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Design and development of a Web based GIS platform for zero energy settlements monitoring

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Abstract

To support the next generation of multi-process big data and service-oriented computing, a Web-GIS platform is considered a viable solution for gathering and sharing of collected data from various case studies NZE settlements, so that the information flows are easily managed and interpreted, by means of spatial thematic maps related to specific levels of information, within the various case studies. Smart interoperable sensor networks installed in the various case studies' buildings, districts, and energy subsystems are prerequisites for the formulation of the physical layer of the monitoring platform. The aim of the present paper is to analyze the characteristics and architecture of a Web GIS Platform for Zero energy settlements monitoring.
The platform development is based on open software tools, targeting to be a flexible and interoperable tool for zero energy buildings and communities.

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1. Introduction

Improving the energy performance of the building stock is crucial in order to meet the long-term objectives of the climate strategy, as laid down in the European low carbon economy roadmap 2050 [1].
The requirements for moving from Net Zero buildings to a district level are even more demanding. Net Zero Energy

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(NZE) settlements should be places of advanced social progress and environmental regeneration, as well as places of attraction and engines of economic growth based on a holistic integrated approach, in which all aspects of sustainability are taken into account [2]. They will also support the efficient use of natural resources, economic efficiency and the energy efficiency in new and existing buildings.

The monitoring and evaluation of the zero energy settlements is an essential part of their success. To this end, the development of a monitoring platform for zero energy settlements monitoring and performance analysis platform is considered necessary.

In order to support the next generation of multi-process big data and service-oriented computing, a Web-GIS platform [3] is considered a viable solution for gathering and sharing of collected data from various case studies NZE settlements, so that the information flows are easily managed and interpreted, by means of spatial thematic maps related to specific levels of information, within the various case studies. Smart interoperable sensor networks installed in the various case studies' buildings, districts, and energy subsystems are prerequisites for the formulation of the physical layer of the monitoring platform. The Web-GIS platform is designed to the following levels for each case study:

- Level 1: Indoor Environmental Quality of Buildings' Users. This includes thermal comfort [assessed by Predicted Mean Vote (PMV) and Percentage of People Dissatisfied (PDD) indices], visual comfort and indoor air quality [4].
- Level 2: Energy demand profiles for buildings and district (public lighting). The measured energy demand and consumption profiles are collected at this level[5].
- Level 3: Energy production technologies monitoring level. At this level, the energy flows within the energy production subsystems for each case study is monitored. The electrical and thermal parameters of each technology are gathered and analyzed.
- Level 4: The Integrated Resources Management Level and Dashboard. The design of this level allows the monitoring of the overall district/case study following smart grid's configurations. This specific level allows the effective management of energy demand and production profiles in order to achieve the various zero energy objectives.

The aim of the present paper is to analyze the characteristics and architecture of a Web GIS Platform that supports the following activities:

- Assessment of the performance of the involved systems and technologies and also the global energy and environmental performance of NZE settlements.
- In-depth analysis of the results of the monitoring and generation of proper technical information for future feasibility analyses and design.
- Development of the NZE monitoring platform based upon the monitoring protocols for the energy production technologies and subsystems, developed for both, building and settlement level.

The WEB GIS platform is developed in the framework of Horizon ZERO PLUS project (http://www.zeroplus.org/) in order to support the monitoring and data acquisition of four zero energy settlements: in Cyprus, France, Italy, and UK.

2. The layout of the Web GIS monitoring platform

The overall layout of the monitoring platform is depicted in Figure 1 and is comprised of:

- The monitoring devices and data acquisition units at building and at settlement level. In Figure 1, they are represented with each case study flag.
- The Cloud Server which incorporates:
  - The database for storing the monitoring data of each settlement.
  - The spatial database for the geographical data of each settlement.
  - The GeoServer for displaying the geographical data.

- The Application Server which communicates the data to the end user and the Front End of the NZE settlements monitoring platform.

- The Communication system between the data acquisition units and the Cloud Server.

