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Research and Innovation Action

CleAnweb Gamified Energy Disaggregation

D3.5 Integrated ChArGED system for real life evaluation

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Abbreviations

API	Application Programming Interface
BLE	Bluetooth Low Energy
IoT	Internet of Things
JSON	JavaScript Object Notation
kWh	Kilowatt hours
MVP	Minimum Viable Product
mPRM	mPower Remote Manager
MQTT	MQ Telemetry Transport
NFC	Near Field Communication
SSL	Secure Sockets Layer
SQS	Simple Queue Service
TCP	Transport Communication Protocol
TLS	Transport Layer Security
REST	Representational state transfer
UI	User Interface

Executive Summary

This deliverable presents the integrated system of ChArGED that is used for real life evaluation and is related to the integration, validation and testing task of WP3. The emphasis is on achieving efficient and low-overhead integration of all sub components (backend systems, gateways and Mobile App).

Technical testing/validation mechanisms takes place prior to providing the deliverables to end-users for validation, to make sure that, as subsystem development is progressing, there are no unforeseen integration issues and technical problems.

The deliverable complements the work done in Deliverables 3.4 "1st Integrated Charged System", that proved the initial integration of all the components and was demonstrated at the first review meeting.

The deliverable implements the prioritised ChArGED challenges, the game concepts and will be used for the validation period. During this period more challenges will be added. It further describes the system architecture and software implementation details for the Data/Core Backend components and how all these evolved for the new integrated version. The document also provides a description of the integrated system demonstrator and indicative screenshots of an end-end challenge implementation that involves all integrated modules. Finally, the deliverable describes the procedure for performing the testing of the ChArGED platform to demonstrate that the ChArGED system implementation meets requirements established in the technical deliverables.

The real application is downloadable at the project website. A video also demonstrates the function of the game which is published on the. This is available to the public in the following address:

https://drive.google.com/file/d/11hwHPMpCWStzvhCF3MProtvrQhdGwGxU/view

The app is also downloadable at the googleplay but this is distributed in a private mode, upon email request. This is due to the fact that the app is not functional without the additional installations necessary at the buildings, which means that the public will not be able to play the game.

https://drive.google.com/open?id=11hwHPMpCWStzvhCF3MProtvrQhdGwGxU

1 Introduction

Purpose and scope

The goal of D3.5 follows the D3.4 and D3.7 which have been submitted at M18 and includes a description of the revised Mobile App and of the related Game challenges that have already been implemented, based on the game design principles that have been detailed in deliverable D3.7 "Incentive mechanisms final report" (submitted at M18).

Intended Audience

The purpose of this deliverable is to document and demonstrate the first ChArGED integrated system.

The intended audience includes the project partners, especially the pilot users and the general interested public. Members of the development team can use this report as guideline for future work.

This report also provides clarity on the ChArGED integrated system that will be deployed at public buildings through various installation stages and also shows the working modules that can be used for hands-on system demonstration and evaluation by the intended public buildings.

Relation to other activities

The integration between the backend system, the gateways and the Mobile App will be still on-going process, following agile methodology approaches and enriching the challenges with new ones which will be implemented during the validation year.

Technical testing/validation mechanisms took place prior to providing the deliverables to end-users for validation, to make sure that there are no unforeseen integration issues and technical problems.

Table 1: D3.4 dependencies and handovers

ID	Title	Comments
D3.7	Incentive mechanisms final report	It provides the design principles to be integrated within the game mechanics component and affects the chosen game challenges.
D3.2	Architecture and system components specification	It describes the initial system architecture and design of system components and interfaces that will also be followed for the 1st integrated system.
D3.3	System Components	This document provides an accompanying guide on the developed software components that are considered for the 1st integrated system.

D4.2	Trials specifications	It provides the specifications of the system components that will be tested at various stage of the piloting exercise, affecting the choices for the 1st integrated system..
D3.4	1st integrated Charged System	It supports the first integrated prototype with description of the integration steps and results.

Document Overview

The deliverable is the demonstration of the integrated version of ChArGED system which goes for real life validation with the end users. This document provides an accompanying description for this demonstrator and give an update on the evolution of the system components and the integration process for 5 complete game challenges. It is organised as follows:

Chapter 2 presents a review of the ChArGED approach, the game concepts, the related use cases and challenges that will be addressed with the integrated system.

Chapter 3 describes the system architecture and software implementation details for the Data/Core Backend components that are included in the integrated system for the full validation.

Chapter 4 provides a description of the integrated system demonstrator and indicative screenshots of an end-end challenge implementation involving all integrated modules.

Chapter 5 describes the methodology for performing the testing of the ChArGED platform to demonstrate that the ChArGED system implementation meets requirements established in the technical deliverables.

Finally, Chapter 6 concludes the document.

2 Review of the ChArGED concepts, use cases and game challenges

ChArGED approach

ChArGED (CleAnweb Gamified Energy Disaggregation) develops a gamified framework that aims to change occupants' energy-consumption behaviors and reduce energy wastage in public buildings. By leveraging low-cost IoT devices (NFC/BLE), ChArGED improves energy disaggregation mechanisms and identify energy wastages at the device, area and end user level. At the same time, it engages and motivates users with serious game approach accessible through a mobile app. The gamified approach in ChArGED advances the state of the art, since it will be employed in public buildings, where multiple appliances are shared among multiple users. Energy disaggregation in this context is particularly challenging due to the vast area that needs to be monitored and the difficulty of associating particular actions to specific users. In addition, other related applications, e.g., Kill-Ur-Watts, Energy Tracker, Watts Plus, etc., mainly focus on increasing energy-consumption awareness, assuming that the users are already interested in their energy consumption and motivated to reduce it. In a public building, employees are primarily busy with their job activities and moreover they do not pay the energy bill. Therefore, their engagement to such a game app cannot be taken for granted and thus a carefully-designed gamified approach has to be followed. There have been some prior efforts to employ serious games for demand side management [1], [2] in public/office buildings. "Energy Chickens" [1] evaluated the effectiveness of a virtual pet game in reducing plug-loads in a mid-size commercial office. Changes in device-specific energy consumption were reflected in the relative "health" of chickens in a virtual farm. ChArGED app has far more ambitious goals than [1] in the sense that it aims to change a vast range energy-wasting behaviors at work. Also, most efforts in [2] focus on boosting user awareness towards energy efficiency, as opposed to incentive building in ChArGED. The ChArGED app employs both direct incentives and peer pressure to achieve the desired behavior change towards energy-consumption reduction.
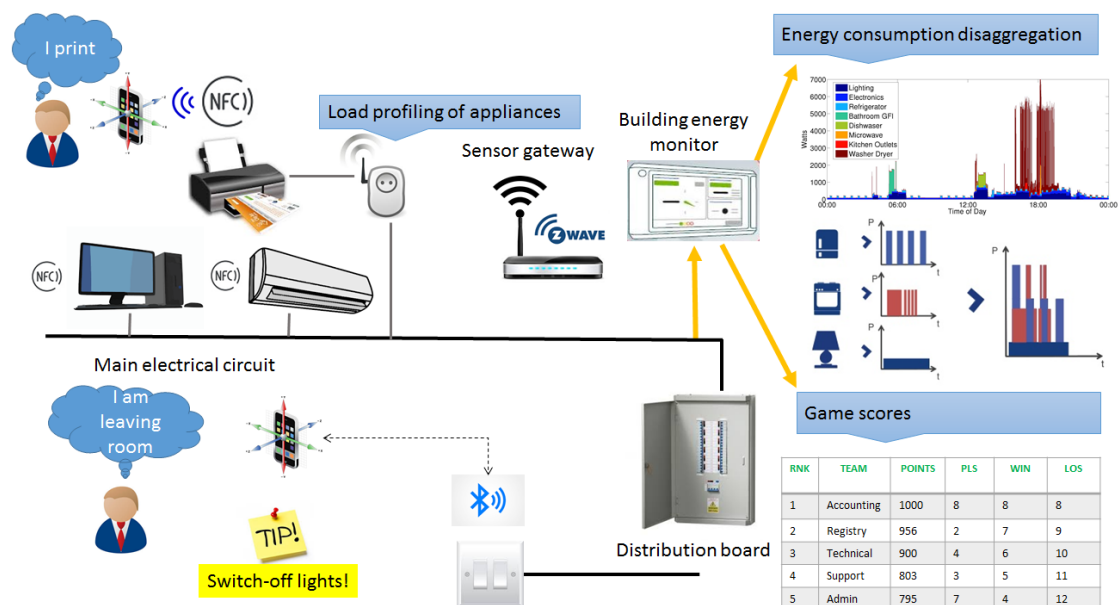

Figure 1 ChArGED approach

The game concept

The Charged Mobile app revolves around a main theme (persona) of a Tree. It shows both the persona as well as the informative parts (current score, team information, current challenge etc.) in a separate but thematically merged user interface The Mobile App includes an onboarding process, revolves around teams and is based on specific challenges that can be either pursued individually by each user or in teams. The user actions performed and validated by the ChArGED system will be rewarded. Rewards can be towards individuals and/or teams; they can also be inside (e.g. badges) or outside (e.g. real awards) the gamespace. The Mobile App also includes leaderboards showing the progression of individual members of the same team or the aggregate progression among different teams.

The core ChArGED concept revolves around a <u>virtual living and evolving main "Persona"</u>, in the form of a Tree, that represents the effects of the energy consumption behaviour of the cumulative users in terms of each (and groups) individual effect on all the energy consuming devices in their vicinity of operation".
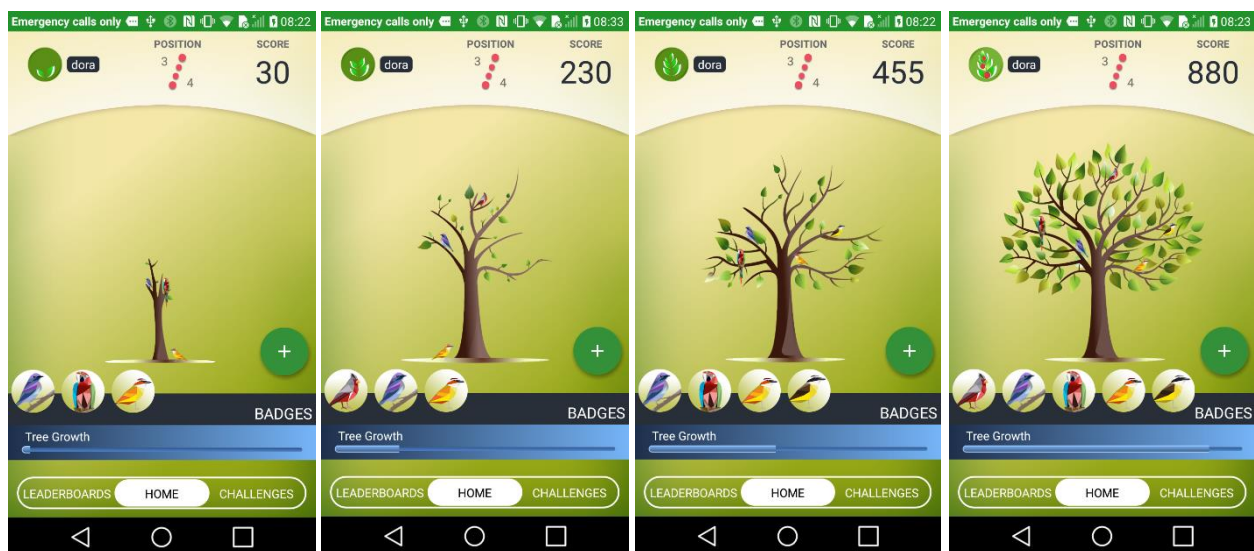
Figure 2 ChArGED UI including the Tree "Persona"

In order to achieve that feedback on energy consumption, the gamification outcomes of users' actions are directly shown to the end user and in parallel the virtual evolving persona accommodates in a graphical form the current state of the game/position or player/state of consumption etc. to create an emotional connection with the end user.

The ChArGED gamified app utilizes a two way on-boarding mechanism to ensure a smooth introduction of the end pilot users to the Mobile app. Initially users will be invited (by the person designated as Pilot Game Admin, at pilots' premises) to download the Mobile app and on first open, users are invited to "Create an Account" or "Login" to their account. Following registration, the game onboarding process begins.

Teams within the ChArGED game are formed with the following criteria:

- **Geographical:** Employees working in the same shared office space belong to the same team. In cases where a number of individual offices/rooms exist next to each-other, the employees may belong to a team competing vs other workplaces/buildings.

- **Role-oriented:** Employees of the same department / with similar, or the same, work description may be grouped in a team.
- **Device-oriented:** In cases where energy-consuming devices (such as printers / air-conditioners, lights, windows) are shared by employees, these users may be teamed together.

Employees will be assigned to teams by the administrator in the beginning of the game and as needed afterwards.

The comparison between teams will be made by their position in the team leaderboard, as well as relative notifications within gameplay. Such messages could read: "Congratulations to the TECHNICAL team for completing the morning challenge first today". "Congratulations to the TECHNICAL team for reaching the 10.000 points threshold" [3].

Types of challenges

Two types of challenges are being designed in order to be included in the Mobile App:

- **Personal challenges**: They are taken-up by individual participants and their outcome is mirrored on the participant's progress in the game, as well as incentives.
- **Team challenges**: They are taken-up by individual participants, but their outcome is mirrored both on the personal and team progress in the game, as well as incentives.

There is set of main challenges that runs over the course of the game and around which the game revolves. Several challenges can run in parallel. Each challenge is graded, according to the level of adherence. Indicative challenges are the following:

"Elevator up" challenge: Upon entering the building, the employees opt for using the stairs, instead of the elevator, to reach their office. (this behaviour is corroborated by swiping on NFC tags existing on the bottom and top of the stairs, while another tag exists inside the elevator cabin, to ensure that no cheating occurs).	Implemented in this version
"Windows" challenge: The users are prompted to close the windows when the air conditioners are on, or to close the air conditioners when the windows are open**.**	Implemented in this version
"Away" challenge: Whenever employees are away from their office, they are prompted to switch off any unnecessary devices that are forgotten on	Implemented in this version
"Lights and A/C off" challenge: The lights are switched off in the workspace by each team, by the last team member leaving their office. As team members switch off the lights, they swipe the corresponding NFC tags.	Implemented in this version
"Equipment off" challenge: Before leaving their desk, the employees turn off any equipment that isn't needed after hours (PCs, printers, etc), at the same time swiping their tags.	Implemented in this version
"Museum Visitors" challenge: This challenge will aim at involving the visitors at the MNHA museum. Since they will not play the same game as the employees, the objective will be to provide them an NFC sticker as they enter the museum (at the reception) and challenge them to use the stairs instead of the elevator. Every time the visitors use the stairs they will swipe their NFC	In process of being developed

sticker over a fixed device (a customized mobile handset fixed on a booth or on the wall in the middle of the stairs and will be scored accordingly. As they leave the museum they will be able to see their score and possible get a small gift (e.g. a museum poster) or other kind of reward in the form of a reduction, etc. The visitor will see the tree at the screen of the Museum and each time one visitor is using the stairs and confirming this by the NFC swipe, the tree will grow more and more. The NFC will be reset at the exit of the visitor to be reused for the next one.	
"Museum Guards" challenge: This challenge involves the control of lighting in the exhibition areas of the National Museum of History and Art (MNHA). Lighting in these areas is controlled by the light control room at the museum. The guards will play the game by notifying the control room on the occupancy of a certain exhibition room, so that the lights are switched off/on at that room. These notifications are sent by the guards via the mobile app of ChArGED. The control room has to respond to these notifications by taking the appropriate actions. This challenge was proposed recently by the MNHA and is currently under development.	In process of being developed
"Solar" challenge**:** This applies to the DAEM site that has a solar microgeneration system. The objective will be to motivate the employees to shift their energy consuming activities to the periods of high expected solar energy production (that will be provided with the solar power microgeneration forecast component.	The concept of the challenge is being redesigned following the review recommendations.

