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# HIT2GAP: Towards a better building energy management

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## Abstract

Recent studies show that the Energy Performance Gap (EPGap), defined as the difference between the estimated and actual energy consumption of a building, is significantly high. This is due to various factors encountered in the different phases of the building life cycle, i.e., inaccuracy of the specifications used in the simulation tools during design phase, poor quality of the on-site practices conducted throughout the construction, inadequate verification of the equipment installed in the building during commissioning phase, and limited analysis of the data collected from the equipment during the operational phase. With the aim of reducing the EPGap, we present an energy management framework defined in the context of an EU-funded H2020 project, HIT2GAP[1]. The proposed solution provides several services from collecting heterogeneous on-site data, to advanced data analysis and visualization tools designed for the different actors of a building (e.g., building/facility/energy manager, occupants, etc.), for building energy performance optimization. In this paper, we give an overview on the proposed framework architecture and detail its different functionalities, with a particular focus on the solution Core Platform, which is in charge of orchestrating the different components, storing and structuring the data, and providing pre-processing services.

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*Keywords:* Energy Efficiency; Smart Buildings; Web-based Framework; Ontological Data Model; Web-service Composition

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[1] HIT2GAP: Highly Innovative building control Tools Tackling the energy performance GAP, www.hit2gap.eu

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## 1. Introduction

Recent measurement campaigns reveal that the actual energy use of buildings is 5 to 10 times higher than calculations carried out during their design [1]. This gap, denoted as the Energy Performance Gap (EPGap), arises from various sources related to the building life cycle phases:

- In the design phase: design specifications are not always reliable [2] and simulation tools can be inaccurate [3]
- In the construction phase: equipment and materials may lack of quality, and construction methods can be inadequate
- In the commissioning phase: the installed systems are not well verified and thus, they do not operate as intended by the building owner and as designed by the building engineers
- In the operational phase: energy systems do not run properly and occupants' behavior highly impacts buildings energy consumption

With the evolution of IT technologies, several solutions have been developed to manage buildings' energy behavior during their operational phase. Some are directly related to the smart building domain and act as building management solutions [4, 5, 6, 7], while others are related to the business analytics domains [8, 9] and can be used to analyze the collected building related data (i.e., internal temperature/humidity, energy consumptions, energy costs, etc.). However, such solutions face major obstacles when being implemented due to various factors, amongst others, 1) the non-interoperability of data between the existing building devices and the management applications used, 2) the limited analysis of data collected from the installed equipment (e.g., sensors, meters, etc.), and 3) the non-adaptability to new building requirements (i.e., adding new sensors, implementing new management applications, etc.). To cope with these limitations, we present in this paper an innovative energy management framework, defined in the context of the HIT2GAP H2020 project. The solution offers various services for collecting and preparing heterogeneous data, structuring and linking it through an ontological data model, and processing it through building-oriented web applications. These web applications can be exploited by different actors, i.e., building/facility/energy managers, occupants, etc., via adaptable visualization interfaces. To orchestrate the different services offered by the framework, a Core Platform acting as a middleware is defined, offering extensible RESTful-based services [10] to the web applications.

The remainder of this paper is organized as follows. Section 2 discusses the main existing limitations of the smart building IT systems and defines the solution requirements. Section 3 presents the HIT2GAP energy management framework architecture and the provided functionalities, with a particular focus on its Core Platform. Finally, concluding remarks and ongoing work are shown in Section 4.

## 2. Existing limitations VS solution requirements

Smart buildings are equipped with various systems and devices that collect and analyze building data to manage their energy consumption. Building management systems (BMS) [11] are the most used solution to this end. They monitor and operate on the electrical and mechanical systems of a building: heating, ventilation, air conditioning (HVAC), lighting, etc. However, BMS face several limitations when being adopted such as, i) data interoperability issues between the different type of equipment and applications, due to the heterogeneous and linked nature of the collected data, ii) limited integration of advanced data management applications [12], iii) erroneous collected data, iv) no integration of data related to building occupants, and v) lack of extensibility to adapt to new building conditions and requirements (i.e., adding new equipment, extending the management applications functionalities, etc.). To address these limitations, several requirements have been identified in our proposed solution, as shown in Table 1:

Table 1. Solution Requirements

| Requirements | Description |
|---|---|
| Field Interoperability | Ensures the integration among diverse installed systems/devices that are developed by different manufacturers and communicate via different communication protocols |
| Management Interoperability | Integrates different type of building-oriented applications and facilitates data exchange between them |
| Middleware Interoperability | Ensures seamless communication between the installed equipment and management level applications |
| Modularity | Allows different modules or components to be added/replaced without affecting the rest of the system |

| | |
|---|---|
| Genericity | Adapts to different environments and type of building |
| Evolutionary | Evolves to meet new requirements when it is necessary (e.g., adding new services or equipment) |
| Advanced processing | Embeds advanced techniques to process the collected building data and acquire valuable information |

## 3. HIT2GAP architecture

Based on the requirements stated in Table 1, we propose a modular architecture with 5 levels, as represented in Fig. 1:

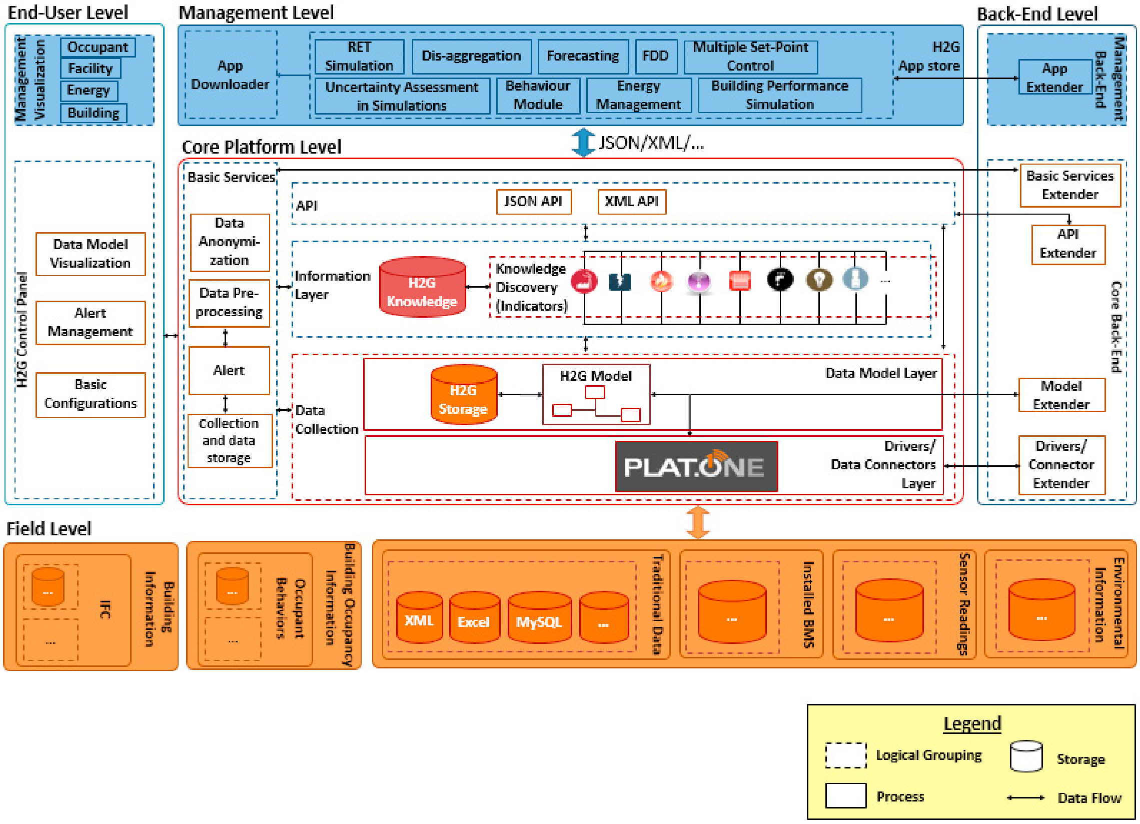

Fig. 1. HIT2GAP Architecture

### 3.1. Field level

It contains all the data sources used for the collection of heterogeneous building data. Such data can be issued from:

- Existing installed BMS
- Traditional and advanced sensor readings (e.g., humidity sensors, multimedia cameras, smartphones, etc.) that are not connected to the BMS
- Traditional repositories not included in the BMS and stored in different format (e.g., XML, Excel Sheets, etc.)
- External services related to environmental information (e.g., weather forecasts, solar radiations, etc.)
- BIM[2] files that describe building static information (e.g., building levels, composition of walls, doors, etc.)
- Occupancy related sheets to collect their preferences (e.g., visual and thermal needs)
- Smart devices and positioning equipment to collect occupancy behavior and state (e.g., presence, heart rate, etc.)