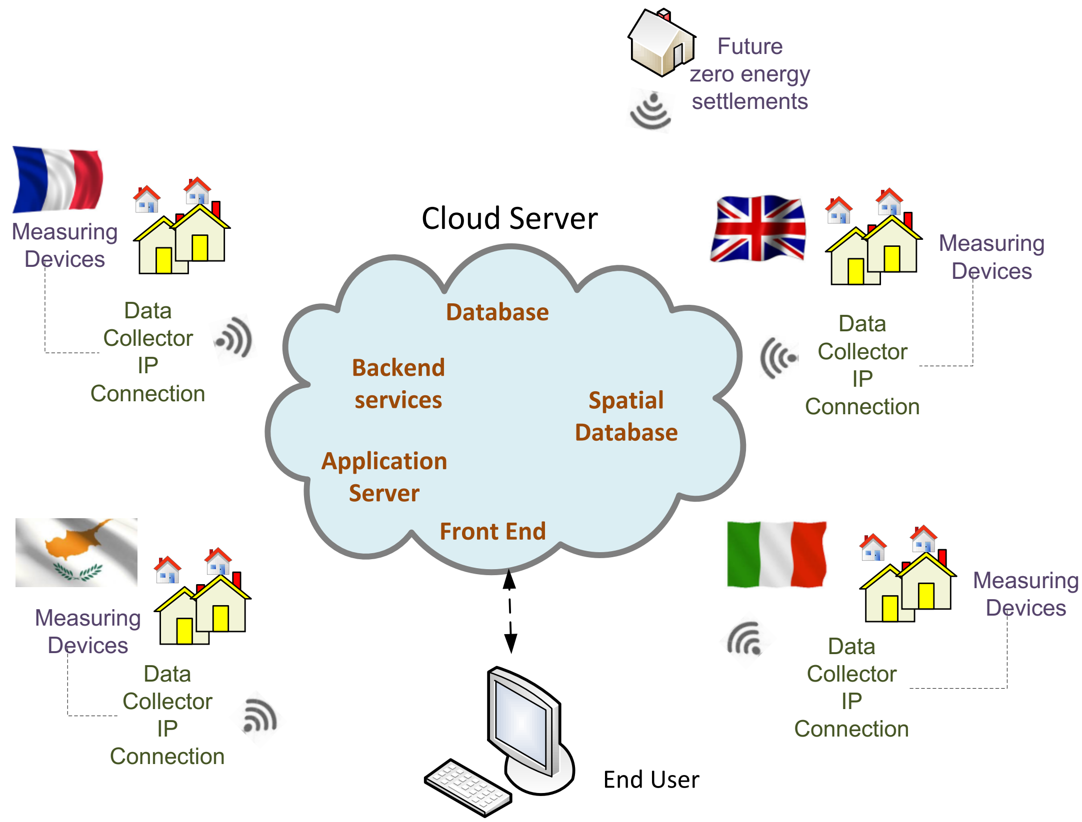

Fig. 1: Overall layout of the Web-GIS monitoring platform

3. Monitoring and Data Acquisition

A large amount of data is necessary to be collected in each settlement. A common description and reference of the data collected from the settlements have been elaborated in order to reduce the complexity of the Web-GIS platform. A detailed list of all measurements and the related Level of Web-GIS platform are tabulated in Table 1. The list includes the measurements for the indoor environment of the settlement's buildings, the energy consumption of the buildings, the energy production technologies and subsystems, either integrated into the buildings or at the district level, as well as the external meteorological conditions.

Table 1. Sensor measurement table ID

ID	Level	Description	Measurement unit
1	1	Space temperature	°C
2	1	Space relative humidity	%
3	1	Space CO2 level	ppm
4	1	Space occupancy	0/1

ID	Level	Description	Measurement unit
5	1	Space Illumination	Lux
6	2	Space equipment electric power	W
7	2	Space equipment electric energy consumption	Wh
8	2	Space light electric power	W
9	2	Space light electric consumption	Wh
10	2	Space HVAC electric power	W
11	2	Space HVAC electric consumption	Wh
12	3	PV electric power	W
13	3	PV electric energy production	Wh
14	3	Wind turbine electric power	W
15	3	Wind turbine electric energy production	Wh
16	3	Other renewables electric energy power	W
17	3	Other renewables electric energy production	Wh
18	3	Other renewables thermal power	W
19	3	Other renewables thermal energy production	Wh
20	3	SB-Skin (PV in envelope) electric power	W
21	3	SB-Skin (PV in envelope) electric energy produced	Wh
22	2	Building equipment electric power	W
23	2	Building equipment electric consumption	Wh
24	2	Building light electric power	W
25	2	Building light electric consumption	Wh
26	2	Building HVAC electric power	W
27	2	Building HVAC electric consumption	Wh
28	2	External light electric power	W
29	2	External light electric consumption	Wh
30	2	Building thermal energy consumption	Wh
31	2	Building oil consumption	m^3
32	2	Building gas consumption	m^3
33	2	Building electric power (consumption)	W
34	2	Building electric consumption	Wh
35	2	Building electric power (production)	W
36	2	Building electric production	Wh
37	2	Building power	W
38	2	Building energy consumption	Wh
39	2	Building energy production	Wh
40	2	Settlement outdoor light power	W
41	2	Settlement outdoor light electric consumption	Wh
42	2	Settlement buildings electric power	W
43	2	Settlement buildings electric energy consumption	Wh
44	2	Settlement building thermal power	W
45	2	Settlement building thermal energy consumption	Wh