In each case the ChArgED platform validates the user actions (kWh decrease on energy measurements) and platform calculate the kWh savings to determine whether the user has completed the challenge and to provide a respective score to user.
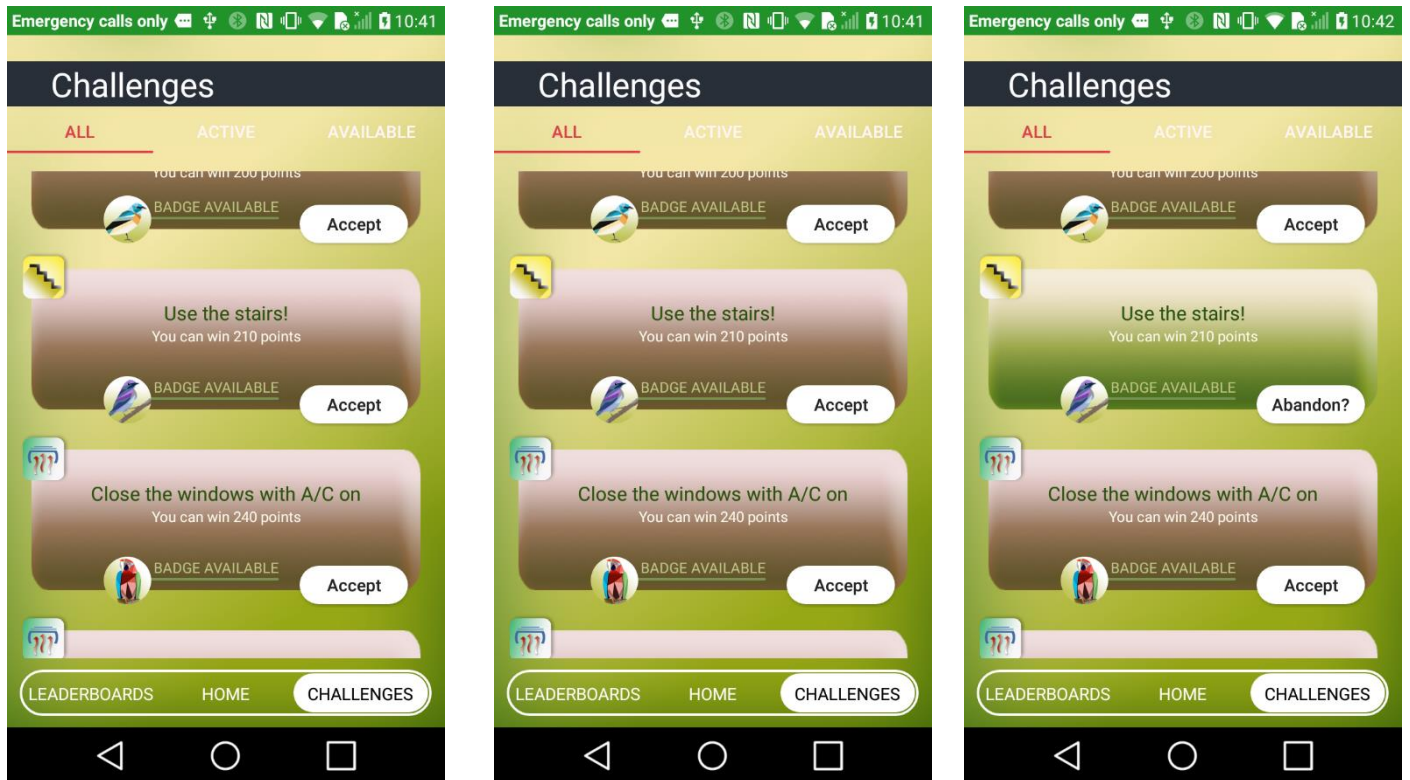

Figure 3 ChArGED UI including the list of challenges

Based on the aforementioned complete list of challenges, the ones that have been selected to be included in the 1st integrated system are:

1. **Personal challenges**
   a. Challenge users to switch PC off when going home. The steps towards the realisation of this challenge are:
      i. the platform engages a user to switch his/her equipment off when going home
      ii. the users swipe NFC sticker with mobile phone to say they're leaving
      iii. the platform validates actions (kWh decrease on energy measurements)
      iv. the platform calculates kWh savings and provides score to user
   b. Challenge users to switch PC off when going away for more than 30 minutes. Steps:
      i. the platform engages a user to switch his/her PC off when going away for long periods
      ii. the platform monitors with BLE when user leaves and returns to the room
      iii. the platform checks if PC has been left on during that period
      iv. the platform provides score to user (bonus points if PC was off or if user returned within 30mn, malus points if PC was on and user left for more than 30mn)
   c. C3. Challenge users to use the stairs instead of the elevators. Steps:
      i. the platform engages a user to use the stairs for a given period (e.g. one week)
      ii. the users swipe mobile phone to say they're taking the stairs

          iii. the users swipe mobile phone to say they're up the stairs (we can also consider the possibility to use only one NFC sticker in the middle of the stairs)

          iv. the platform validates actions (nobody in the elevator using BLE beacons and NFC stickers swiped)

          v. the platform calculates savings and provides score to user

2. Team challenges

    a. Challenge team to close (do not open) all windows if A/C is on. Steps:

        i. the platform engages a team to close all windows (keep windows closed) when the A/C is on.

        ii. the platform monitors if windows are open using switch sensors

        iii. the platform assigns points to team if windows are closed and A/C energy measurements show A/C is on

        iv. the platform requests team to close windows if A/C is found to be on

        v. the platform validates action (kWh on A/C energy measurements to check A/C on and sensors on window to check if open), but if no action taken after timeout period the team loses points (or gets no points)

    b. C5. Challenge team to switch lighting and A/C off in room after hours. Steps:

        i. the platform engages a team to switch off lighting and A/C when there is no one left in the office

        ii. the last user swipes mobile phone to say the room is now empty

        iii. the platform validates actions (kWh decrease on lighting and A/C energy measurements and nobody in the room using BLE beacons)

        iv. the platform calculates savings and provides score to team

3 Approach of the implementation of the system architecture and system components in the 1st integrated system

3.1 Integrated system architecture

The system architecture (depicted on Figure 4) has been developed, consisting of four main groups of functional blocks:

- The Data/Core Back-end group is responsible for providing an environment in which data, assets and users are stored and managed. The Back-end components provide the software infrastructure on which the ChArGED application is developed. That group of components is application agnostic, however it is tuned towards the needs of ChArGED project.
- The Gateway group is responsible for integration of energy use and environmental data to the Back-end system, to determine variations over the energy context within the building.
- The Analytics Back-end component is responsible for delivering insights that will enable the ChArGED application to deliver custom and targeted feedback and incentives to the end-users.
- The Gamification group is responsible for processing field data and insights created from such data and make decisions as to the evolution of the game for each user, i.e. what the next step is towards more energy savings. That group also delivers the mobile app the end-users interact with which acts as an interface between the user and the charged system updating the user with the current game state and also provides information to the system about the users' behaviour towards the energy saving goals set.

The architecture also includes an external system that is utilized to provide a solar power microgeneration forecast based on weather predictions for the specific location. It serves to maximize the building energy savings, increase end user awareness as well as to enable the use of the mobile app to maximize the solar-based electricity consumption during production, avoiding the need for energy storage.
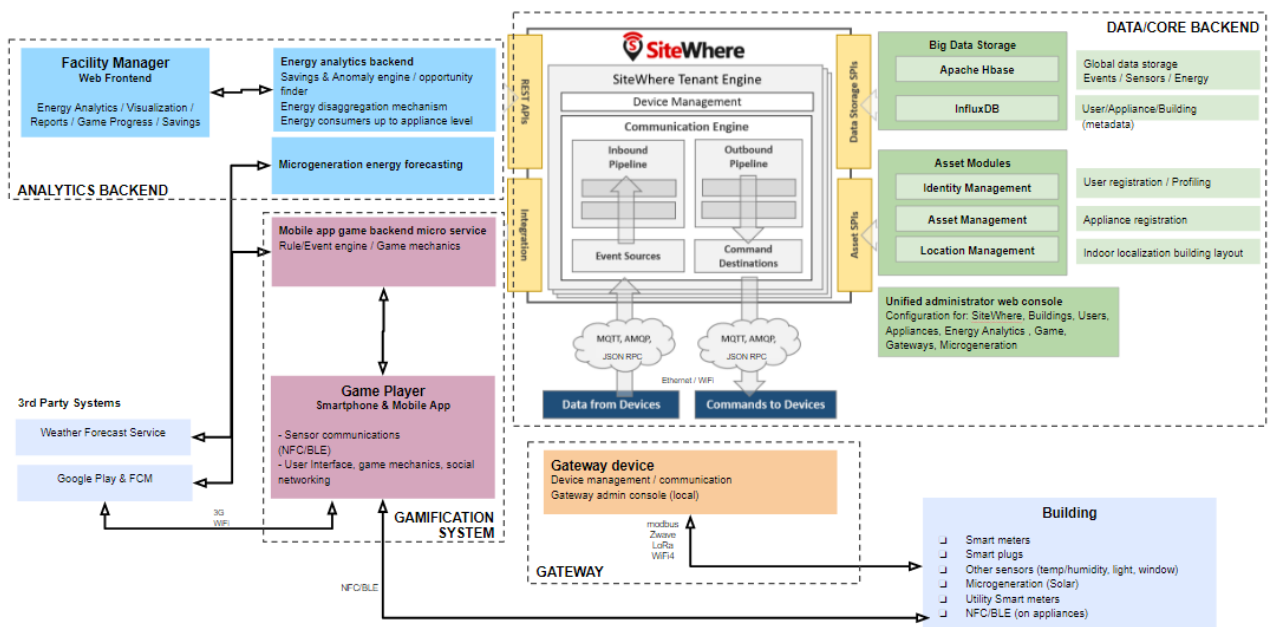

Figure 4 ChArGED system architecture

3.1.1 Data/Core Backend System

The Data/Core Back-end system components and infrastructure were implemented in SiteWhere [4]. This was chosen as the Data/Core Back-end system, as it provides an open-source platform with a number of rules and mechanisms for data exchange and operations. SiteWhere's main functionality is to supply a server-based JAVA SPRING middleware between the sensing infrastructure and the different system components and acts as a controller for the processing of device data. It connects with NoSQL & Timeseries databases in order to provide persistence of the sensor data and scales effectively with a large number of devices so that the whole sensor data history is maintained and can be accessed at any point. It also provides the entities management mechanism in order to structure the devices and categorize them according to their type, location and ownership and offers full control on a device's lifecycle (providing the functionalities of creating, deleting, updating, grouping, sending data). Moreover, it provides a web based administrative console application that allows all of the system data to be viewed and manipulated in a structured way which makes their overview and administration easier and more accessible. The available functionalities are the following:

● Each new asset or entity (i.e. a sensing device, an appliance, a specific location area, a person) is assigned a unique ID and can be autonomously monitored via external software. Specifically, a model for standard types of generated event data is provided for each device (which includes measurements, alerts issued and location updated by the device). The logged events are stored in massively scalable time series datastores (InfluxDB).

● Devices (appliances such as printers, air conditioners, a PCs etc) can be assigned to / associated with other entities. A device can be associated with a person, a location or another sensor device of our infrastructure thus giving us the ability to establish ownership room/location metadata and establish relationships with device.

● Devices can be grouped together according to a common role they fulfil, thus, enhancing efficiency by simplifying the way the devices can be retrieved by other backend processing services.

● Every top-level entity is modelled as a tenant and can have a completely different configuration and structure without affecting other tenants. This can be used for modelling infrastructures that are unrelated to each other such as different locations, different buildings, pilot users etc on the same server.

SiteWhere provides an extensive list of third party frameworks and software tools that can be interconnected in order to extend its capabilities. The options include different databases, identity management frameworks, event streamers, event processors, enterprise service buses and others. Moreover, being an open source software solution, new interfaces with other software tools and services can be created as needed. External communication with SiteWhere was achieved via a built in extensive REST APIs. A communication interface utilizing the MQTT protocol was also implemented to be used by devices and other embedded systems to send or get notified about new events and sensor data (e.g. NFC/BLE alerts and energy measurements).

The integration and connection of major system components as implemented is illustrated on Figure 5. The WSO2 Identity Server handles the identity management and user authentication, the Game Backend implements the logic to update the game progress of the users (i.e. score, completed challenges etc) by processing the users' actions, the Energy Analytics Backend performs estimations on user savings and is responsible for the energy monitoring of the building, and the mobile app acts as a frontend for the whole system and is the main point of interaction with the users.
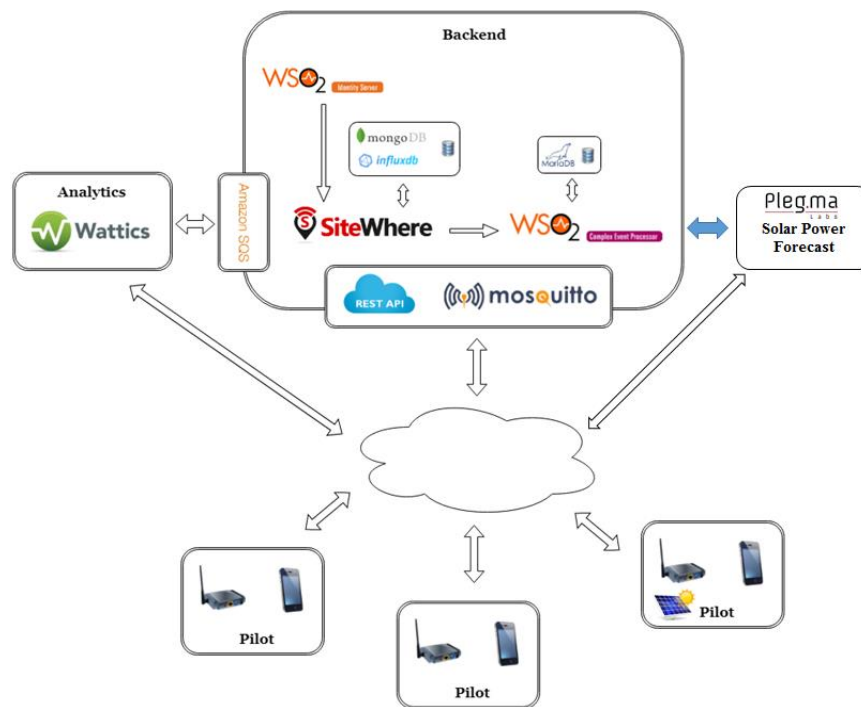
Figure 5 Organisation of SiteWhere System Components in ChArGED

WSO2 Identity Server is used for the creation, management, deletion and accessing of the user accounts. Its main functionalities include the following:

- *A sign in solution for the mobile app*

Users will need to sign in to the server through the app that will run in their smartphones. This allows their participation in the game challenges and offer personalized data to them (progress in a challenge, team information for group challenges, leaderboards etc). Persistent login functionality is provide to the users, i.e. so that users log in and then for a certain period of time they are remembered by the system so they don't have to frequently enter their credentials. WSO2 Identity Server adopts many state of the art open standards, used today by the industry, that provide user authorization/authentication (oauth2/openid connect, SAML2).

- *A user account provisioning tool*

WSO2 also handles the storage of the user credentials and user info on the server in a secure way. These data are imported by SiteWhere on the background to be used for creating the user entities.
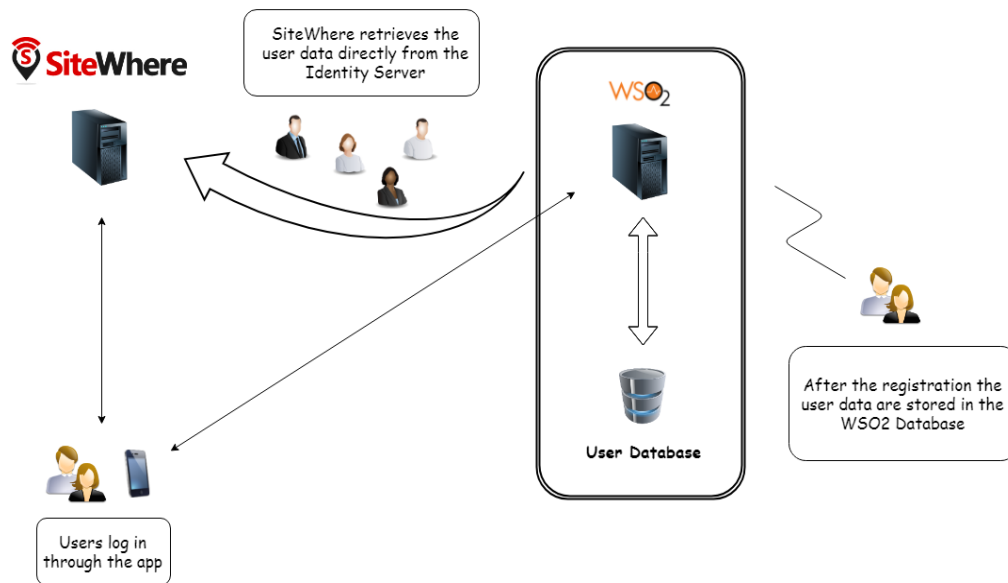
Figure 6 Capabilities provided by ChArGED Back-end

Devices and locations of the infrastructure are modelled as assets inside SiteWhere. In the case of the devices the asset provides a general description of the device (for example Printer). This asset was used to create a specification. Specifications also provide a general description of a device but are more specific that an asset (for example Printer Model). This specification then was used to create all the devices that exist in the infrastructure. For example, as described above, Asset -> Printer is used to produce a Specification -> Printer Model and then this specification can be used in order to create all the printers of the specific model in the building.

The devices can be inserted manually in the system by the site administrator through the graphical interface or created remotely through the SiteWhere API. This enables easily addition of a new device without access to SiteWhere's user interface as well as enable the possibility for devices to self-register when they are first integrated in the system. Locations can also be modelled as assets. The administrator can then associate the assets with devices to denote the room each device is in.
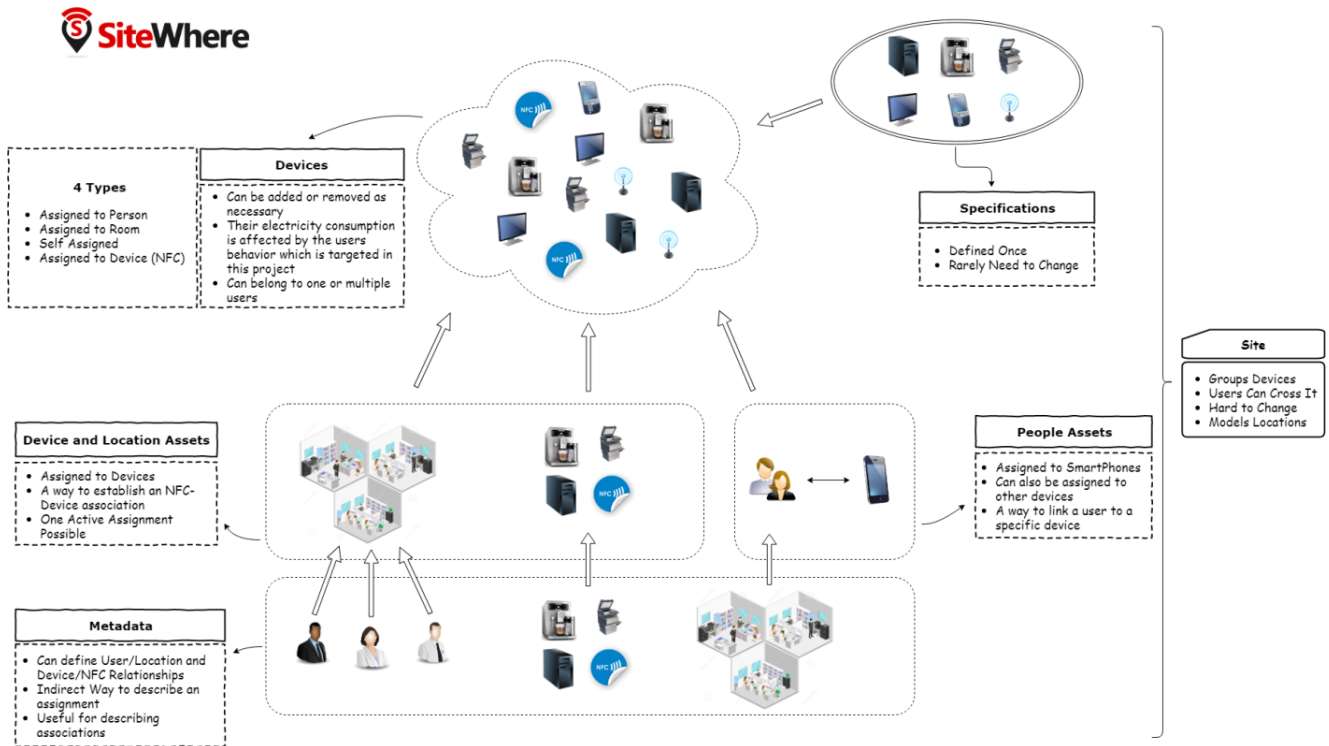
Figure 7 Asset management in the ChArGED Back-end

3.1.2   Gateway

To achieve the data acquisition process the Sensor Gateway has two connection interfaces within the global architecture, one with the building sensors (e.g. Smart plugs and Smart Meters) and another with the SiteWhere Data/Core backend. Various hardware and software requirements have to be fulfilled to support the needs of the platform. The Sensor Gateway software/middleware by Bosch Software Innovations is used as the basis of the Sensor Gateway. For the remote software management and provisioning of the product, the ProSyst Remote Manager (PRM) [5] is also used.

