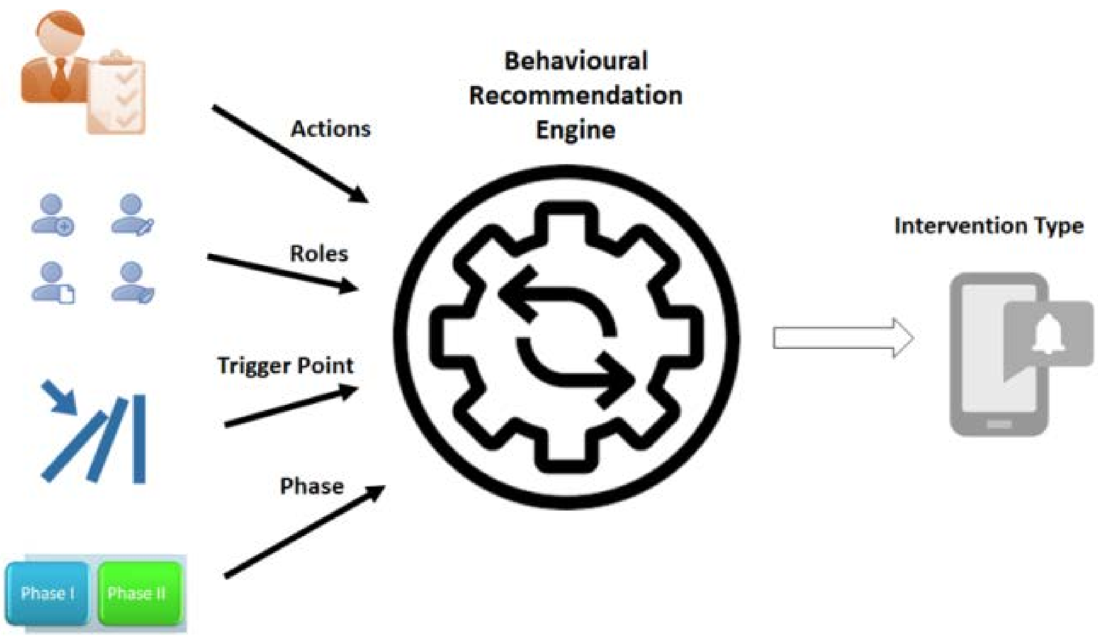


Figure 6 Knowledge base architecture



The incorporation of BPM information is a key element to create user and operating profiles as a system novelty. The framework for energy data processing is defined on the basis of the selected energy performance indicators and the Energy Insights which both form the core of the decision-making system.

3.4 Decision-making level

The decision-making level integrates modelling and decision functions with the visualization tools of building parameters to allow user interaction with the system. The level of system control provides important personalized information on equipment performance used to enhance the active participation of end-users in decision-making. The individual subsystems that constitute the decision-making systems are described in the next sections.

3.4.1 Knowledge base

The knowledge base includes a collection of rules determining the alerts sent to end users. The number of rules defined in the semantic model is associated to the end user activation model parameters which are integrated into a single cognitive model (Figure 6).

The basic functions of the system are:

1. Integration of activation strategies available to the building facility manager. The entry data include:

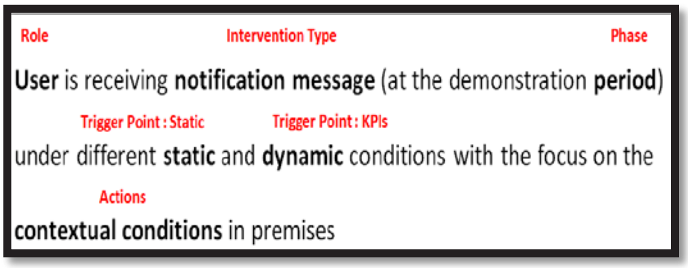
- Actions / Activities: Definition of activity-related parameters as a factor in the behavioural change framework.
- User roles: Target group definition, e.g., instrumentalist, scepticist, follower, concerned.
- Activation points: Definition of model parameters integrated in the analysis, such as user demographics and building space characteristics (user age, zone type), user profile characteristics (high/low consumption, flexibility potential etc).