ID	Level	Description	Measurement unit
46	3	Settlement PV power	W
47	3	Settlement PV electric energy production	Wh
48	3	Settlement Wind turbine power	W
49	3	Settlement Wind turbine electric energy production	Wh
50	2	Settlement total electric power (consumption)	W
51	2	Settlement total electric power (production)	W
52	2	Settlement total thermal energy production	Wh
53	2	Settlement total energy production	Wh
54	2	Settlement total energy consumption	Wh
55	1,2	Outdoor air temperature	°C
56	1,2	Relative humidity	%
57	1,2	Wind speed	m/s
58	1,2	Wind direction	Degrees
59	1,2	Rain	mm
60	1,2	Global radiation on horizontal surface	W/m^2

The local data acquisition (DAQ) unit in each settlement should have the ability to interconnect to the various sensors using different protocols (wire or wireless) in order to measure all the required measurements. Also, DAQs must have the ability to transfer the measurements via Internet IP connectivity. The communication between the settlements' DAQs and the Web-GIS platform is described in Section 4.

4. Description of the Cloud Server

The Cloud Server is the heart of the Web-GIS monitoring platform and supports the data management, as well as the security and visualisation of the ZERO PLUS system. The operating system of the Cloud Server is the Debian distribution of Linux [6], due to the following characteristics:

- It is open-source.
- It supports the latest release of various open source programs and libraries.
- It inherits security features.

The Cloud Server is comprised by the parts described in the following paragraphs and depicted in Figure 1.

4.1. The database for storing the monitoring data of each settlement

The database holding the measurements data (see Table 1) fulfils the following requirements:

- Variability of user access levels to ensure security of the data.
- Ability to store different data objects, such as files, floats, photos, maps, etc.
- Interconnection with several software and programming languages, such as Java, C, JavaScript, PHP, etc.
- Supports various database management systems that are available and ready to be used for any specific application.

The PostgreSQL is selected to support the data storage of the Web-GIS monitoring platform.
Three different user account types provide access to the data stored in the database, ensuring the platform's security:

- Account type 1: Administrator. This account has full access to all functionalities.

- Account type 2: Internal account. This allows the communication of the Cloud Server with the Data Acquisition Units.
- Account type 3: Internal account. This allows the communication of the database with the Application Server.

The database entities include building and settlement level information for all monitored parameters and are tabulated in Table 1.