The Raspberry Pi (version 3 Model B) was chosen as the hardware basis for the Sensor Gateway. The Raspberry Pi is installed with a standard Raspbian OS, including the Oracle Java SE Runtime Environment (Java8), the Communications Device Class Abstract Control Model (CDC_ACM) USB to serial driver and, as mentioned before, the ProSyst mBS SH Runtime for ChArGED.

The data collection process required development of sensor drivers to retrieve data from third party sensors using industry leading communication protocols. For the connection of Z-Wave (Plus) devices, various controller options have been investigated, and two units have been selected: (1) "Razberry" GPIO Module for Raspberry Pi, (2) USB Z-Wave Controller.

Various Z-Wave devices were connected to the Sensor Gateway such as: (1) Fibaro Smart Plugs, (2) Fibaro 4in1 Sensor (Temperature, Humidity, Luminosity, Motion/Presence), (3) Fibaro Contact sensors.

These devices are managed by the mBS SH Runtime and included into the product portfolio, which allowed data to be immediately collected from the devices. The AcuRev 2000 multichannel Modbus

meter by Accuenergy and the Solar Inverter by Kaco was also connected to the Sensor Gateway via the Modbus protocol, to collect detailed energy measurements at the three pilot sites and the solar energy measurements at the DAEM pilot side. All connected devices communicate their data to the Sensor Gateway, which pre-processes and forwards it to the SiteWhere backend via MQTT.
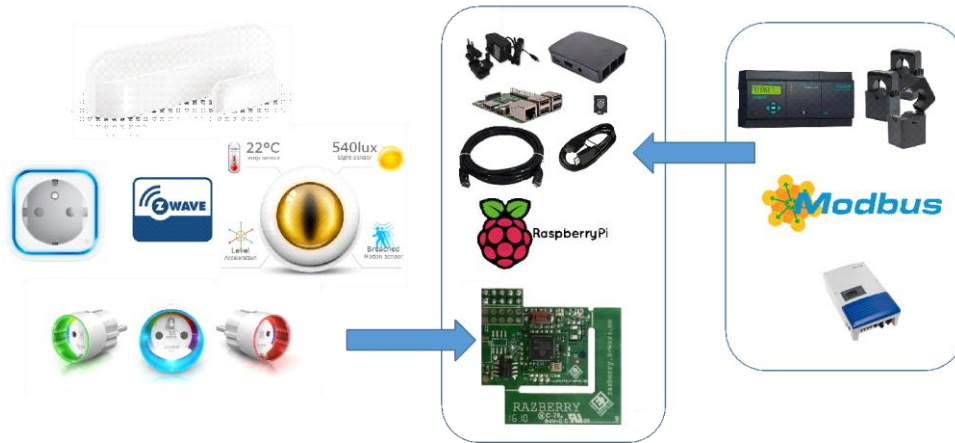

Figure 8 Illustration of the Sensor Gateway and interconnected devices and modules

For the management of the mBS Runtime the ProSyst Remote Manager (mPRM) backend is used. mPRM is a software and device management system developed by Bosch Software Innovations. mPRM enables lifecycle management of software bundles running in the mBS Runtime. Existing bundles can be updated, new bundles installed and depreciated bundles uninstalled. All of these actions are done during runtime, this means that all not affected bundles are actively running, while the specific bundles are processed. Therefore, a 24/7 runtime of the sensor gateway is achieved.
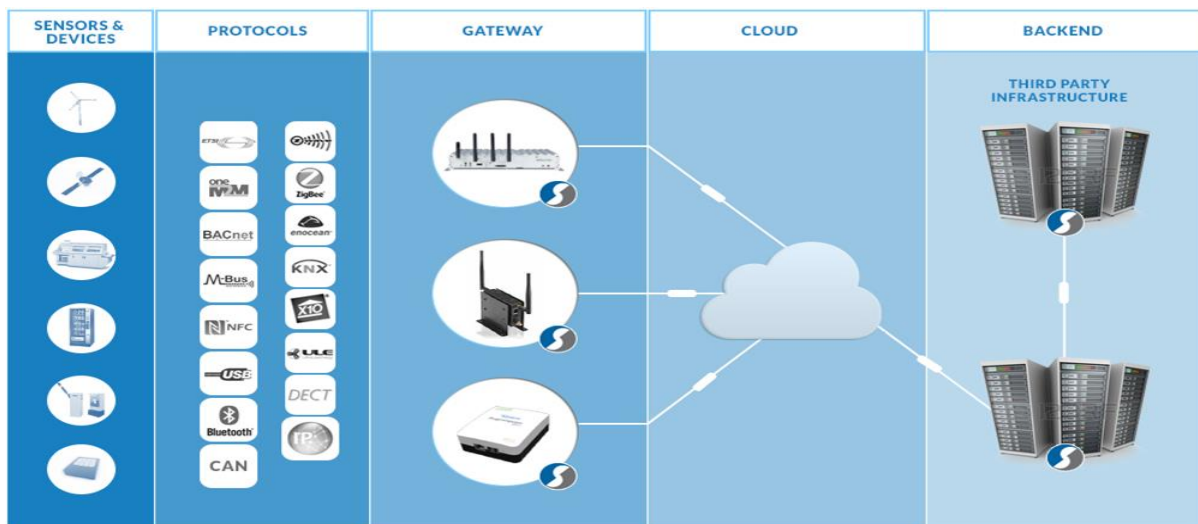

Figure 9 Typical IoT Architecture with mBS and mPRM

3.1.3   Analytics Backend

The Wattics Analytics backend is interfaced with the Sitewhere backend via RESTful web services, which allow energy measurements, NFC swipe alerts and BLE location events to be received as input, and measurements of load demand reduction and energy savings as well as energy saving opportunities to be returned. Authenticated data streams are processed in real-time through parallel analytics engines to produce valuable insights for the application.
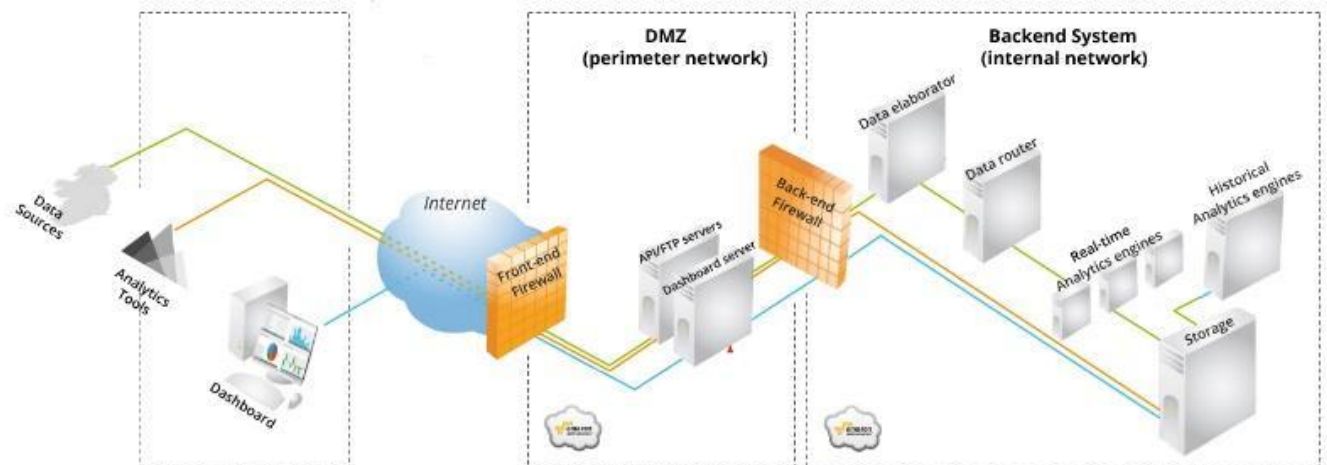

Figure 10 The Wattics Cloud Backend System Architecture

The Wattics backend infrastructure is brought to the project as background IP, and has been adapted to the needs of the project with the following additions:

● API endpoints to process NFC and BLE data packets.

● Analytics engine to validate control actions have been taken by users (e.g. device switched off when going home or when away for more than N minutes), and to estimate the energy savings achieved by such actions. In addition, the new Analytics engine is able to diagnose inefficient operation of electrical devices based on concurrent power activity (e.g. A/C left on when window is open), and to estimate the energy wasted due to such actions.

● Notification mechanism to export insights generated to Sitewhere. In addition to these extensions to the Wattics backend, a micro service was developed to reside in between SiteWhere and the Wattics Analytics backend to enable seamless integration of both backend systems via Amazon SQS.

The analytics component in charge of validating the control actions and estimating the savings generated. The following set of figures shows the intermediate steps for monitoring a building, gathering events and performing the necessary analytics actions to identify energy savings.
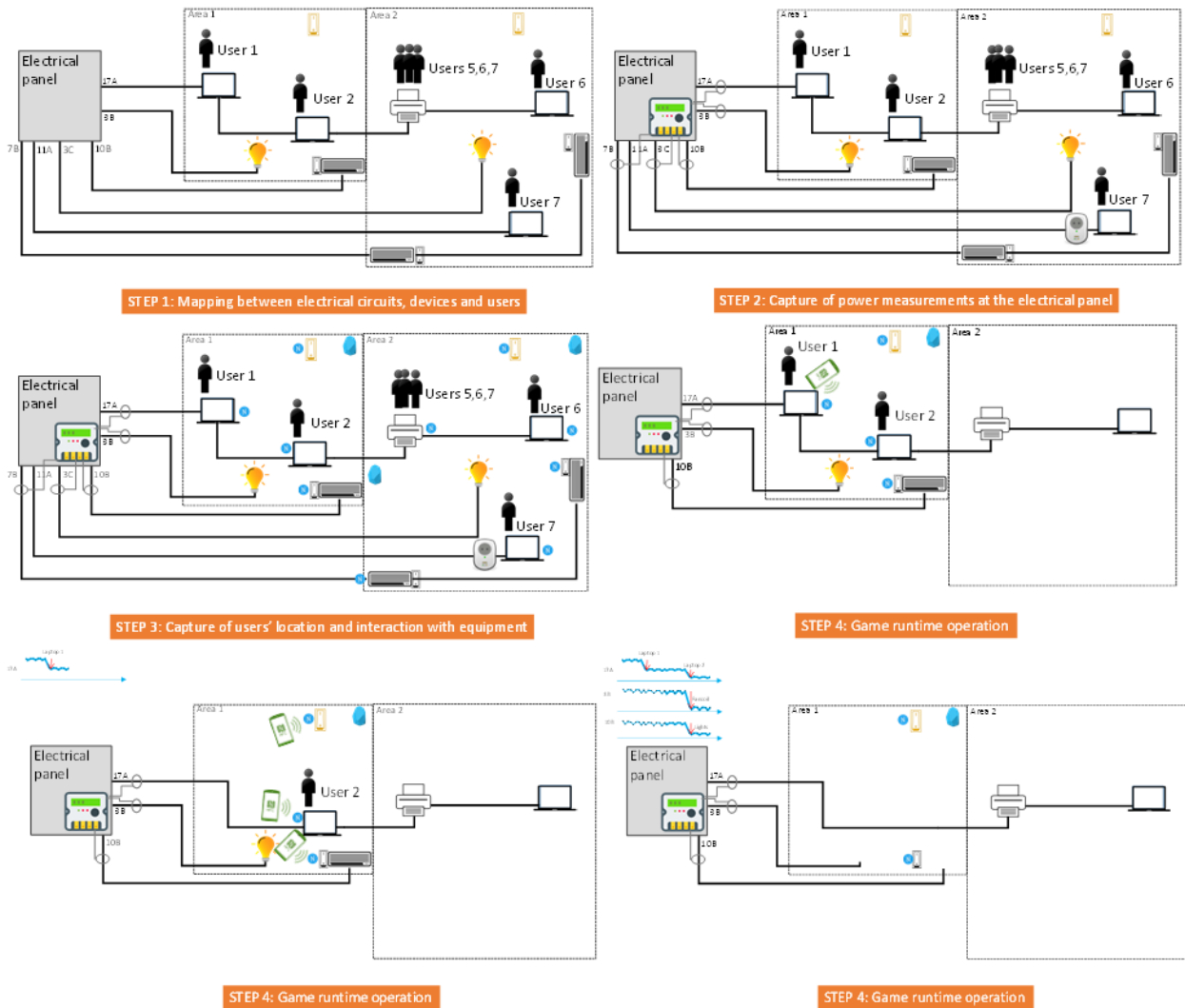
Figure 11 Intermediate steps for energy monitoring and performing analytics

The Pre/Post Event Analysis is where the algorithms for control validation and energy savings estimation happen. The disaggregation and energy allocation engine works as follows: (1) The core/backend platform informs the analytics engine that an appliance has been operated by the user after it received an NFC swipe alert from the user's mobile app, (2) the analytics software runs the NFC swipe alert against the power measurements of the circuit feeding the appliance operated by the user to detect significant power variations, (3) the analytics software analyses the power variations and informs the core/backend platform of the drop in energy use measured in relation to the user's operation of the appliance, as well as a quantification of the savings achieved by doing so and (4) the game backend calculates the points to be given to the user and the savings are stored within the platform database.
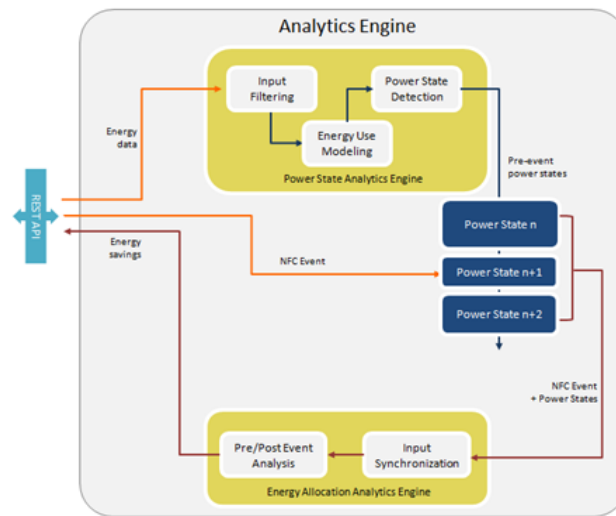
Figure 12 Architecture of the analytics engine in charge of validating user control actions and estimating energy saving generated

3.1.4   Gamification Group

The Game Backend implements the game rules logic that is going to be used in order to decide the progress of a user or a team in the game, update the scores and leaderboards, and keep track of the currently accepted/available challenges. It has been implemented in Java and interfaces with SiteWhere via MQTT and REST. All the communication between the software components happens through SiteWhere.
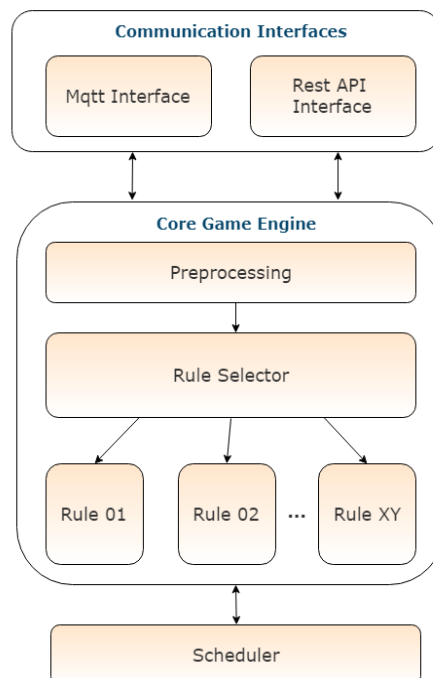
Figure 13 Game Backend Internal Architecture

Whenever an event is sent to SiteWhere from a device (i.e. a measurement or an alert), the event is stored and forwarded to a predefined MQTT topic which is listened by the other software components. The Game Backend listens to events sent to SiteWhere that describe the users' behavior and its results (such as NFC swipes, user location updates and energy updates), processes the data and determines the user progress with respect to the challenges that have been accepted or schedules delayed or recurrent processing. The processing performed by the game backend is not necessarily tied with the specific time an alert has arrived. Separate logic can also be triggered or executed at a different time to check/update the game progress and provide updates to the other system components. Internally the Game Backend consists of three different subcomponents. The first one is responsible for interfacing with the rest of the system through MQTT and REST. This interface is used to receive/request and update data according to the results of the rules. The second sub component is the core engine that implements the game logic. It consists of a pre-processing component which handles the incoming messages and accordingly selects the relevant rule out of a list of rules. These are the main part of the game logic and game challenges or actions that should be performed. One such rule determines that at the end of the week the challenges which have not been completed should be identified released if they have been assigned to any user. The third subcomponent is the scheduler. Its main use is to schedule delayed rules that should be scheduled for the future or executed at specific time intervals (i.e. every day, every week etc). New rules can be added as needed to incorporate new challenges. A separate submodule allows to easily add rules thus, ensuring the scalability and continuous enrichment of the game challenges. It organises rules in a specific structure by inheriting from an abstract class Rule, which defines a common interface as well as implements common functionality.
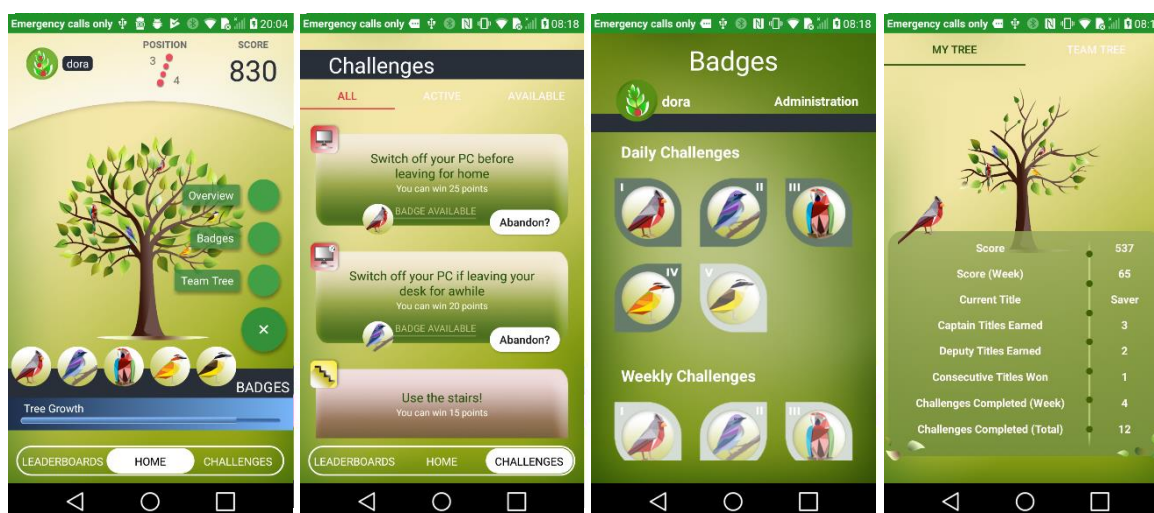

Figure 14 Screenshots of the Mobile App

The ChArGED Mobile App is the end-user front-end and visualizes data and game challenges in a user friendly, appealing, modern and motivating interface to ensure continuous engagement. The app is designed for Android smartphones supporting API Layer 21 (Lollipop) and above, equipped with NFC and BLE capabilities. The gamified app visualizes information about energy behaviour both at user level and team level. Users are informed about their progress while their actions directly contributing to the energy impact can be traced. Achieving energy savings and accomplishing challenges results in accumulating scores. A visual emotional inceptive in the form of a living tree grows and prospers according to the user score, thus rendering the game also visually attractive and engaging. When a challenge is completed, the scores and the game progress for each user and their team are updated in real time between the backend and the mobile app. The game backend has been installed on the

project server and connected with the other software components through MQTT and REST. The design goal of the backend is to implement the game mechanics, manage user/team scores and leaderboards and send notifications whenever there is a new update.