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[2] Building Information Modeling

### *3.2. Core Platform level*

It acts as a middleware between the Field and the Management level. It is mainly responsible of the collection, storage and pre-processing of the building data retrieved from the Field level, and contains the following layers:

- The Drivers/Data Connectors' layer, contains different drivers and connectors that connect to the data sources of the Field level and retrieve the required data. "PLAT.ONE[3]" is one of the connectors adopted in the solution.
- The Data Model layer, contains a data storage based on HDF5[4] to store time-series, and an ontology-based data model to store semantically linked descriptive information. In fact, and due to the heterogeneous nature of the data collected from the Field level (i.e., Energy data, occupancy data, building data, weather data, etc.), we defined an ontological data model that links all collected data and makes them easily exploitable. The ontology is a set of common concepts and terms describing and representing a domain of knowledge [13], which is the building energy performance domain in the our case. The main advantage of using an ontology-based data model is to unify and normalize the data flowing between all the architecture components, by establishing common vocabularies and semantic interpretations of terms that are comprehensible for both system applications and users. The ontology is designed to cover different aspects for building energy management: building information (i.e., physical characteristics and systems installed) based on the IFC-OWL ontology [14], advanced features of sensors (based on the SSN ontology [15]), and occupants' information and simulations. The defined ontology, resulting from the alignment of these different ontologies, is generic and extensible. It is applicable and adaptable to different environments and types of building (residential, commercial, etc.).
- The Basic Services layer, includes the following basic services:
  - The collection and data storage service that allows the storage of the collected data from the Field level. The storage is done according to a well-defined data structure to meet the requirements of the solution data model.
  - Data pre-processing is used to improve the quality of data [16]. It encapsulates several services that prepare the collected building data before being processed by the Management level applications. In fact, the collected data from the heterogeneous sources existing in the Field level may be i) incomplete, due to missing values (blanks data) retrieved during certain times, ii) erroneous, containing outliers that are values outside the range of the normal values, and iii) not temporally synchronized, due to different data collection frequencies (e.g., per 10 mins, per 30 mins, etc.). For this matter, we provide pre-processing services for: 1) outliers and blanks detection with several methods useful for data correction, 2) unit conversion to convert data units (e.g., Celsius to Kelvin for temperature values, Atmosphere to Pascale for pressure values, etc.), 3) data alignment to align multiple time-series data to the same frequency (e.g., per day, per 15 minutes, etc.), and 4) data aggregation that includes several arithmetic operations (e.g., sum, subtract, mean, percentage, etc.).
  - The alert service is used to signal alerts (if occurred) at each data stage: on the acquisition, storage and pre-processing of the data (e.g., alerts indicating that the data value was not acquired, which can be caused by a malfunction of an equipment or a system).
  - The data anonymization service is responsible of protecting the sensitive and private data. For instance, it includes encryption functionalities on the personal data related to building occupants.
- Information layer, is mainly responsible of acquiring valuable information related to building energy management. This is done by reasoning on the ontological semantic data model that structures and links the building collected data (e.g., heat energy consumption, lighting and water consumption, etc.). In fact, through advanced queries applied on the ontology model, useful information are obtained to study and analyze building energy performance.
- API layer, embeds RESTful APIs5 through which applications existing in the Management level are able to collect data and access the Core Platform services. These APIs are conceived as web services independent from any platform and development language, and thus they can be accessed by any type of application.