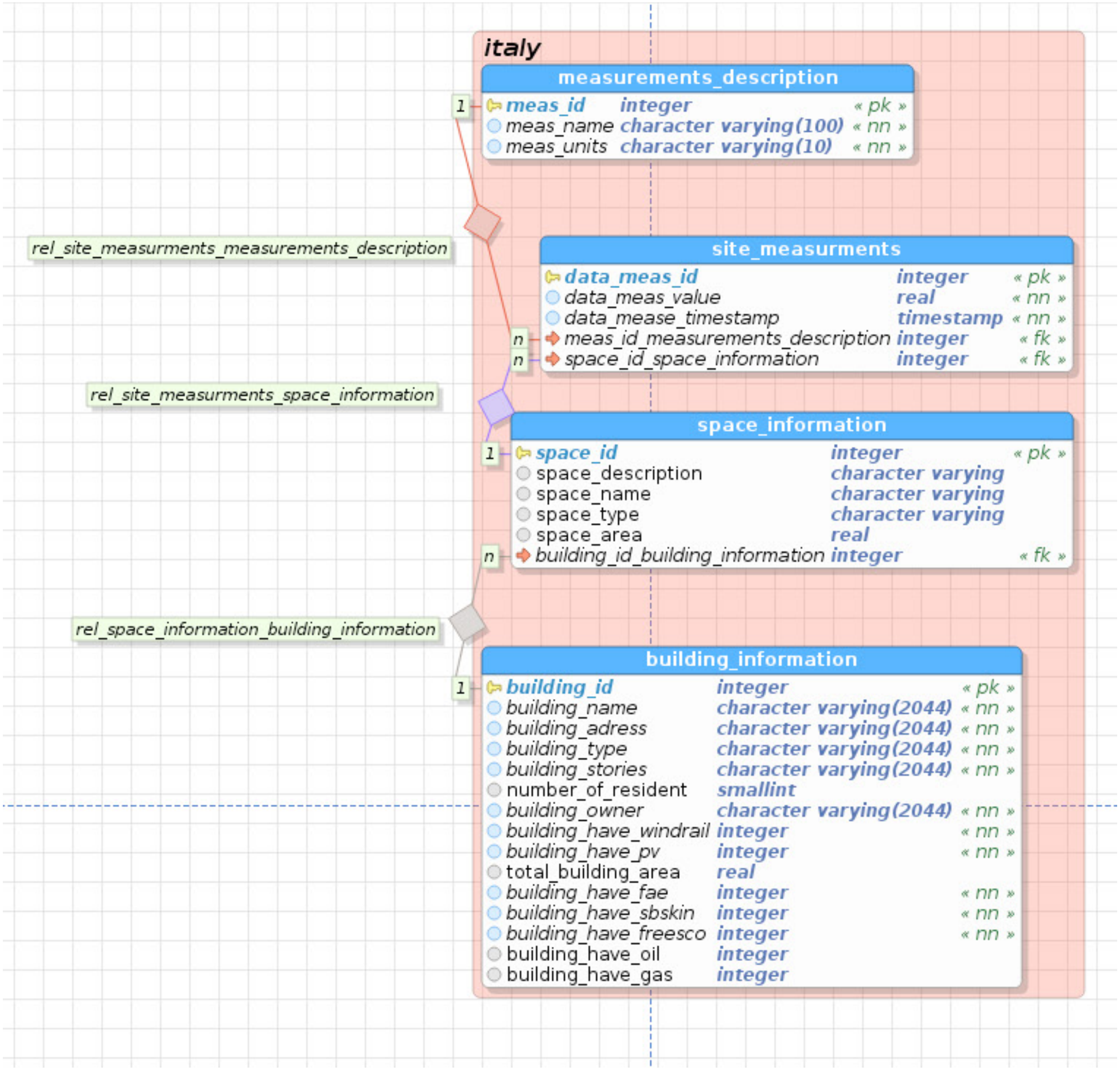

Fig. 2: The Data Base schema

4.2. The spatial database for the geographical data of each settlement

The spatial database includes the following data:

- Geographical data extracted from the OpenStreet Map Project [7].
- 3D models of the four ZERO PLUS buildings and energy production technologies.

The specific feature supports the visualisation and spatial distribution of the ZERO PLUS measurements in geographical maps (see Figure 3).