Besides the design and engagement concept, the following subsections present the functionalities that are provided to the user in order to use the first prototype:

User authentication

Users authenticate at the backend using their username and a password. The Implementation will follow the functionalities described in "Identity Management" and also support automatic re-login using a provided token mechanism.
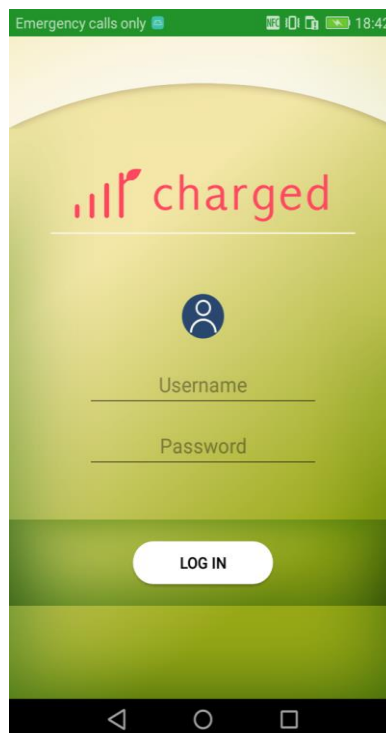
Figure 15 Login screen

Home Screen

The home screen is the first screen after a successful login. It displays a general overview of the current progress. It contains the personal and team trees as well as the player's score and badges.
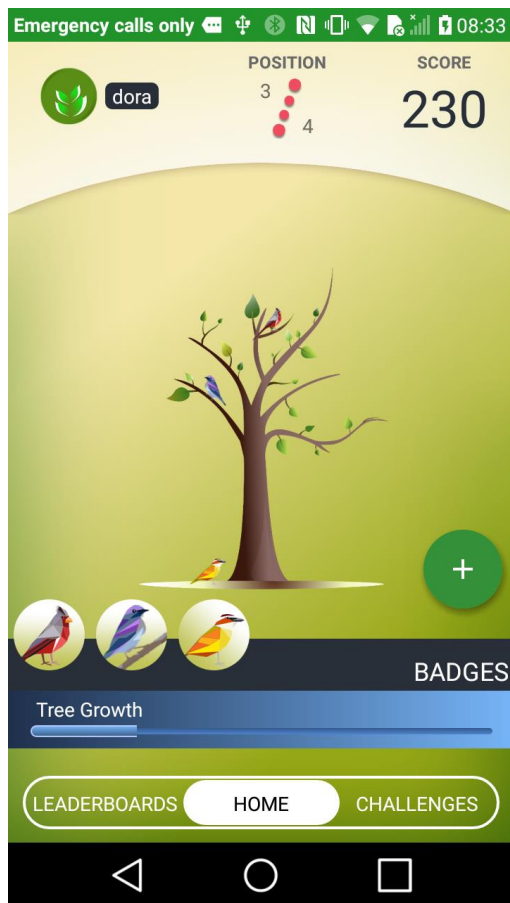
Figure 16 Home screen (Small Tree)

Figure 17 Home screen (Fully grown tree)

As the user completes different challenges he is awarded points and challenge badges. If the score is high enough (according to predefined threshold) the tree will also bloom and grow bigger. The longer the game is played the player gains experience and is assigned a corresponding user avatar (top left). Special borders of CAPTAIN and DEPUTY are also available for the two first players in each team.

Challenge Selection

The challenges screen contains all currently available and active challenges. A user can start playing by selecting one or more challenges. A challenge can also be abandoned at any time.
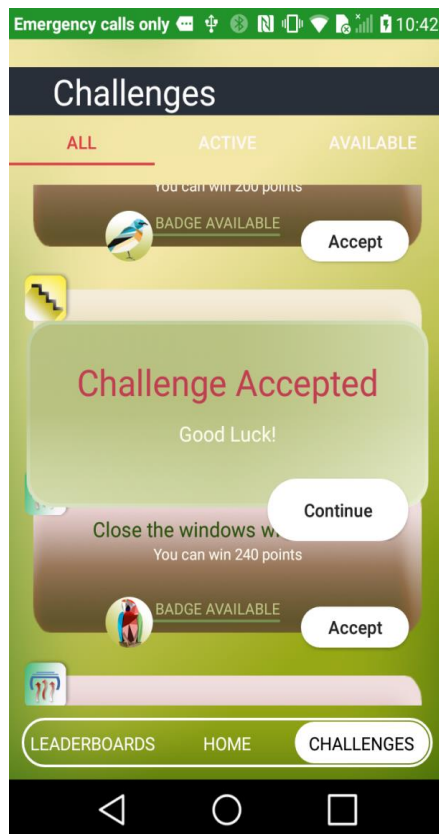
Figure 18 Accepting a new challenge
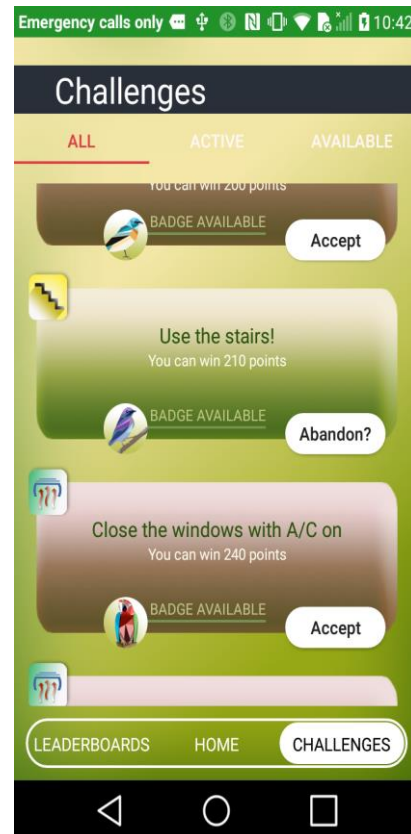
Figure 19 Challenges Overview

Leaderboards and Badges

The leaderboards screen enable the users to track their progress with respect to the other players of the same team as well as the progress of the different teams. The app communicates with the server to get and display the most recent game data.

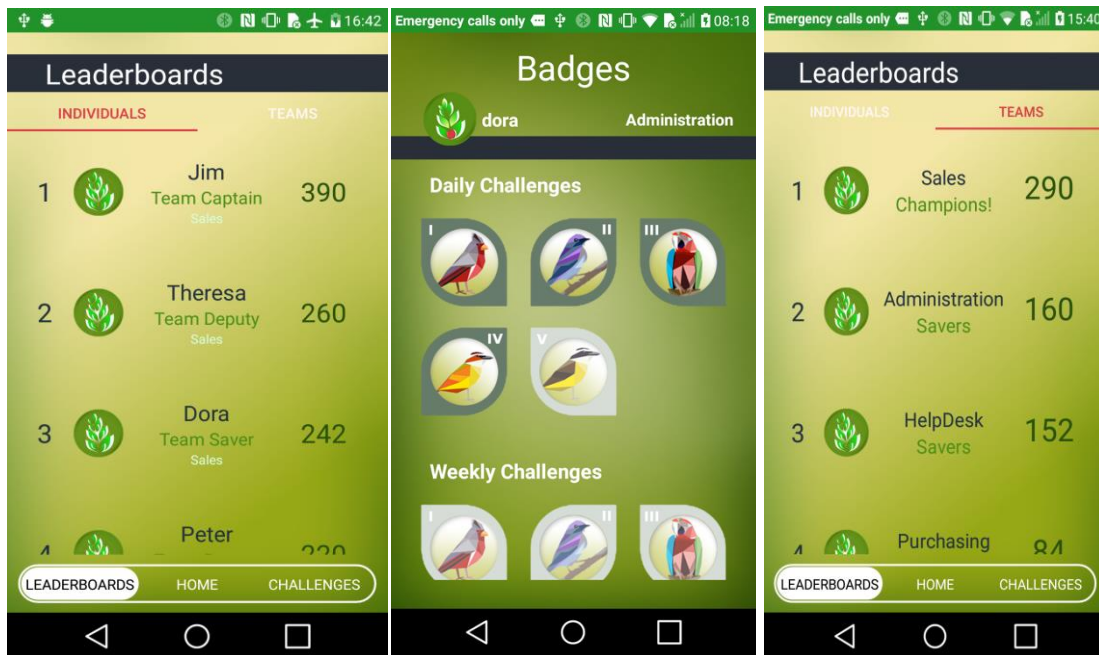This screen contains all the obtained and available badges that one has been awarded when completing a challenge.

Figure 20 Individuals Leaderboard, Bodges and teams leaderboard
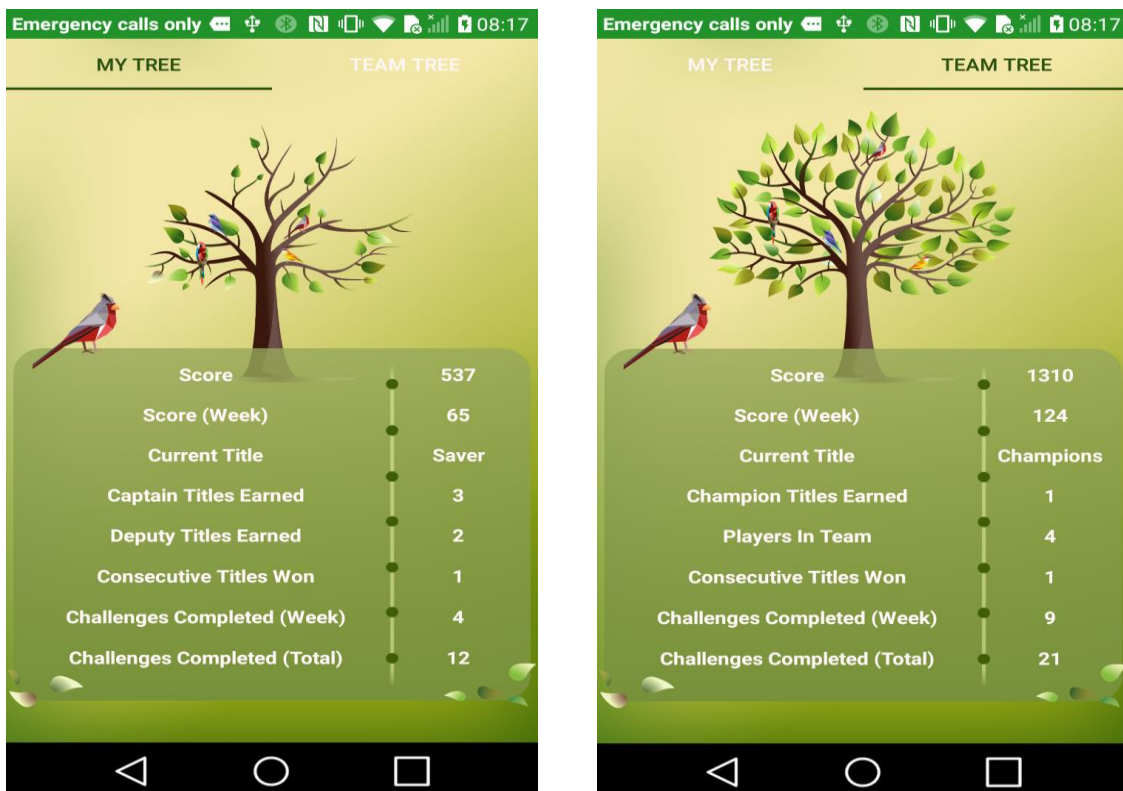
Figure 21 Overview of achievements

Overview of achievements

Detailed info about the user's progress can be viewed at any time. Separate tabs, one for the user's progress and one for the team's progress are available. This screen provides various statistics such as user/team scores, titles won and completed challenges.

NFC integration

Smartphones NFC functionality is exploited to inform the system about specific user actions that correspond to challenges, for example switching off appliances such as desk equipment or monitoring a shared device usage such as a printer. NFCs associated with devices are used by each player by swiping their phones on the especially for this purpose installed NFC stickers on the CHARGED involved devices. By doing this, the energy saving that is identified by disaggregation /analytics engine is assigned to a specific player.
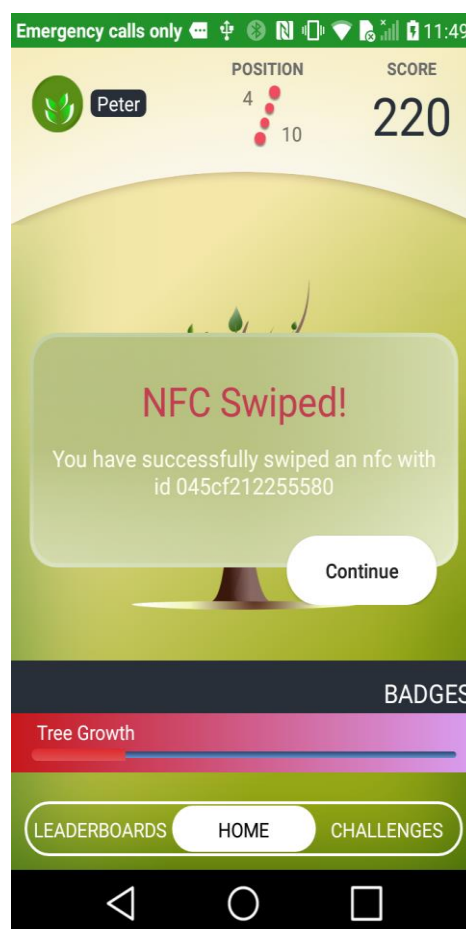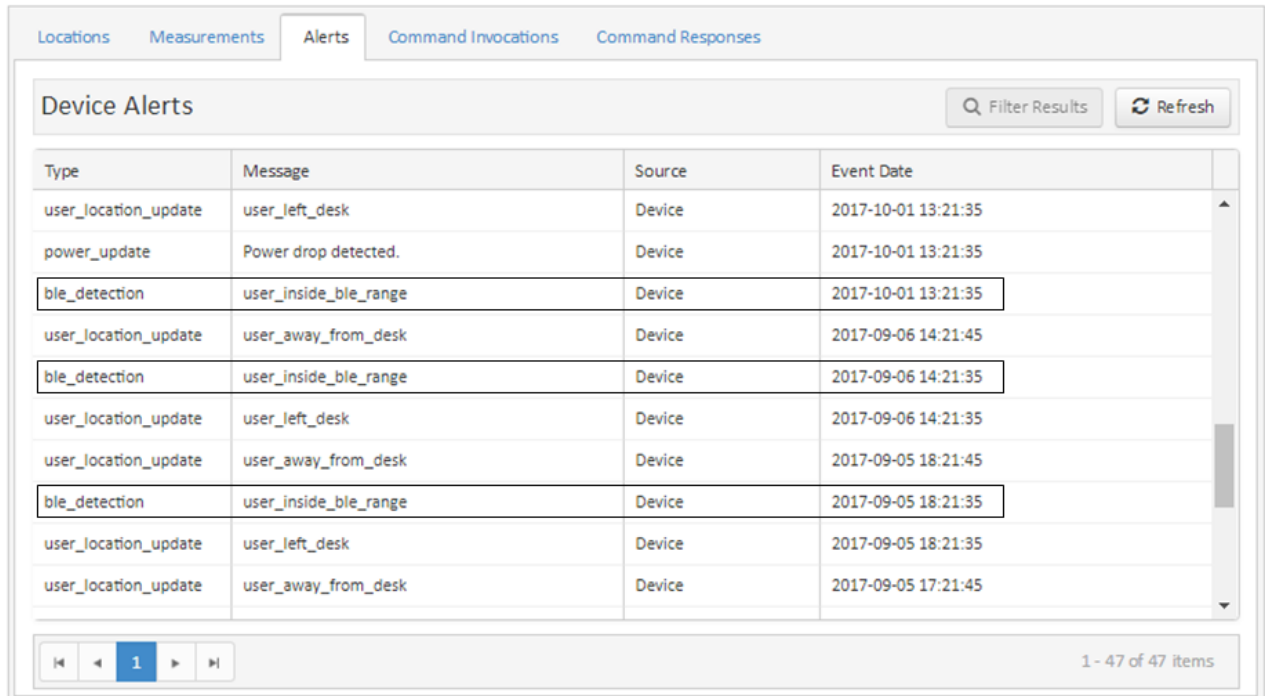

Figure 22 NFC Swiped Message

BLE integration

BLE is used to track the presence of users within a specific part of a building and can be used to distribute energy consumption from appliances which are shared between different users (ceiling lights, air conditions etc). The smartphone detects the closest BLE and informs SITEWHERE about its

ID. This information is processed by the Game Backend. All the BLEs are modelled in the system and each incoming ID is matched to a specific location inside the building. Like the NFC this is a separate mechanism used to assign energy disaggregation to a user or a team.

Figure 23 BLE messages sent by the user's smartphone inside SiteWhere

3.1.5   Component for microgeneration Energy Forecasting

The opportunity for a solar micro-generation in ChArGED, is to maximize the advantage of free/clean energy, without storing it, by shifting loads during peak generation time at most beneficial times. The most beneficial use of this component is to plan activities that consume energy when solar power production is maximised or reduce the activities when price of electricity is higher than normal - in future dynamic pricing scenario. Load shifting can be achieved again by altering user behaving via gamification, however, an accurate solar power generation forecast is required to optimize the results and thus a dedicated component was introduced in to the system architecture.