2. Establishing a dynamic approach for model re-adjustment.

3.4.2 Decision-making system

The ultimate goal of the module is to provide a multiple parameter and criteria analysis for the holistic system operation. The module compiles real-time information from different sources to support decisions regarding the necessary end-user activation commands. This function is directly related to the knowledge base as presented above. In this ontological approach, the semantic representation is the core component of the system and a rule-based engine is defined as the Decision Making System. An "*If This Then That* (IFTTT)" logic, being a widespread decision-making system logic, is adopted, as indicatively presented in Figure 7.

Figure 7 Decision making system



3.4.3 End user interfaces

The basic functions of the User Interfaces are directed to two types of end-users:

For the Facility Manager, a web environment is developed in order to:

- Provide real-time information about the energy consumption of the building.
- Provide historical data on the operational status of the infrastructure (energy consumption data, KPIs).
- Provide analytics on business processes, as exported by the system, with enriched knowledge of building operation.
- Apply the appropriate modes to reduce total consumption, taking into account the building operating status and business processes.

For the end users, a web application is developed to enable them to:

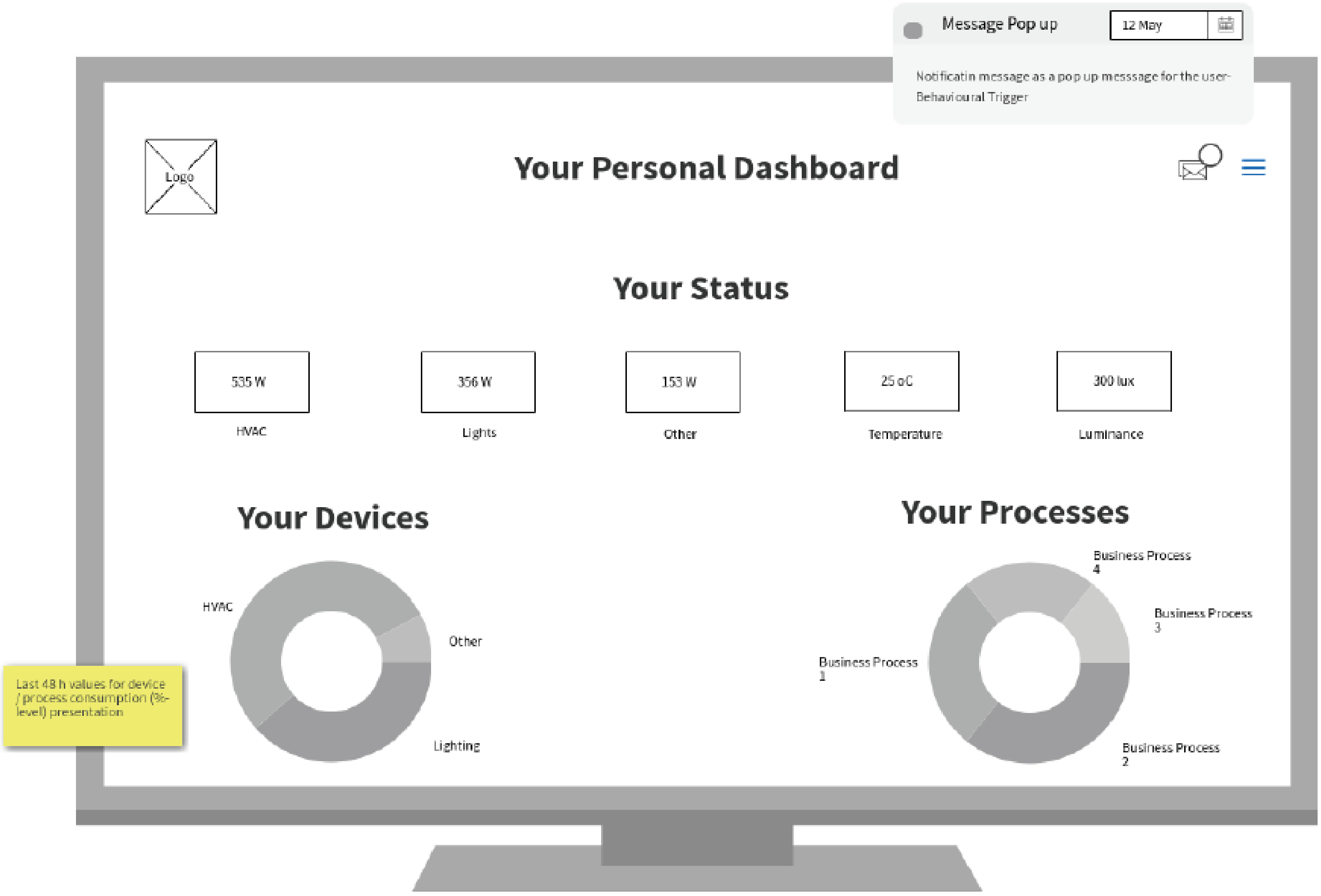
- Gain access and be informed about their energy consumption performance and receive notification messages in order to alter their energy consuming behaviour when required.