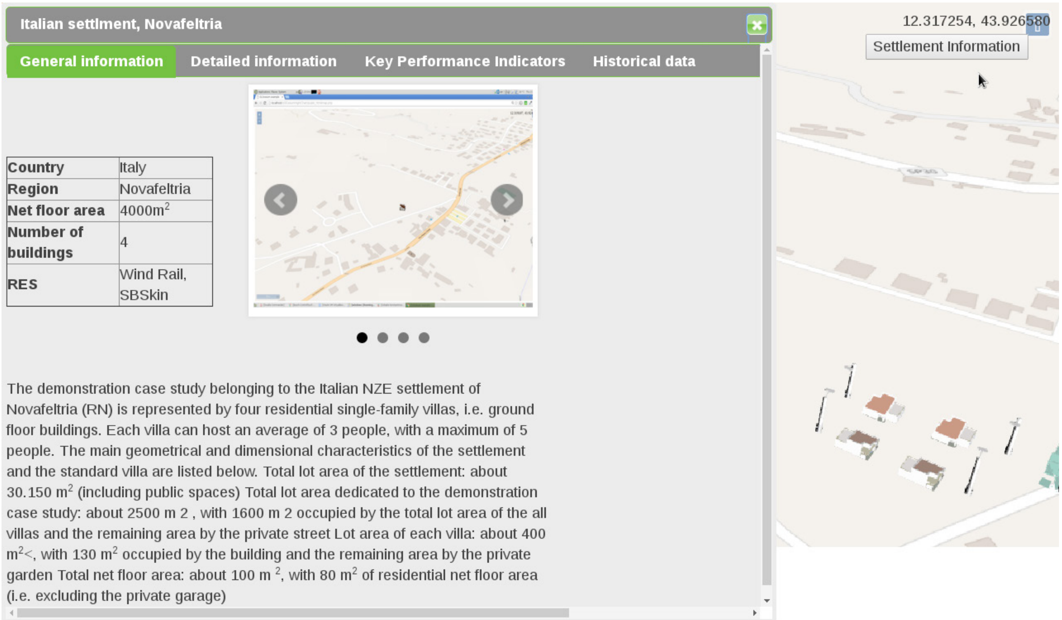

Fig. 3: The spatial database visualisation

4.3. The GeoServer for displaying the geographical data

The GeoServer is introduced to manage the spatial data stored in the spatial database and provides the final image visualised by the end user [8](see Figure 3). The GeoServer should:

- Support various types of spatial data format (vector, raster, KML, ESRI Shapefile, GeoJSON datasets).
- Implement the various services required for the visualisation such as the Web Map Service, the Web Coverage Service and the Web Processing Service.
- Support a web-based interface for its own configuration.
- Provide editing facility for all types of geospatial data.

The following geospatial data servers were examined and tested for the needs of the monitoring platform:

- GeoServer
- MapGuide Open Source
- Mapnik
- MapServer

Finally, the GeoServer is selected, because it serves most of the above requirements.

4.4. The Application Server

The Application Server communicates the data to the end user via the Front End of the WEB GIS monitoring platform. It is comprised of the parts described in the following paragraphs.

The Front End of the monitoring platform
The Front End is designed to allow the visualisation of the monitoring data using any web-browser, such as Internet Explorer 9 and higher, Firefox Mozilla, Google Chrome, etc. Therefore, the data visualisation does not require any installation of extra software.
The Front End should:

- Require low memory and computational power.
- Support various types of spatial data formats (GeoJSON, Web Map Service, ESRI Shapefile).
- Support complex 3D models with small size files.

The following Front Ends were examined and tested for the needs of the WEB GIS monitoring platform:

- Geomajas
- OpenLayers
- Leafletjs
- GIScene.js
- Leafletjs
- Turfjs
- OpenLayers – Cesium

Finally, the libraries OpenLayers – Cesium are chosen as the more efficient option.
Data visualization
The data visualisation feature supports all various chart types, i.e. Basic line with data label, time series, Spline graph, Area graph, Stacked and grouped column, Pie chart, Gauges, Heat maps, etc.
The following three visualisation libraries were tested for the data chart types:

- D3's
- Fusioncharts
- Highcharts

The Highcharts is selected as the most efficient library for the specific application [9].
In Figure 4, the interconnection of all the above different hardware and software tools and technologies for the Cloud Server is illustrated.

5. Description of the Communication system

The communication system must comply with specific standards in order to ensure interconnection of the settlements' components and technologies (via the DAQs) with the Web-GIS monitoring platform. An overview of the communication system is illustrated in Figure 5. The communication system consists of:

- The communication protocol between the DAQ and the Cloud Server.
- The communication protocol between the Front End and the end user.
- The communication protocols between the various parts of the Cloud Server.

The interconnection between the DAQ and the Cloud Server is based on Transport Layer Security (TLS) protocol which ensures data privacy and safety. The implementation of the TLS protocol is based on the HTTPS protocol, as depicted in Figure 5.
All the measurements gathered by the local DAQs must be transmitted to the Web-GIS monitoring platform following one of the next services:

1) Using the web services provided by the local DAQ.
2) Using Machine2Machine (M2M) communication by the local DAQ to the Web-GIS monitoring platform
3) Implementing the developed Application Programming Interface (API) by the local DAQs.

In order to use any of the above services, the transition channel must be encrypted in order to ensure the anonymity

and privacy of the settlements' users.
The communication protocol between the Front End and the end user is performed via Internet using secure transfer protocols. The various end user categories have specific privileges for security purposes:

1. Administrator: access to all available data form all settlements and capability to modify the database.
2. Researchers: they have only read access to all available data from all settlements.
3. Building owners: they have access to their own building data.
4. Public account: access only to average values without specifying the building owners' details.