This component utilizes a solar inverter (Kaco) with rich data communication capabilities (over Modbus TCP protocol) in order to monitor the generated electricity and assist the energy production forecasting mechanism which is based on daily weather forecasts. This forecasting is used for directing the game challenges towards optimizing energy use. The solar inverter is connected to the Sensor Gateway with the middleware / IoT integration software mBS SH. Through the device abstraction of the mBS SH the data are sent via MQTT to the ChArGED core platform and from there they are made accessible to all other system components. The Component for Microgeneration Energy Forecasting gets periodically (every day for five days ahead) updated on the specific location weather forecast and provides the hourly forecast of the expected energy. The solar forecast software is connected to 3rd party weather forecast provider APIs for obtaining the weather forecast data (yr.no, wunderground.com, weatherxm.com etc).
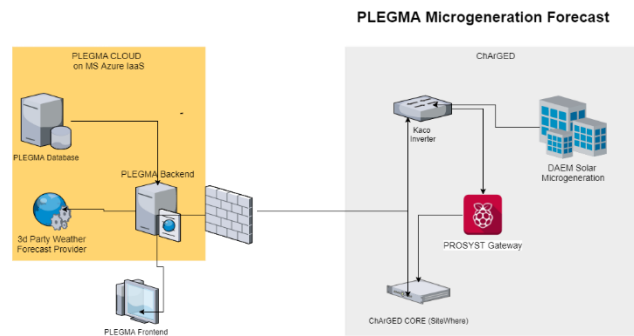
Figure 24 Solar PV Prediction Architecture

During the initial staged of development, various approaches where explored:

a) Forward calculator
Enriched by weather forecast PV & inverter specs X theoretical solar radiation based on lat/lon & cloud coverage and historical area performance. Apply cloud coverage forecast and temp cell efficiency correction
b) Butler FP7 solar forecast server

http://open-platforms.eu/library/renewables-energies-forecasting-smartserver/

c) Machine Learning

Finding correlations between all weather conditions and actual production on the pilot site.

The first approach (a) was initially considered adequate for the requirements of the project, by all technical partners. The solution was built by utilizing / validating results with data from EUs Photovoltaic Geographical Information System.
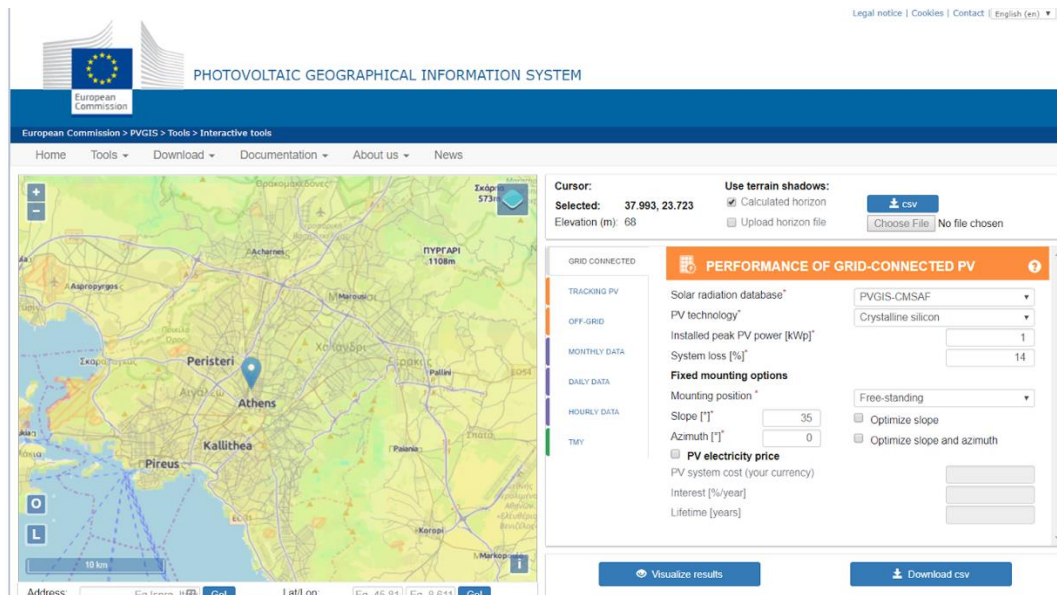

Figure 25 Photovoltaic Geographical Information System

A theoretical yearly forecast was produced for the specific PV system deployed in DAEM and was later corrected utilizing real data from the Kaco inverter and weather data / forecast from YR.NO.
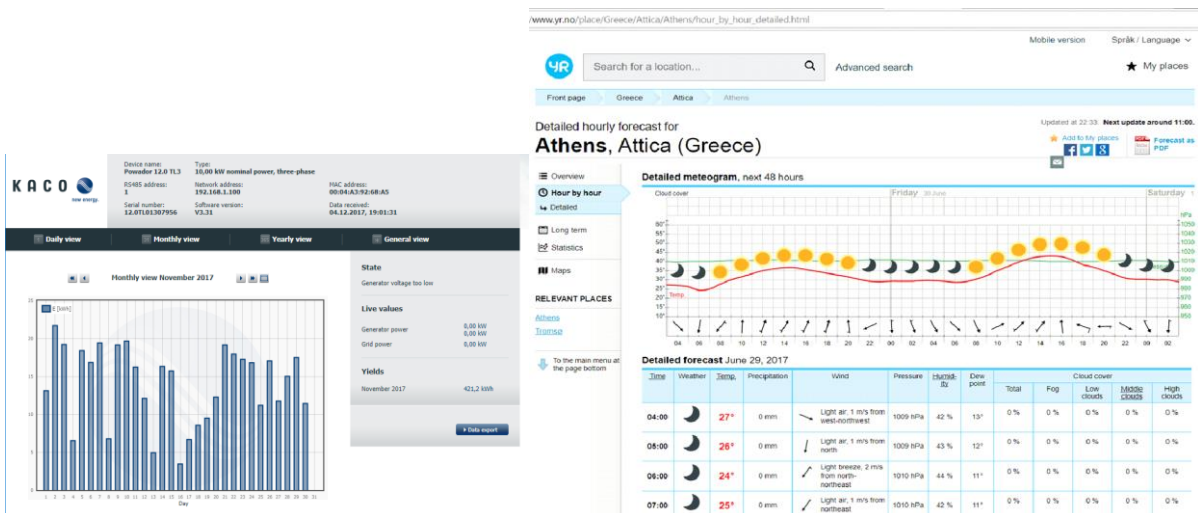
Figure 25 Weather Forecast inputs to the module

Figure 26 Solar PV Prediction Results

The results of the forecast are submitted on a daily basis to SiteWhere and include the weather data and energy forecast data for the next 48 hours, in hourly intervals, so that any component from SitheWhere can utilize it. Actual energy produced vs forecasted the day before, is plotted in the above figure, using the Grafana quick dashboard capabilities.

4 Demonstration of the Integrated ChArGED system

4.1 High Level Description

This version of the charged integrated system builds on the 1st integrated prototype. This version of the ChArGED integrated system includes new functionality of the game and energy analytics backend which now support more challenges as well as visual and functional updates for the app that enhance user experience and update the communication with the ChArGED server.

In addition to the goals of the integrated system now supports the following complete demonstration scenario

- User's smartphone / ChArGED Mobile app scans an NFC tag while user interacts with the corresponding appliance (or enters the proximity area of a BLE beacon), thus the user action is identified by the system in the specific area.
- The user action events are transmitted via the Mobile App to the Game Backend, processed, and then forwarded to the Analytics Backend.
- The Analytics Backend analyses the energy measurements of the electrical circuit/smartplug that corresponds to the appliance that the user manipulated (e.g. PC, lights, etc.) and calculates the energy drop related to the reported user action (e.g. energy of last minute for this appliance).
- The Energy Analytics backend then calculates the energy savings that are the result of the users' actions.
- These calculations are then sent to the Game Backend that notifies accordingly the user via the Mobile App regarding the achievement of the related challenge.
- The Game Backend also produces other various statistics such as number of challenges completed per day/week/month, assigns user/team titles and monitors user and team scores separately.
- The user can access these resources through the app to monitor the current game state.

Software and Hardware Configuration for the 1st integrated system demo

1. **Sensing equipment integrated:**
   - Fibaro Smartplugs
   - Mobile Handsets with NFC/BLE capabilities (LG-K8-Dual-2017-16GB)
   - Estimote BLE beacons
   - NFC stickers

2. **Core backend:**
   1. Receives, stores and makes available energy consumption data at the level of appliances and/or electrical circuits, according to the availability of smartplugs and Accuenergy smart meters.
   2. Receives, stores and forwards to other system components alerts that describe the user actions inside the buildings that are used to play the game such as NFC swipes and BLE detections.
   3. Provides an interface where the different system components can connect to.

3. **Energy analytics backend:**
   1. Receives energy data and user interaction events from SiteWhere (via Amazon SQS connection):

- Energy data originated from zwave plugs, Accuenergy Modbus powermeters and the DAEM solar microgeneration system (via a Modbus connection to the Inverter)
- User interaction events originated from smartphones swipes on NFC stickers
2. Analyses power measurements variations around user interaction events
3. Pushes measurements of power variations and generated energy savings back to SiteWhere
4. Provides historical power measurements within a graphical user interface for advanced analysis

4. Game Backend
1. Receives the alerts generated from the mobile app (NFC and BLE events) process them and uses these events to initiate/complete specific challenges.
2. Communicates with the Energy Analytics Backend to retrieve energy information necessary to decide the outcome of a challenge (such as the power drop of the consumption in a circuit used to deduce if the user has closed a device).
3. Assigns the necessary points and challenge badges to users on successful challenge completions, updates the game data and manages the game leaderboards.
4. Creates general game statistics such as number of challenges completed per player or per team, current titles consecutive titles won etc.

5. Gateway
1. Connect via Modbus to Accuenergy smartmeters installed at all pilots for monitoring consumption at electrical circuit level. Modbus integration ensures higher speed of polling (e.g. every 10 sec) as opposed to the traditional polling of 15 min.
2. Improve data update/push-to-sitewhere mechanism to make system more responsive
   - Taking into account zwave plugs have internal push thresholds (Fibaro) which might be useful to take advantage
   - Taking into account Accuenergy smartmeters (interfaced via Modbus) will be polled at high-speed but if there is no major value change, data should not be pushed to save resources

6.. Gamified mobile app
1. Listens for NFC/BLE events and forwards them to SiteWhere
2. frontend through which the users can interact with the system and play the game. Through it the players can
   - Track their overall progress, points and finished challenges
   - Receive notifications and updates from the backend
   - Accept new challenges
   - Check their position in the leaderboards
   - Browse game statistics and badges won

4.2 Measurements

The measurements from the meters and the sensors are sent to the gateway and from there forwarded to SiteWhere which allows to continuously monitor the energy consumption of the buildings. These data are used in the game challenges the users undertake as well as to monitor the total energy usage and energy savings achieved.
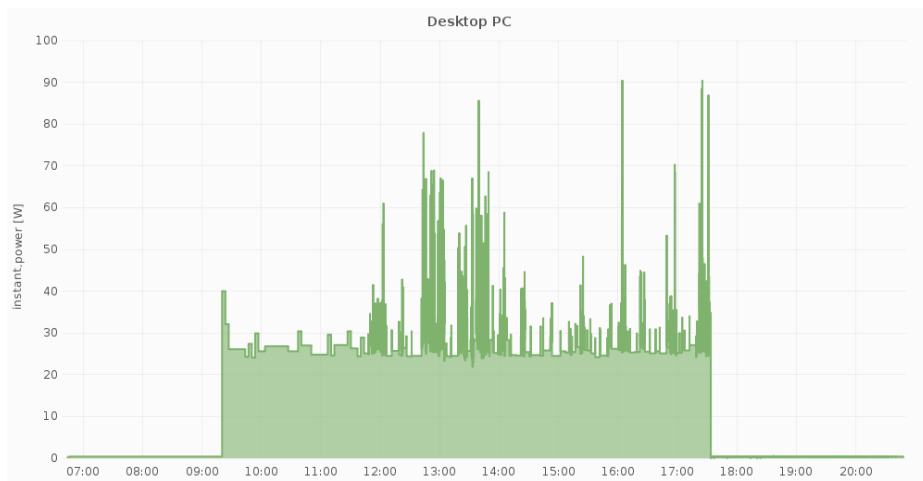
Figure 27 Indicative measurements of the electric consumption measured for different devices (I)
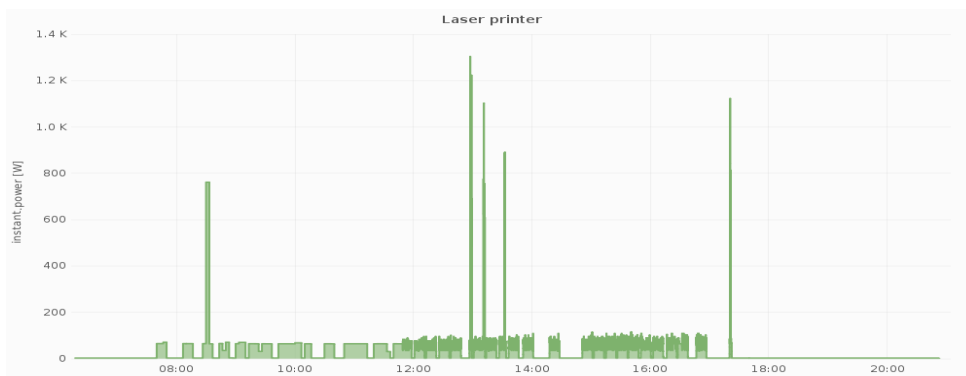

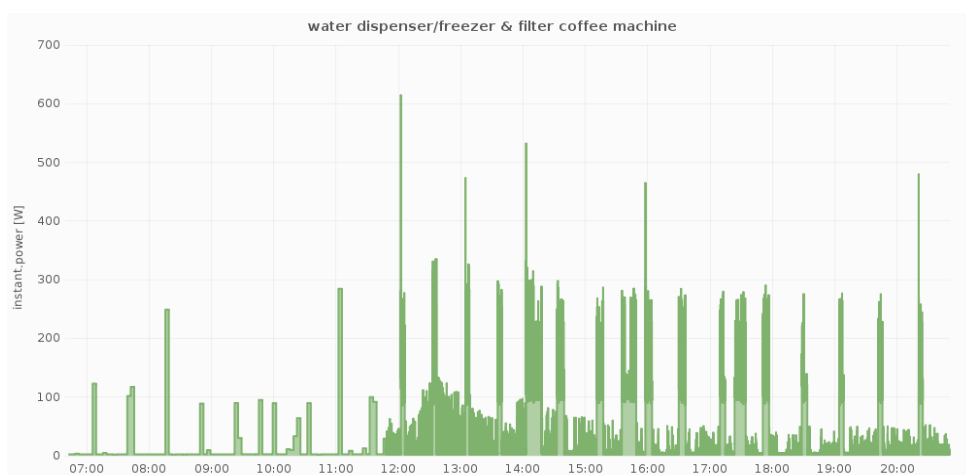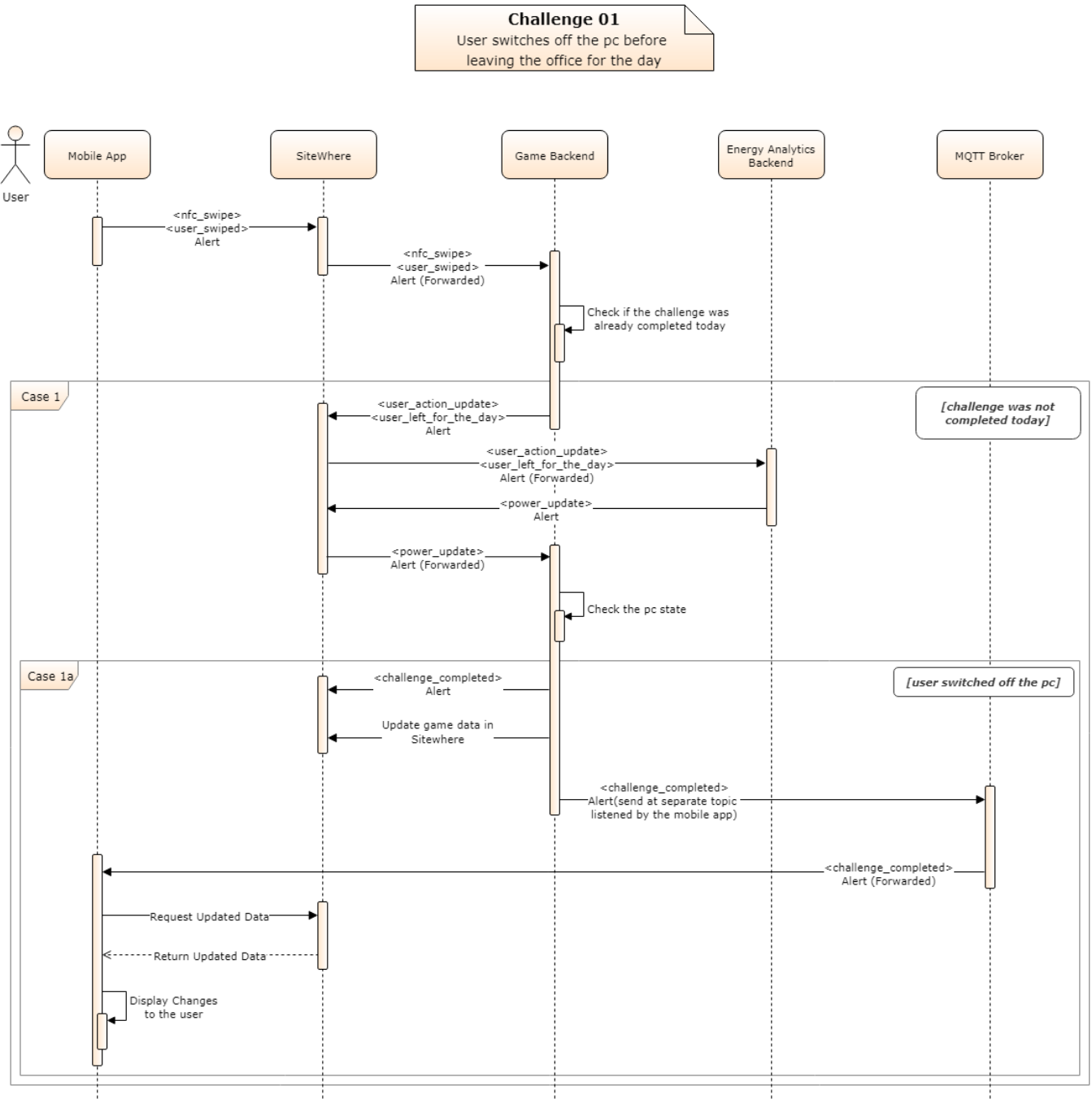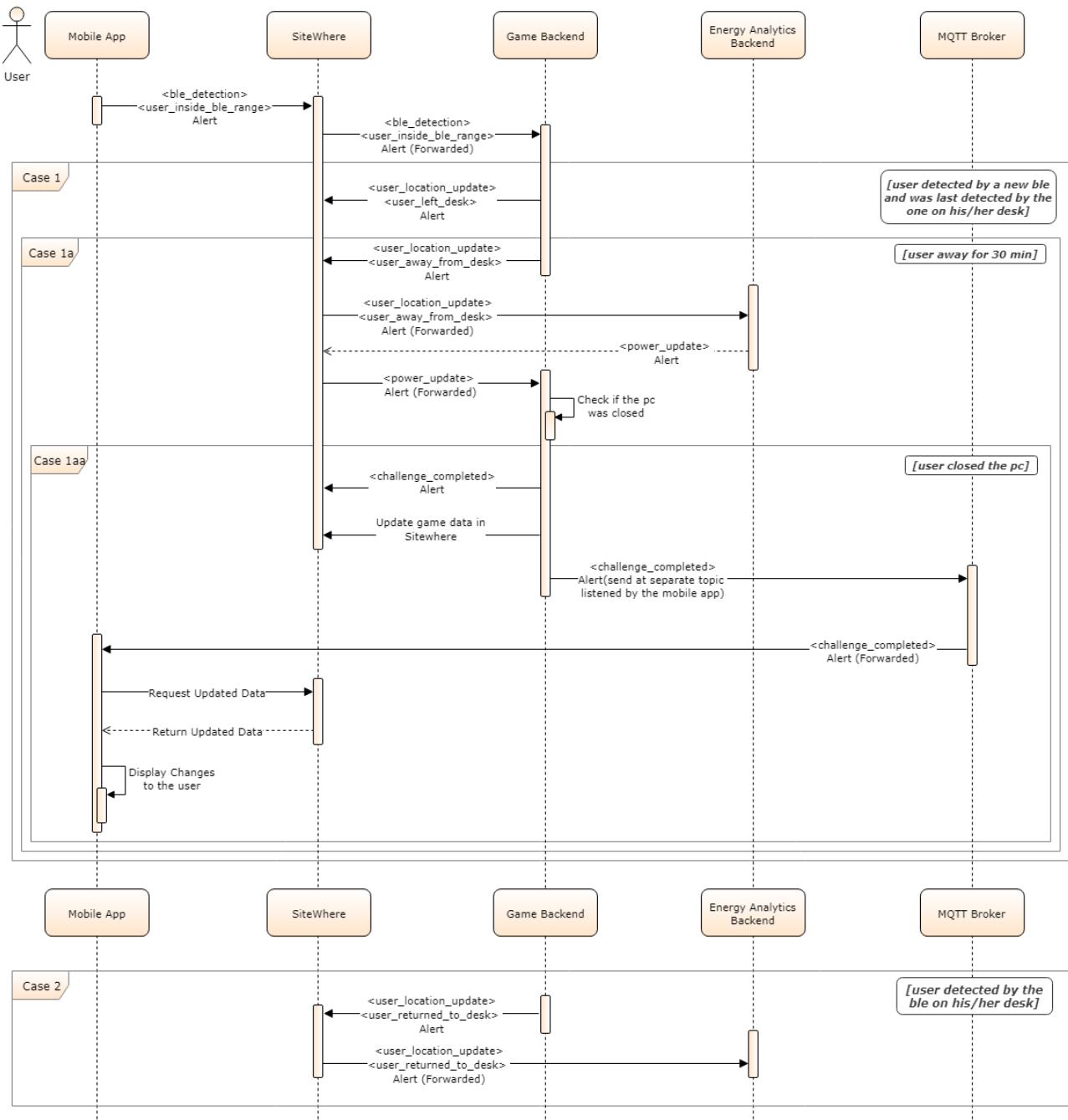*Figure 28 Indicative measurements of the electric consumption measured for different devices (II)*