The representation of the end user interface for information visualization is depicted in Figure 8.

4. Pilot case

The evaluation of the enhanced energy management framework is being performed in a multifaceted building of the University of Patras incorporating in the analysis several parameters that affect the overall system performance. Validation of the framework involves an extensive 6-month pilot roll-out period in a variety of building spaces (administrative offices, technician facilities, meeting rooms) and engages more than 10 employees in action for assessing and possibly modifying their energy behaviour.

Figure 8 Application design layout for the end user



Prior to a large scale demonstration, a pilot simulation model has been established as a trial testbed for the early evaluation of the proposed framework. The main principles of the digital twin concept have been adopted towards modelling and simulation of building operations based on actual data coming from sensors and metering devices installed in premises (Boschert *et al*, 2016).

In the digital twin model, historical data are received from real installations and are imported into a precise digital copy of the facility to evaluate the individual processes. The aim of this approach is the technical and functional evaluation of the information system and the assessment of the energy saving potential (while the real-time assessment of the holistic approach is part of the main pilot). Table 4 depicts the loads used in the application scenarios, providing some general technical details.

In addition to the static representation of measuring and building devices and characteristics, time-series data from open knowledge repositories are used. Also, other datasets (e.g., IAWE, http://iawe.github.io/) with energy consumption data and environmental data are used, demonstrating the correlation between the devices operation and the environmental conditions in the building.

Table 4 Installation loads

Digital Twin Installation Loads	
Lighting	• 16 x (4 x 18 W) fluorescent lamps
HVAC	• Split devices • 8 x Air to Air units 0,5- 2,0 kW • 8 x thermostats(operation control)
Office Devices	• 17 x computers and screens • 10 x printers

The business processes are defined within the hours of staff schedule: from 07:00 to 17:00 with possible extension occasionally until 19:00. Altogether, 17 employees are employed in 8 different zones, divided into 3 categories: administration offices, administrative staff offices, and public attendance offices.

Initial baseline calculations and simulation results are presented in the following figures for the targeted controllable devices (Figure 9a, b, and c).