The communication between the various parts of the Cloud Server is implemented using their APIs and services.

6. Navigation on the Web-GIS ZERO PLUS Platform

When accessing the Web-GIS monitoring platform through any web browser. Then, after typing in the users' credentials, the user is moved to the map of Europe, where the ZERO PLUS settlements are pinpointed (see Figure 6).

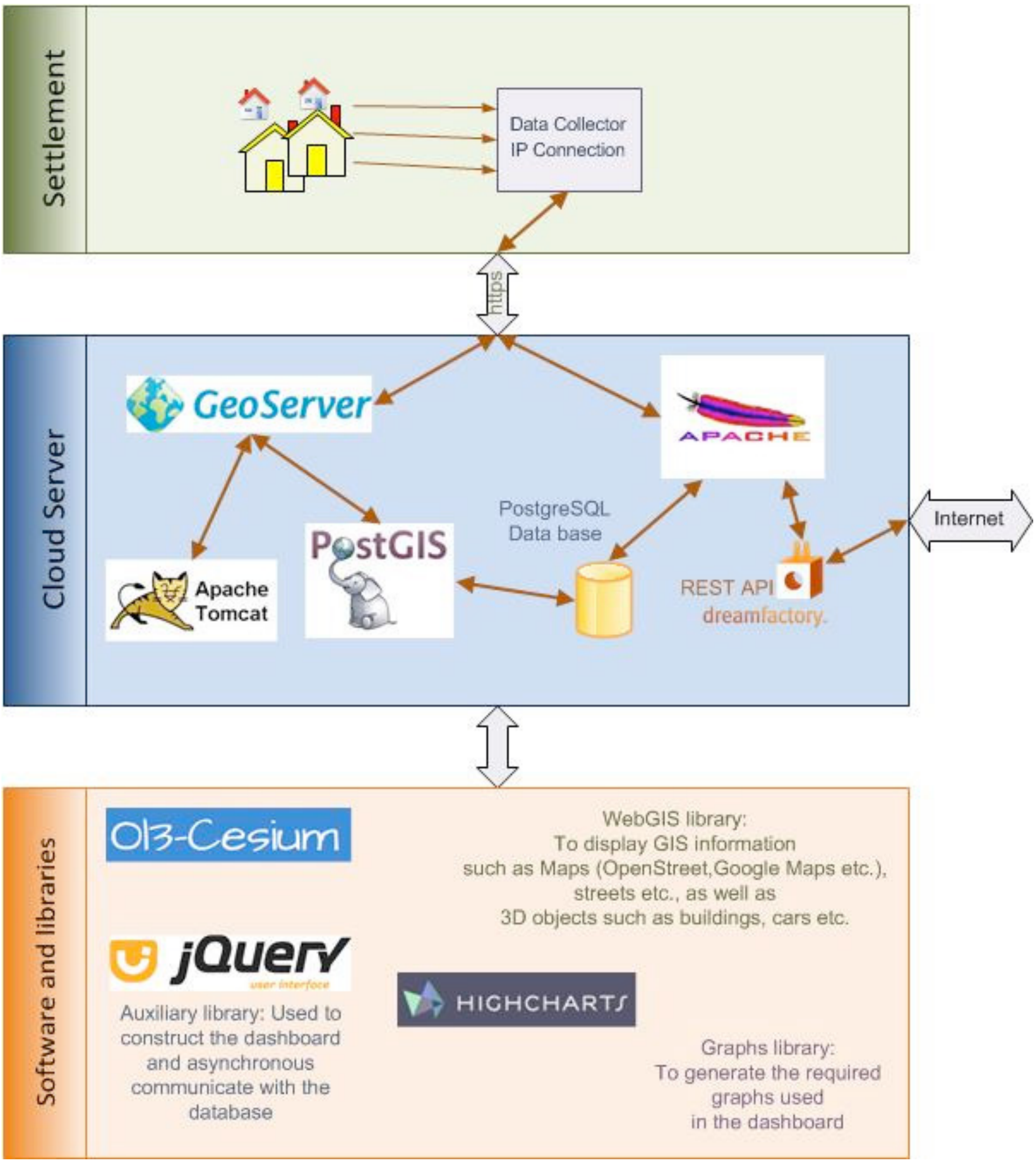

Figure 4: Detailed structure of the Cloud Server

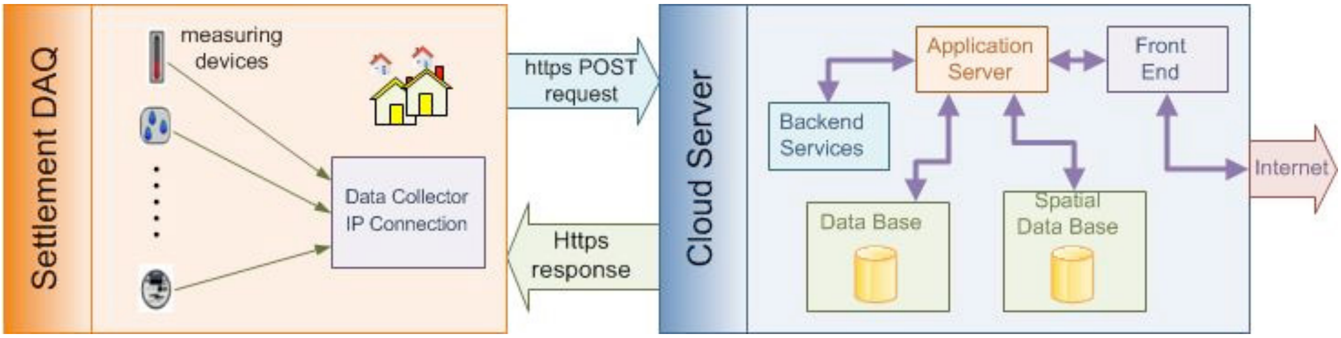

Figure 5: Communication protocols overview

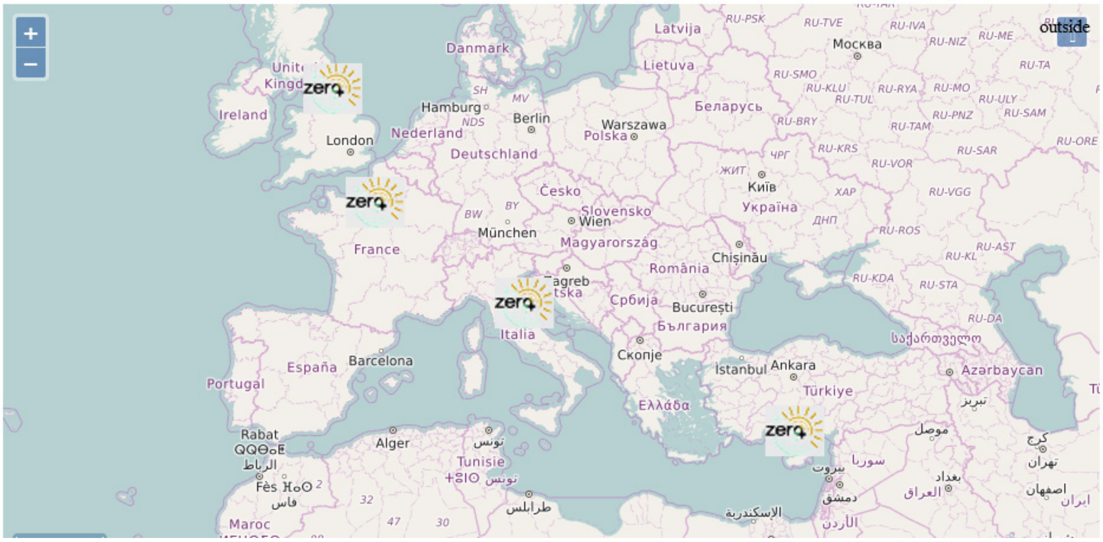

Figure 6: Case studies located on map

The structure of the Web-GIS platform is illustrated in Figure 7, where all four levels are displayed for each case study (details in Figure 8).