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[3] http://plat.one

[4] Hierarchical Data Format (HDF) is a set of file formats designed to store and organize large amounts of data

[5] Application Programming Interfaces

### *3.3. Management level*

It acts as an “App Store” that includes various building-oriented web applications, currently developed by the partners of the HIT2GAP consortium. These web applications, downloadable via the “App Downloader” service, are:

- Renewable Energy Tool (RET) Simulation, conducted by the Energy Warden Simulator (EW-S). EW-S provides optimal sizing of RETs systems and their components in new installations and retrofits, based on user preferences.
- Disaggregation, used to provide insight on the performance and maintenance needs of electric appliances, through a cost effective monitoring, sparing the need for costly and intrusive sub metering.
- Forecasting [17], used to predict building energy consumption and anticipate reactive behavior.
- Fault Detection and Diagnosis (FDD), used for detecting faulty system operations based on advanced monitoring capabilities. It generates warnings and recommendations for the facility management.
- Multiple Set Point Control, applies several strategies for indoor thermal comfort (temperature and humidity control) of the building spaces according to different set-points (e.g., economy and comfort).
- Uncertainty Assessment in Simulations, which mainly accounts for uncertain input parameters in simulation models and aids in indicating the most influential parameters for energy optimization during design or operation.
- Behavior Module [18], which offers services related to how users use building spaces and energy systems.
- Energy Management Module, used to analyze energy data deviations and aid in the decision making of corrective actions. It follows the ISO 50001 standards.
- Building Performance Simulation, which help in analyzing the discrepancies between the simulation results and the actual measured data, and adjusting the simulation model or the operation accordingly.

The proposed solution follows the RESTful architecture [10], where services are provided to the Management level applications (considered also as services), through published and discoverable interfaces (APIs). Each service provides a specific functionality to answer building actors’ requests. However, buildings actors may have complex requests that require the interaction of two or more services. In order to fulfil such demands, and by using resource-oriented web services technology [19], our solution allows semantic RESTful services composition [20] to satisfy complex users’ needs related to building energy management. This is done through a user-friendly interface, from which the building actor can access the provided services to build the needed composition. To facilitate the composition developing process for end-users with limited technical skills, the system is able to dynamically select the services required for the composition. This is achieved via semantic annotations comprehensible for the system, and used to describe the links between the provided services. Once the composition is built, the solution will verify the composition behavior to ensure its correct execution. Such approach provides facilities to build new client composed services and reduces the required technical skills.

### *3.4. End-User level*

It is responsible of the interaction between the end-user and the framework services. It contains visualization applications/modules, used to graphically represent the building energy performance related data. Such display modules support various adaptable interfaces developed for different end-users profiles: occupants, building/energy/facility managers, etc. In our solution we have four kinds of visualization modules:

- Energy Management Visualization Module: matches the ISO 50001 requirements and covers two main functions: Energy Planning & Monitoring, and Energy Audit & Document review.
- Facility Management Visualization Module: contains different components, i.e., i) a display of aggregated building energy consumption measurement, forecast data and indoor thermal comfort indicators, ii) a dashboard with information collected from the FDD module, and iii) a representation of the buildings time-series data with scatter plots useful to analyze and understand systems operations and faults.
- Building Occupants Visualization Module: raises the awareness of the occupants on the energy performance of their building and encourages them to adapt their behavior, i.e., actions on the HVAC or lighting systems, actions on windows and shading systems, etc.
- BIM Visualization Module: provides an easy to use 3D platform to access and visualize building related data, i.e., historic and live data collected from the building sensors.

Also, this level allows the definition of several basic configurations (e.g., registering new building related information, setting the frequency data time acquisition, etc.), the monitoring of data quality, and the configuration of alerts.

### *3.5. Back-End level*

It is responsible of extending both the Core Platform and Management levels functionalities. It permits to add or modify i) the basic services, ii) the APIs functionalities, iii) the data model concepts and properties, and iv) the drivers and connecters functions. It also extends the Management level services through the app extender service that allows adding new applications/modules to the framework, and updating the existing ones with new features.

## 4. Conclusion and ongoing work

In this paper, we presented an energy management framework defined in the context of HIT2GAP, an EU-funded H2020 project. It is a generic, modular, and scalable environment that provides several web services to manage buildings energy behavior during their operational phase. From heterogeneous data collection, to data preparation, structuring, and advanced processing, the provided services target various buildings actors' profiles through adaptable visualization interfaces. With these potentials, the proposed framework is able to optimize building energy performance, improve systems operation, impact users' behavior, and thus reduce the Energy Performance Gap.

The solution, which is currently being developed, will be demonstrated in 4 pilot sites situated in 4 different European countries: France, Ireland, Poland, and Spain, covering different buildings typologies.

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