Figure 9a Potential energy savings - lights

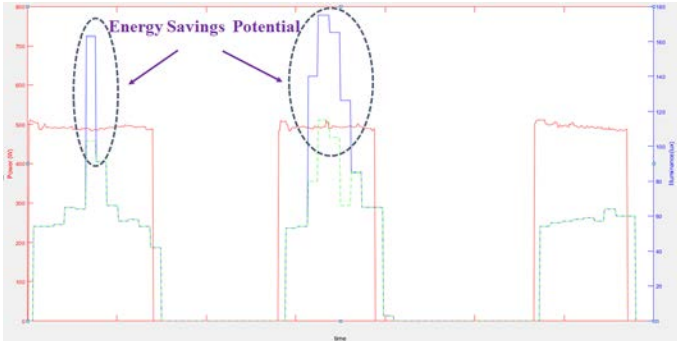


Figure 9b Potential energy savings - plug devices

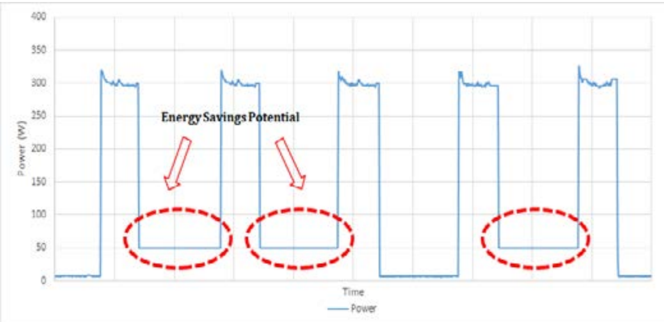
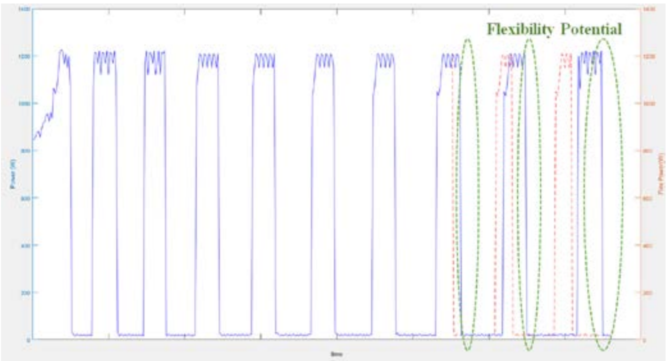


Figure 9c Potential energy savings - HVAC



Results indicate potential energy savings between 5 and 20% for the different device types and, more specifically, 15-20% for lights, 5-10% for office devices and 7-10% for HVAC.

Considering the long term evaluation of the framework, a hybrid pilot is developed for a step by step holistic evaluation (Figure 10). The overall validation methodology involves different though tightly related phases:

1. Calibration and baseline analysis to quantify the actual building performance prior to any intervention.

2. Pilot roll-out and testing under real-life conditions towards the evaluation of the results achieved.

3. Technical evaluation of the system with the focus on scalability and expandability of the framework.

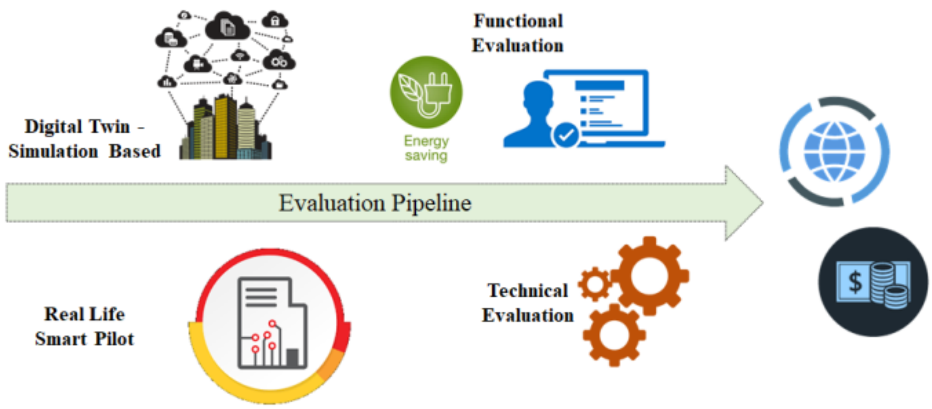
Along with the technical viability of the solution, the business evaluation of the energy management framework is examined. The focus at this stage is on the definition of business models where the proposed framework can easily fit and provide added value for the key business stakeholders, namely:

- Energy Utility Companies that aspire to analyse portfolio data and provide added value services to their customers in a deregulated and commercially intense market environment.

- Energy Service Companies (ESCOs), Public Authorities and Facility Management enterprises with an established portfolio of customers in providing innovative energy services within the aim of energy efficiency.

- Business Analysts and Enterprise Experts willing to gain multi-parametric insight about the performance of business processes by incorporating energy related attributes in the analysis.

Figure 10 Pilot deployment and validation framework



5. Conclusions

The energy management process in tertiary buildings heavily relies on three interrelated factors: building stationary characteristics, business and operational processes, and human behaviour. In this paper, a holistic energy management framework is presented which incorporates these heterogeneous factors in a unified framework. This is a user-centered energy management framework that encompasses the ability for real time building energy monitoring and management on the basis of the business and organizational characteristics and in line with the end user comfort preferences. Along with the presentation of the overall methodology and the system component modelling, preliminary validation activities and evaluation results are presented which indicate that there are significant potential energy savings. Current work focuses on wide validation of the proposed framework and system in conjunction with optimization analyses towards (a) the evaluation of the proposed framework in different building types, business processes, and user characteristics in the holistic framework and (b) the framework extension to address extra load types.

6. Acknowledgements

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