Figure 30 Indicative measurements of the electric consumption measured for different devices (III)
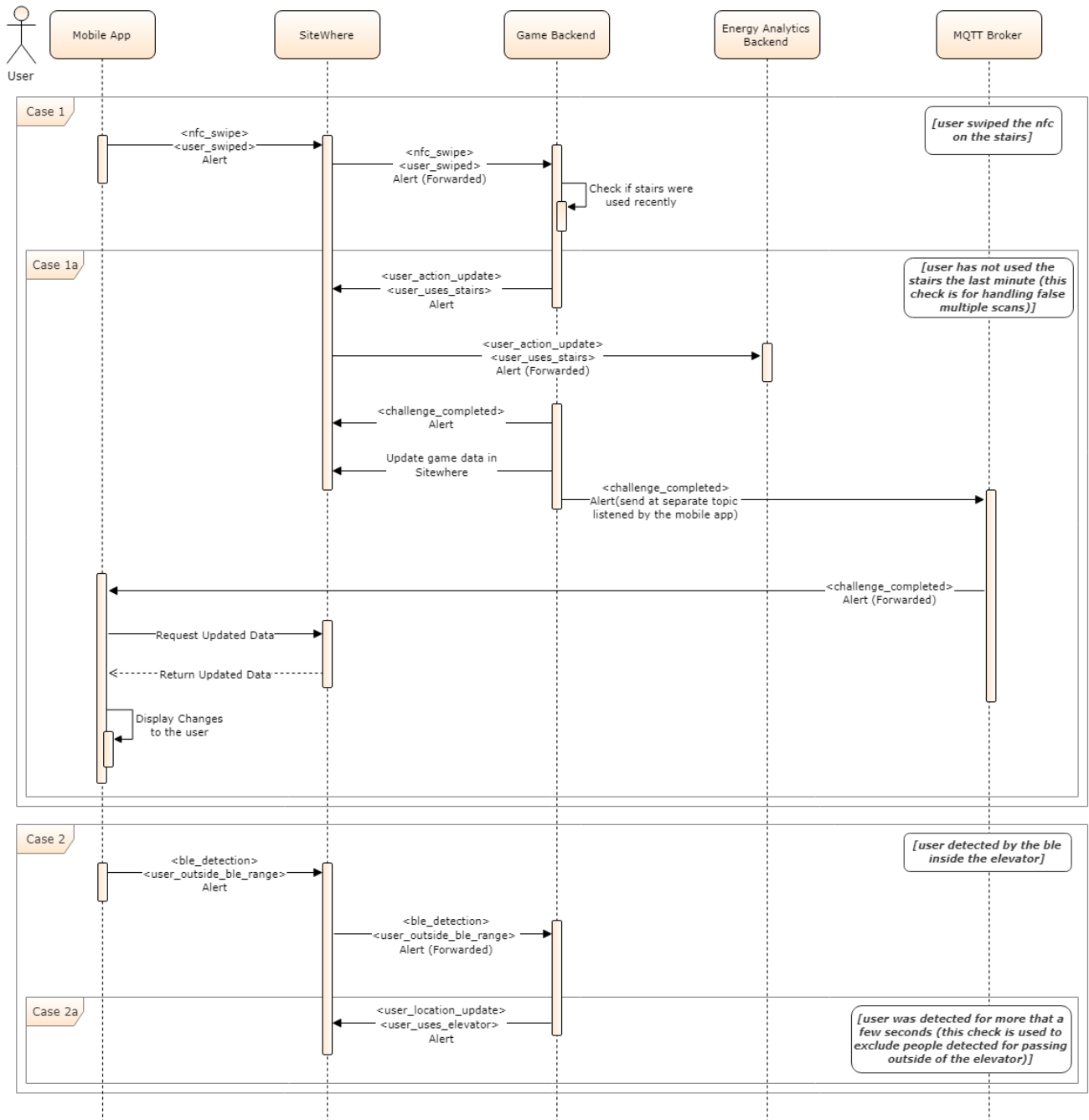
4.3 Component Integration

For each challenge, specific logic and data flows between the components have been designed and implemented. The sequence diagrams below describe the data flow for the first five challenges and support the integration tasks.
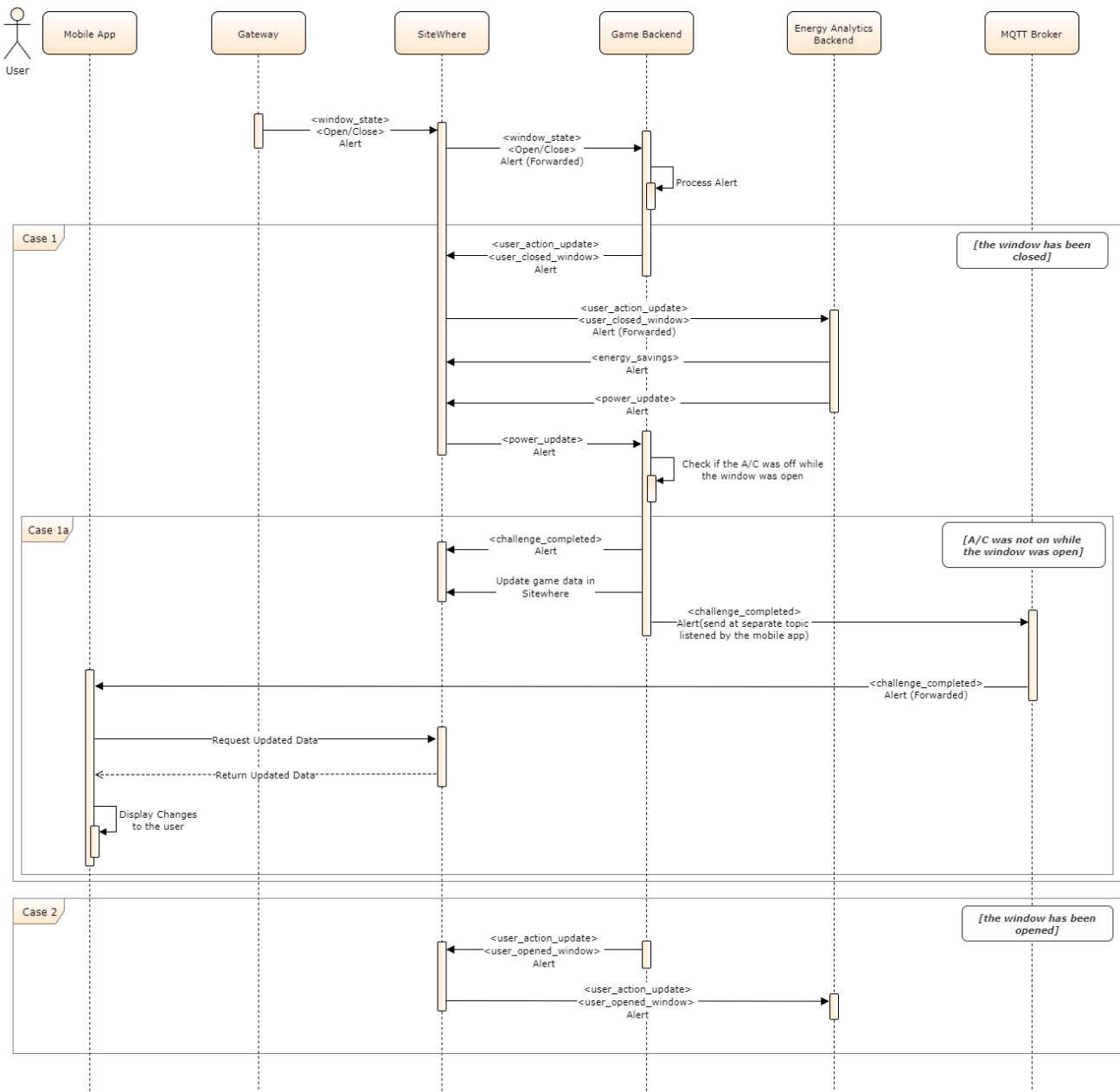
Challenge 03
User uses the stairs instead of the elevator

User Mobile App SiteWhere Game Backend Energy Analytics Backend MQTT Broker

Case 1

[user swiped the nfc on the stairs]

<nfc_swipe>
<user_swiped>
Alert

<nfc_swipe>
<user_swiped>
Alert (Forwarded)

Check if stairs were used recently

Case 1a

[user has not used the stairs the last minute (this check is for handling false multiple scans)]

<user_action_update>
<user_uses_stairs>
Alert

<user_action_update>
<user_uses_stairs>
Alert (Forwarded)

<challenge_completed>
Alert

Update game data in Sitewhere

<challenge_completed>
Alert(send at separate topic listened by the mobile app)

<challenge_completed>
Alert (Forwarded)

Request Updated Data

Return Updated Data

Display Changes to the user

Case 2

[user detected by the ble inside the elevator]

<ble_detection>
<user_outside_ble_range>
Alert

<ble_detection>
<user_outside_ble_range>
Alert (Forwarded)

Case 2a

[user was detected for more that a few seconds (this check is used to exclude people detected for passing outside of the elevator)]

<user_location_update>
<user_uses_elevator>
Alert

Challenge 04 (Team)
Team closes (and does not open) windows while A/C is on.

Challenge 05 (Team)
User switches off lighting and
A/C in room after hours
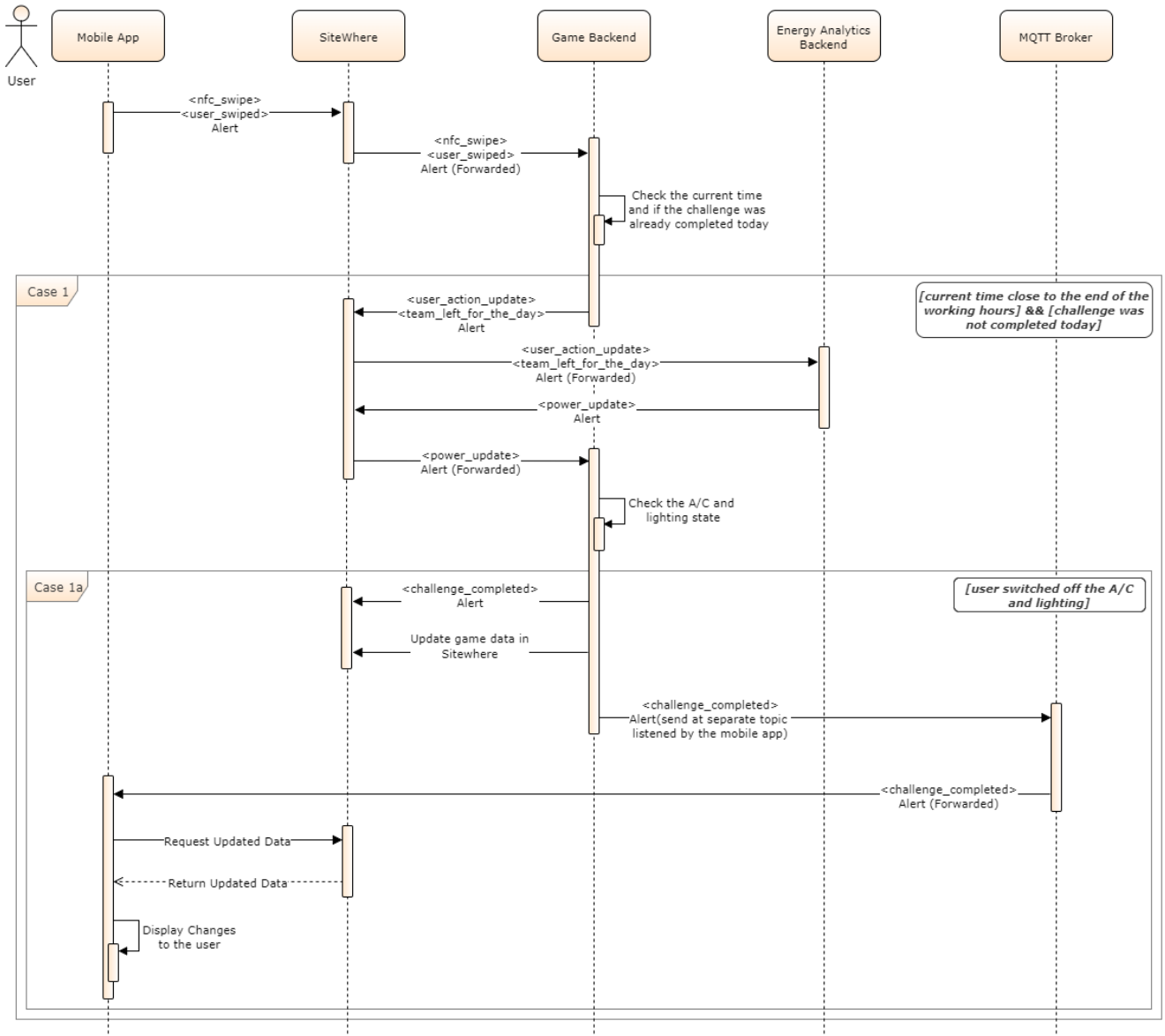
4.4 Integrated (End-End) Description of Challenges

4.4.1 Switch off your pc before leaving for home

4.4.1.1 Challenge Overview

All the challenges listed in paragraph 2 have been implemented. One of the challenges was demonstrated end-to-end as if played by a player, demonstrating the data flow and the communication of the subsystems. In this challenge, the players are required to close their pc before leaving the office in the afternoon after swiping the NFC on their desks. The ChArGED system is informed by the players' actions and awards them with points and a badge if the challenge is completed successfully.