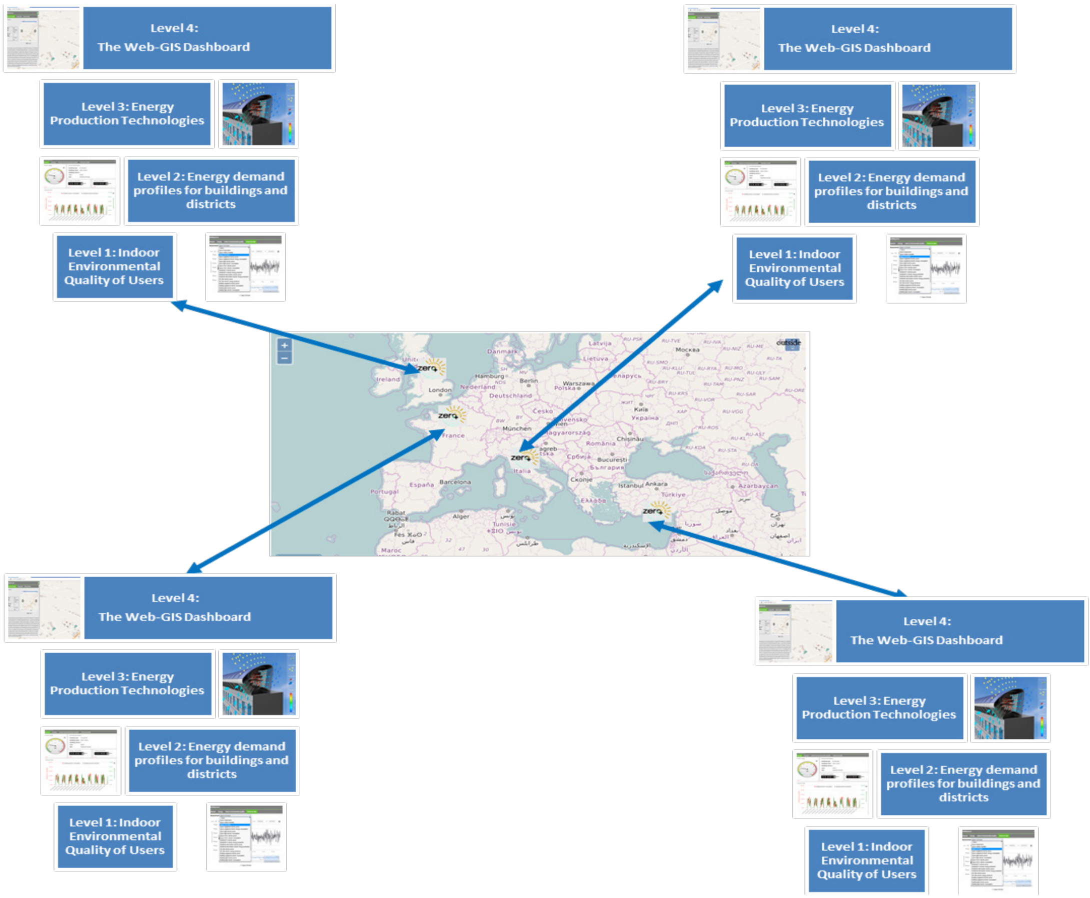

Figure 7. The layout of the Web GIS platform

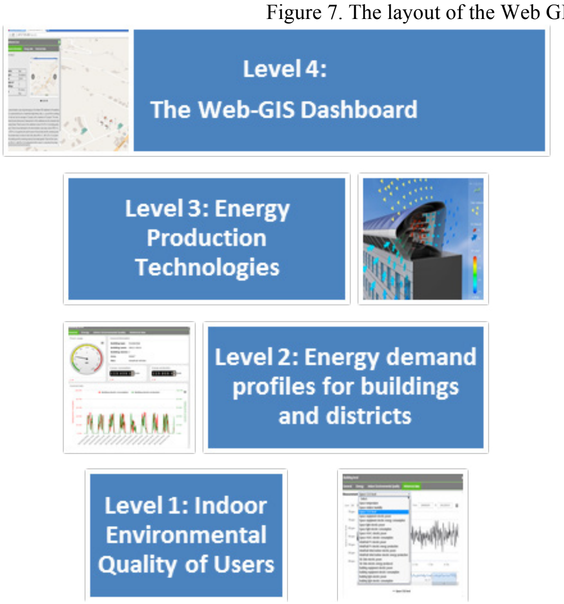

Figure 8 : The four levels of Web GIS for each case study

7. Conclusions

A WEB GIS data monitoring platform is developed for the data gathering of zero energy settlements. The platform development is based on open software tools, targeting to be a flexible and interoperable tool for zero energy buildings and communities. The Web GIS platform will be interconnected with four settlements in European level.

8. Acknowledgements

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