4.4.1.2 User selects the appropriate challenge from the mobile app
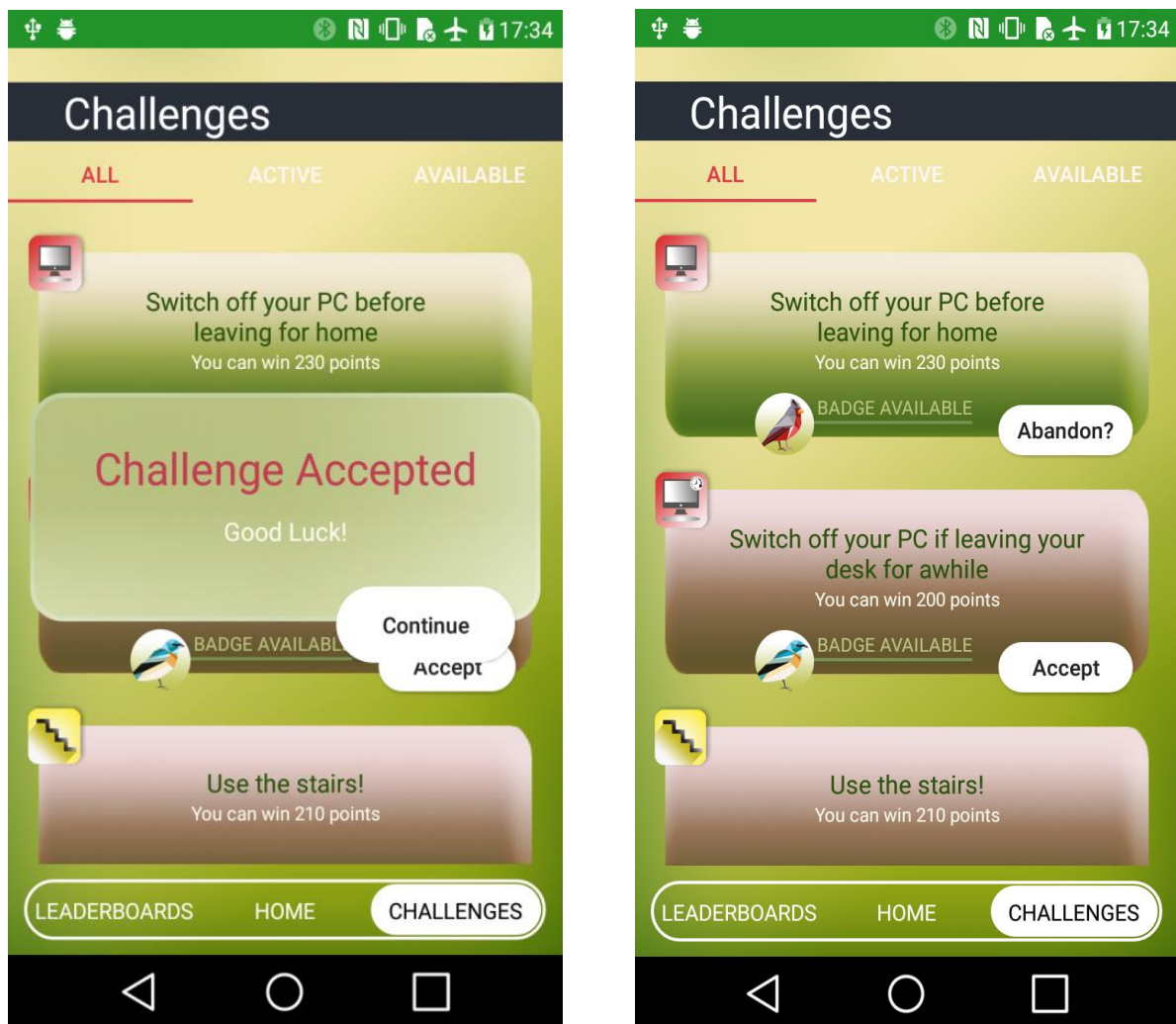
Figure 29 User Selects a Challenge

4.4.1.3 User Swipes the NFC

The user swipes the NFC on the desk. This NFC event is picked up by the app and forwards it to SiteWhere with the other relevant information (i.e. date and time the event happened, username, and identifier for the smartphone that produced the alert etc.). The PC on the desk is paired in the system with the corresponding NFC which lets us match the action being performed to the appropriate device.
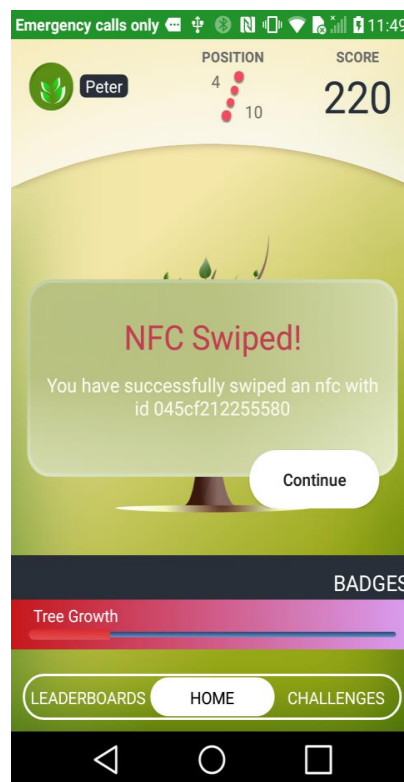

Figure 30 User Swipes The NFC Tag

4.4.1.4 Alert Received by the System

Inside SiteWhere a relationship has been declared which allocates players to smartphones. This is how when an event is received for an NFC alert the Game Backend queries the relationships identifies

the players who did the NFC swapping. The following screenshot presents the pairs of players and phones (example).

Figure 31 User Model Inside SiteWhere

Figure 32 NFC Swipe Event In SiteWhere

4.4.1.5 Alert Processing

When the alert is received by the Game Backend it is processed and matched to the specific challenge (using data from the system and the time of the alert). When the challenge is identified the game backend communicates with the energy analytics to confirm that the event i.e of shutting down the PC has been identified. For this the measurements for the specific PC are retrieved by the energy analytics which then confirms the power drop in the electricity consumption. If the energy analytics confirm the power drop matching to the event of PC shut down (Fig. 33), the challenge is considered completed. The entire communication is stored in SiteWhere (see Fig. 34).

Figure 33 PC Electric Consumption

Figure 34 Messages Exchanged by The System Components

4.4.1.6 Challenge Completion

When the event "PC has been shut down" has been recognised, then the game backend sends a "challenge completed" message to the app and assigns points to the user and a challenge badge. It also stores the results on the database and updates the game data in the system. If the user achieves enough points the tree will also grow to the next stage.

4.4.2 Switch off pc if leaving your desk for more than 30min

4.4.2.1 Challenge Overview

In this challenge BLEs installed inside each room are used to detect when a user leaves or returns to their desk. When a user leaves the desk a new message is sent by the app to the backend. The time is then measured and if half an hour passed and the user has not returned to their desk then the power consumption of the user's desk is processed at the time the user left. Then by detecting the drop in the electricity consumption we deduce if the user closed their pc and if yes we the challenge is completed.

4.4.2.2 User leaves/returns to desk

One way that has been adopted to reduce the scanning for the user, was the use of BLEs. When a user leaves or returns to his desk the event is detected by the mobile app with the help of the installed BLEs. The alert is then sent to SiteWhere.

Figure 35: User leaving and returning to his desk has been identified.

4.4.2.3 Alert processed by the system

The game backend waits 30 minutes and then informs the system that the user is away. The energy analytics processes then the measurements from the users pc and returns a power alert with the drop in the electricity consumption the game backend then evaluates the result and decides if the use has closed the pc and if yes the challenge is completed.

4.4.3 User uses the stairs

4.4.3.1 Challenge overview

An NFC sticker is placed in the middle of each flight of stairs. When users climb the stairs instead of an elevator they scan the NFC to inform that they did so. This challenge can be played multiple times per day but a time period restricting the repeated scanning is imposed (for example 5min).

4.4.3.2 Alert processed by the system

When the user scans the NFC a specific alert is sent to the system and matched to a specific user. Here there are no electric power measurements to evaluate so the event indicates that the user used the stairs and thus completed the challenge.

4.4.4 Close the windows if the A/C is on (Team)

4.4.4.1 Challenge Overview

In this challenge the players are asked to close the windows if they turn on the A/C. An inductive proximity sensor is placed on the windows of the room. When someone closes or opens the window an alert is send to the system. The backends validate if the A/C was off while the window was open. If yes, the challenge is completed and all the users working in the same room are awarded points and the challenge badge.

4.4.4.2 User selects the appropriate challenge from the mobile app
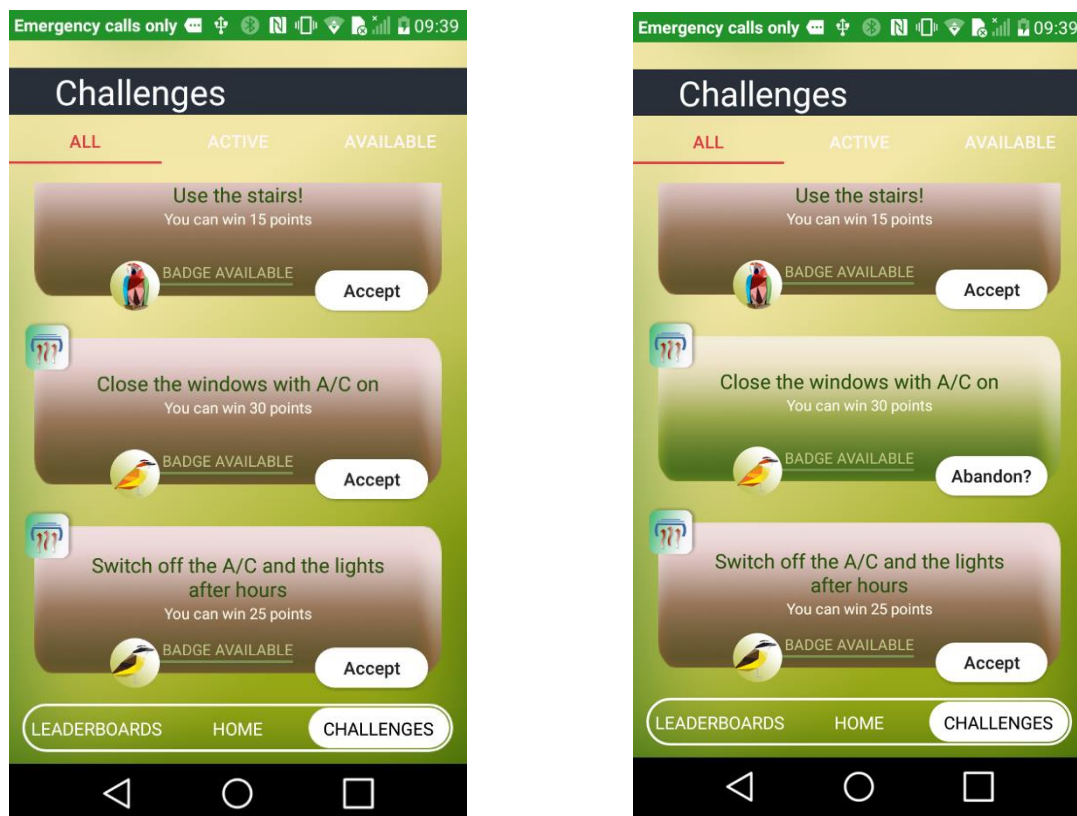
Figure 36 User Accepts the Challenge

4.4.4.3 User opens or closes the window

When a user opens or closes a window the change is detected by the proximity sensor. The sensor communicates with the gateway which sends an alert to SiteWhere.

4.4.4.4 Alert Received by the System

Inside SiteWhere all the window sensors are assigned to specific rooms and the teams that work in these rooms. Every new alert from the real sensor is sent to a modelled sensor device as seen in the figures below:

Figure 37 Sensor Device in SiteWhere

The Game backend processed these alerts and produces a user action update message read by the energy analytics.

Figure 38 Sensor and Game Backend Alerts

4.4.4.5 Challenge Completion

When the user closes the window the energy analytics calculate the amount of energy that was used by the A/C units in the room while the window was open as well as the energy savings (if any) achieved during the same period. This information is sent back to the Game Backend which decides if the energy consumption detected was low enough to indicate that the A/C was closed. In these case all the users in the room are awarded points and get a challenge completed message in their smartphones.

Figure 39 Energy Analytics Alerts

Figure 40 A/C electricity consumption measurements
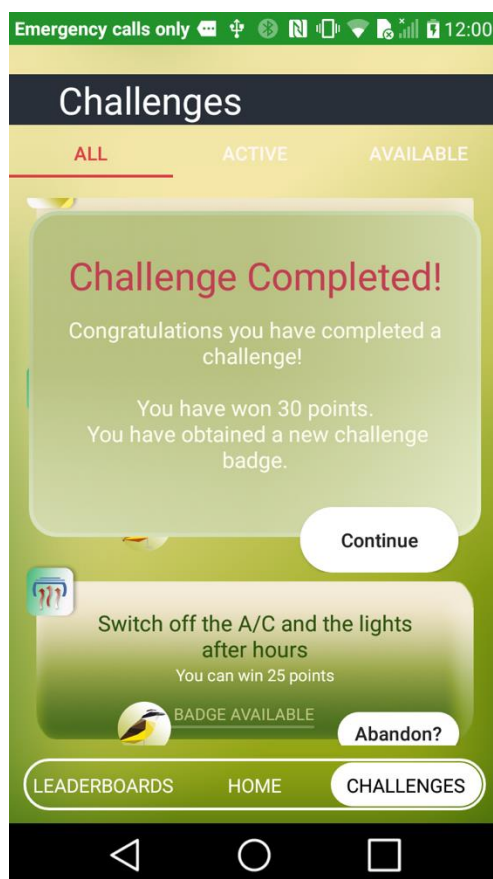
Figure 41 Users receive notification inside the app

4.4.5 Switch off the A/C and lights after hours (Team Challenge)

4.4.5.1 Challenge overview

In this challenge the person leaving the room at the end of the day is asked to close the A/C units and lights. This is a team challenge so when successfully completed all the users belonging to the same team are awarded points.

4.4.5.2 Alert processed by the system

An NFC is placed at the exit of each room close to the light switches. When the last user leaves they can scan the NFC and close the A/C and lights. A new event that the user scanned the NFC on the room is sent to the Game Backend. This event is then identified that it corresponds to the users having left for the day. The Energy Analytics then calculates from the measurements if the devices have been closed. If yes the challenge is completed and the each player of them team is awarded points

4.4.6 Rewards

After any successful challenge completion the user receives points and the daily challenge badge. The challenge badges appear at the badges section and the birds appear on the tree. The points are added to the user's and the user's team scores. The home screen can display two different versions of the tree one that belongs to the user and one that belongs to the team.
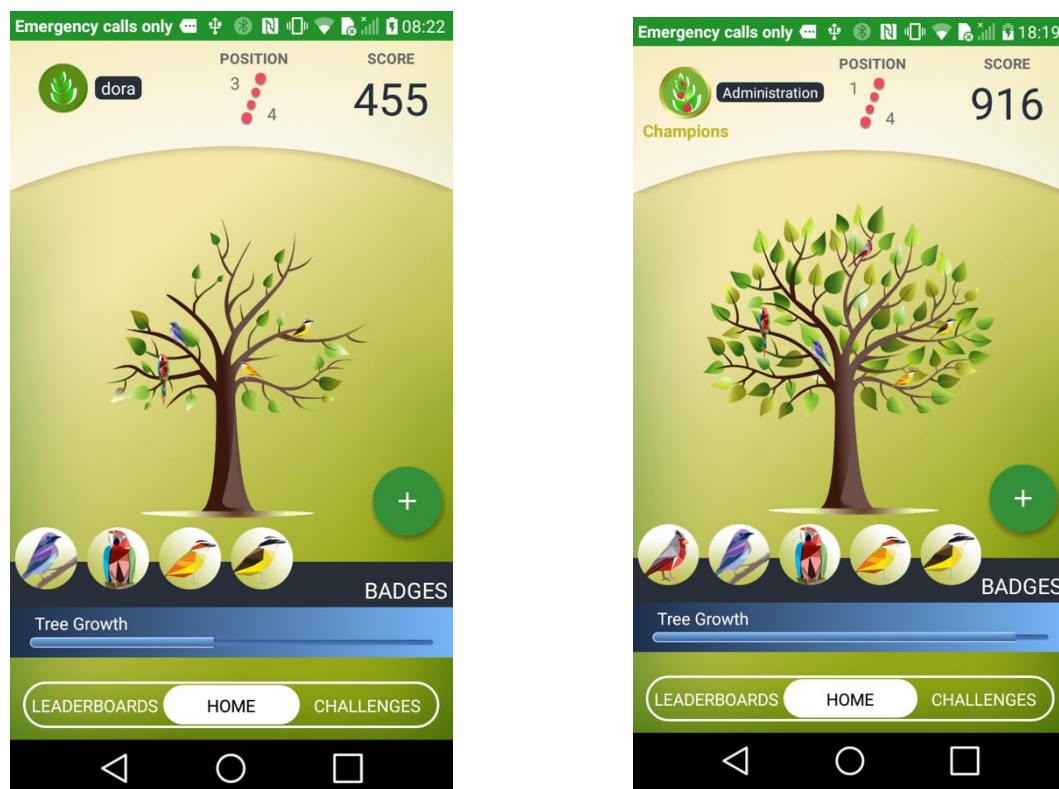
Figure 38 Users receiving rewards at individual and team level

4.4.7 Progress Overview

The ChArGED system keeps statistics of the current game state. The users have the possibility to access different screens on the app to get an overview of theirs and their team's current progress.
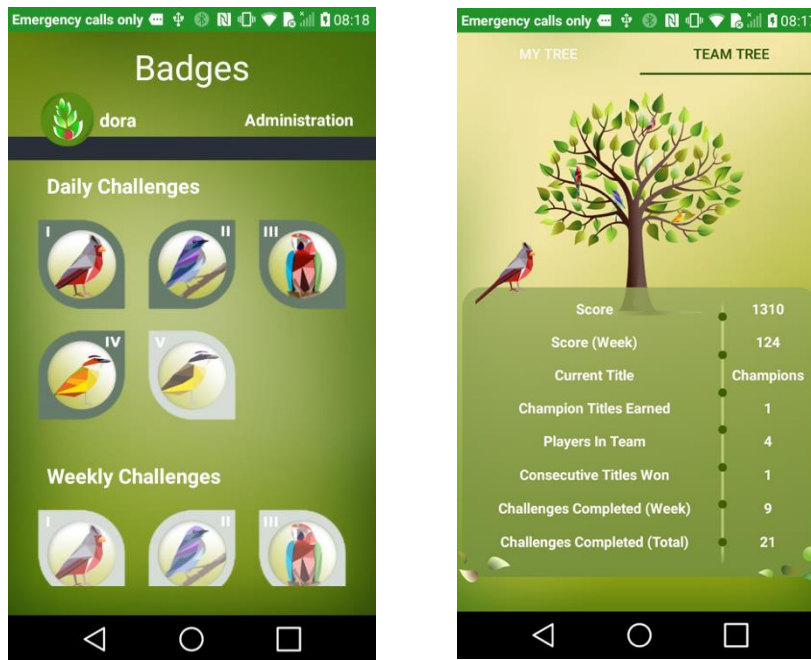
Figure 39 Badges and progress overview

5 Technical Testing Plan and Results

The Validation Plan presented therein describes the general methodology that will be followed for performing the testing of the ChArGED integrated software before any release of the platform for trial at the pilot sites, inline with the multiple validation phases. This methodology aims to capture all aspects of the system operation which, when executed successfully, demonstrate that the ChArGED system implementation meets requirements established in the technical deliverables. In particular, this validation plan must be documented so as to cover the information below:

1. Software components and interfaces included in the software release
2. Application scenarios to be supported by the platform
3. Description of the pilot test topology
4. Step-by-step description of the test cases
5. Acceptance criteria and evaluation results to confirm that the system meets pre-defined requirements
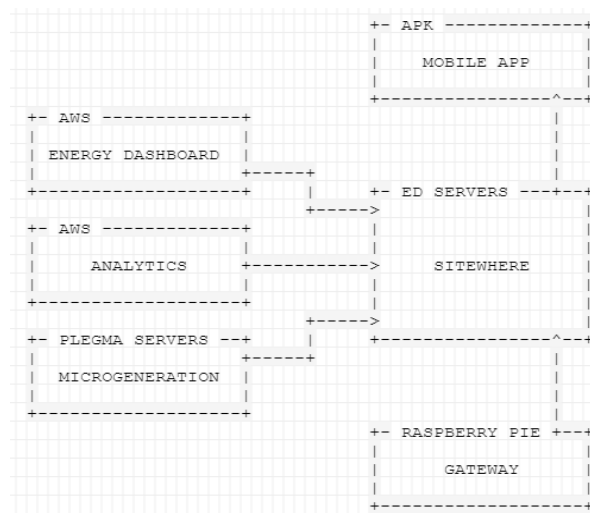
Figure 40 Topology of system components

The test cases aim to support the scenarios, including the components' inner processes and interfaces between components. The Validation Protocol must therefore be constructed to recreate the major application data flows.

The scenarios supported at this stage of the project revolve around four main data flows, which are described below.

1. Collection of data from the field via meters and environmental sensors

After ChArGED deployment the database must be configured to reflect the topology and inventory of electrical equipment that will be targeted by the gamified application. The data sources that already exist within the building, as well as new meters, smart plugs and environmental sensors are also registered within the platform backend and integrated to the platform via the ChArGED data gateway using industry standard protocols.

Once the platform is configured, the gateway initiates transmission of data to the core backend and runs functionality to manage and maintain reliable connection to the various measurement devices.

A number of test cases were defined to reflect the current compliance with those specific requirements. A number of test cases are presented below to illustrate the structure and type of tests that were executed.

STEP 1: Configuration of the ChArGED backend for a new building	
Instruction	The game admin creates the new building and the various assets that will be part of the game in the database.
Expected Results:	- The game admin accesses the SiteWhere's backend admin user interface. - The game admin registers a new tenant (building). - The game admin registers a number of sites within the building corresponding to floors, departments, rooms and offices. - The game admin creates location assets to further describe the rooms if needed. The game admin creates a set of device assets with a general description of the device type to reflect a type of devices that can be found in the building. - The game admin creates devices based on the device asset specifications. The devices are the electrical equipment that we want to include into the game. - The game admin assigns each device to a person. If the device is used by many users at the same time, the game admin assigns each device to a location/room. - The game admin creates a set of IoT device assets with a general description of the device type to reflect a type of IoT devices that will be used within the building. - The game admin creates IoT devices based on the IoT device asset specifications, which are the monitoring equipment used for the purpose of the application. - The game admin associates the IoT devices to devices via their metadata to indicate how the energy use of devices is measured. - The game admin adds properties to the various assets to indicate information useful for the application, e.g. users belonging to a location.
Results	*The validation tests have been successfully executed in the controlled environment (at partners labs), which were already demonstrated at the review meeting.*

STEP 2: The Gateway is configured to collect measurements from the field sensor devices	
Instruction	The Gateway is configured to read measurements from all the sensing devices deployed within the building.
Expected Results:	- The game admin accesses the gateway admin user interface - The game admin registers new data points by specifying their name, protocol and configuration settings
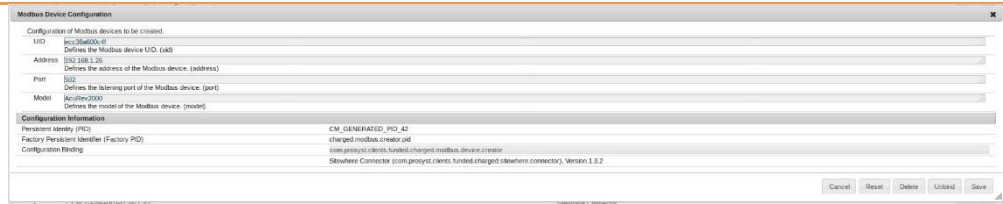
Figure 41 Configuration Example for the modbus Meter Channel

- The game admin tests the connection to the various sensing devices
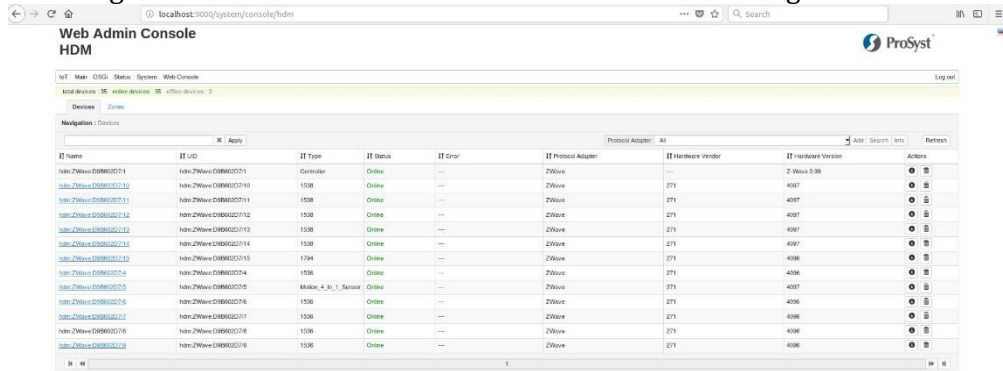
Figure 42 Admin Console overview of all connected Z-Wave devices and their status

- The game admin initiates data collection from the sensing devices to the Gateway

Results	*The validation tests have been successfully executed in the controlled environment (at partners labs), which were already demonstrated at the review meeting.*

STEP 3: The Gateway maintains reliable connection with the sensor devices and the SiteWhere platform	
Instruction	The Gateway maintains the connection to the sensor and SiteWhere and continuously sends data between them.
Expected Results:	- The backend is configured to listen to messages published to the MQTT Broker - The backend receives data payload messages sent by the Gateway and parses the data point identifier to accept the data - The backend processes the event via the inbound processing engines - The backend stores the data to the correct IoT Device assignment - The backend forwards the event to outbound processing engines for use by other system components

Results	*The validation tests have been successfully executed in the controlled environment (at partners labs), which were already demonstrated at the review meeting.*

STEP 4: The Gateway is configured to initiate data upload to the platform backend	
Instruction	The Gateway is configured to initiate data upload to the platform backend, by associating the data collected to the identifiers of the IoT device assignments, and by specifying the output communication protocol.
Expected Results:	● The game admin accesses the gateway admin user interface ● The game admin selects a data point monitored and registers its ChArGED backend identifier ● The game admin registers the MQTT Broker as output protocol destination to forward the data to ● The game admin initiates the upload of data from the Gateway to the MQTT Broker for all data points monitored
Results	*The validation tests have been successfully executed in the controlled environment (at partners labs), which were already demonstrated at the review meeting.*

STEP 5: The ChArGED backend processes incoming data payload	
Instruction	The backend system receives data published by the Gateway, and processes it to store it and generate events for other system components
Expected Results:	● The backend is configured to listen to messages published to the MQTT Broker ● The backend receives data payload messages sent by the Gateway and parses the data point identifier to accept the data ● The backend processes the event via the inbound processing engines ● The backend stores the data to the correct Device – IoT Device assignment ● The backend forwards the event to outbound processing engines for use by other system components
Results	*The validation tests have been successfully executed in the controlled environment (at partners labs), which were already demonstrated at the review meeting.*

2. **Supply of instructions to assist the end users in saving energy**

Data collected from measurements devices and the mobile app are forwarded from the ChArGED platform backend to the analytics engine for construction of predictive models and detection of abnormal patterns of energy use. The analytics engine continuously diagnoses the data collected to

identify signs of waste energy. When detected, the analytics engine notifies the platform back-end of such events, upon which actions are taken by the game mechanics engine to notify the end-user via his/her mobile app that opportunities for saving energy exist. In parallel, the mobile app runs a number of pre-set challenges to engage the users in running through a number of best practice actions and incentivises them via gamified reward mechanisms. A number of challenges are implemented to give various options to the end-user.

STEP 1: The ChArGED Data backend integrates with the Analytics backend to forward power measurements	
Instruction	The backend system receives measurements from the submeters and smart plugs published by the Gateway, and forwards them to the Analytics backend for processing.
Expected Results:	● A mechanism is enabled in SiteWhere to forward data to a standard 3rd party interface ● A mechanism is developed to receive and parse the data stream received from SiteWhere on the 3rd party interface and forward the relevant dataset to the Analytics backend
Results	The Amazon SQS queue system is used to connect the two backend systems, providing a queue where measurements are stored and retrieved asynchronously. The SiteWhere's backend outbound processing engine is configured to forward all measurements received from the Gateway to Amazon SQS (standard supported extension). *Figure 47: Creation of a new SQS queue in Amazon SQS instance to receive SiteWhere data*
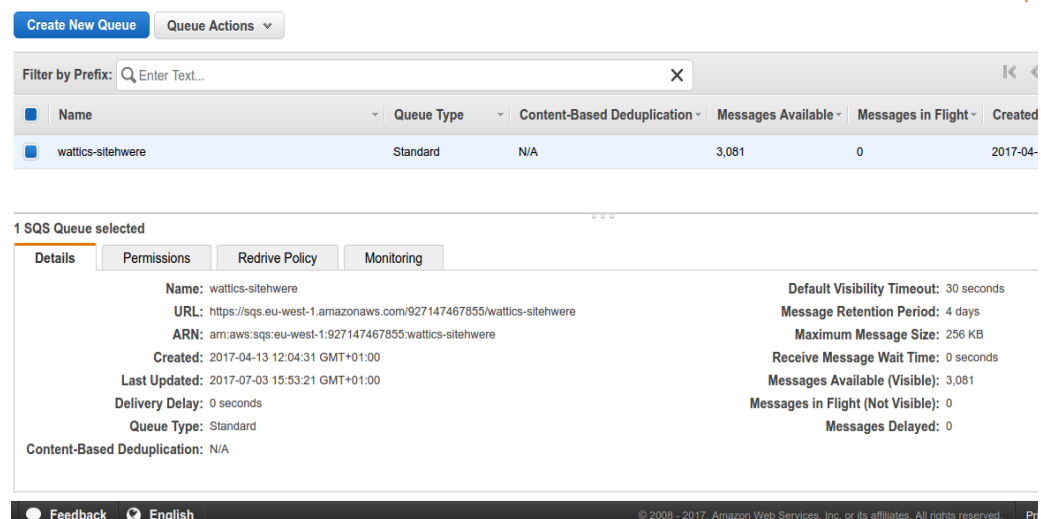
Figure 48: Configuration of data forward to the Wattics' Amazon SQS In SiteWhere via 'Manage Tenants'

Figure 49: Creation of new Amazon SQS Processor

Figure 50: Configuration of Amazon SQS credentials

At that stage, SiteWhere is configured to forward all readings to the Wattics' Amazon SQS queue.

Figure 51: Examples of power measurements stored within SiteWhere

Figure 52: Examples of power measurements stored within the Wattics Amazon SQS queue

A custom data parser (SQS Poller) is configured to continuously poll the Amazon SQS system for new data. The identifier of each new dataset is analysed to filter measurements that are neither recognised nor of interest for the Analytics backend.

The SQS Poller engine forwards relevant measurements to the Analytics backend Web API for processing

The Analytics backend receives measurements on its API end point and stores them internally for use by its analytics engines

The integration tests have been successfully executed with all components (SQS queue system, SQS Poller and Analytics backend) running online on Amazon Web Services Production servers. Tests have been conduction using real data from the DAEM pilot site (meter and smart plug data) and with events generated through the MQTT Broker.

STEP 2: The ChArGED Analytics backend maintains a reliable connection with the SiteWhere platform

Instruction	A number of tools are used to monitor the data communication performance between the SiteWhere Data backend and the Analuytics backend. Important information and errors are logged, and various alerts mechanisms are in place to notify when anomalies are detected. Finally, mechanisms to automatically restore a reliable communication between backend systems is enabled.
Expected Results:	● Important information and errors are logged ● Various alerts mechanisms are in place to notify when anomalies are detected ● Mechanisms to automatically restore a reliable communication between backend systems is enabled
Results	● Amazon Web Services' CloudWatch monitoring tools have been enabled to monitor the status of the Amazon SQS queue system, in terms of oldest message in queue and number of data packets (power measurements, NFC and BLE alerts) processed per hour. **Step 1:** Number of data packets (power measurements, NFC and BLE alerts) processed per hour by the Analytics backend for the DAEM site. Screenshot taken from Amazon SQS monitoring platform connecting SiteWhere to the Analytics backend. *Figure 51: Data packets per hour by Analytics backend*
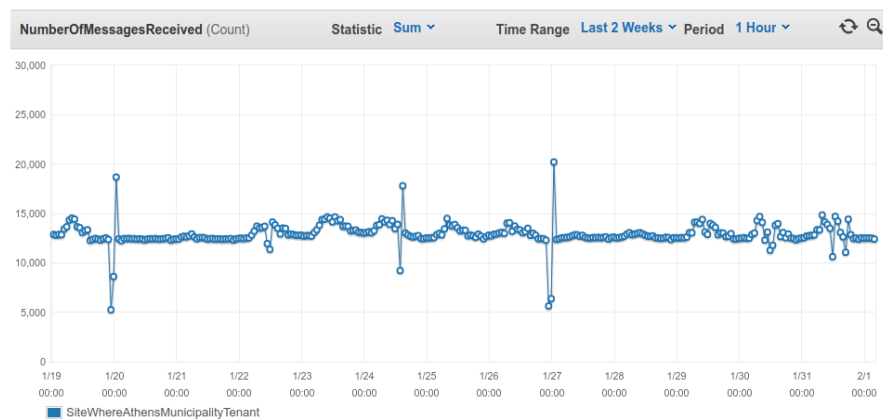
On average the Analytics backend processes over 13,000 data packets per hour. The average size for a packet is 480 Bytes. We receive power measurements from 50+ metered points at the DAEM site, refreshed every 20 seconds. All power measurements are stored and processed for creating baseline models and for user action validation, and NFC and BLE beacons are used to trigger validation of challenges.

Step 2: Approximate age of oldest message in the Amazon SQS queue connecting SiteWhere to the Analytics backend for the DAEM pilot site, where on average 13,000 data packets are sent per hour.
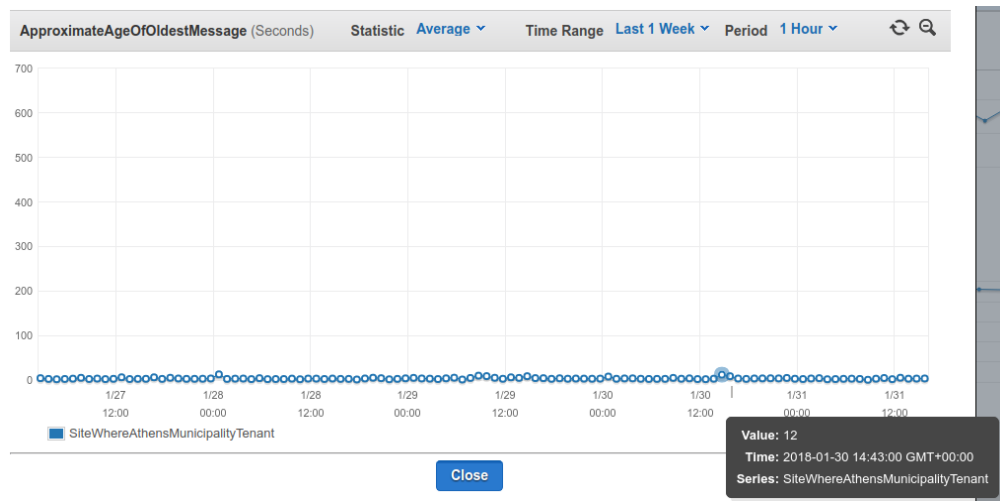
Figure 52: 7-day period graph of the oldest data packet within the queue 12-second old, while the average was 3.35 seconds. This means an average delay of 3.35 seconds before a user-triggered event is processed and computed for validation of a given user challenge.

Step 3: The server running the SQS Poller is also monitored via Amazon SQS providing performance data on processing power and memory.

Figure 53: SQS Poller monitoring

- A comprehensive log management system was developed to allow the admin team to review errors or analyse specific datasets

Step 4: The result shows the measurements received from SiteWhere and posted to the SQS queue system and monitors for the workings of the analytics engines in the Analytics backend. The bottom right part shows the data packets created by the Analytics engines being sent back to SiteWhere.

- Alerts and a portfolio of parameters have been configured with the Monit tool to allow the system to trigger email notifications when thresholds are passed and to trigger automatic self-healing measures allowing the system to react to changing metrics and solve the issues autonomously.

Step 5: The Monit configuration shows that the processor, server, system log and filesystem are monitored continuously, allowing auto-reinitialisation if alerts are triggered.

Step 6: An email is sent by Monit when an alert is detected, to provide the source of the error, a copy of the data request and the status of the environment when the error happened for troubleshooting.

STEP 3: The ChArGED Analytics backend diagnoses energy use to identify energy saving opportunities	
Instruction	The Analytics backend processes power measurements to identify abnormal energy use and notify the game engine that energy saving opportunities exist.
Expected Results:	- The Analytics backend models energy use to define the expect power curve lower and upper boundaries over time - The Analytics backend compares incoming power measurements to energy models - The Analytics backend detects deviations and triggers notifications
Results	Wattics proprietary Sentinel software engine was designed to profile a specific use of energy and to construct models to diagnose deviations from the desirable patterns, e.g., electrical appliance left powered on after working hours. Sentinel analytics software is commercially available and runs within Amazon Web Services. **Figure :** Illustration of the model created by Sentinel (green band) using historical data readings (x-axis is time, y-axis is kW demand). The green band is the area in which energy use is considered normal for a specific time of the day.
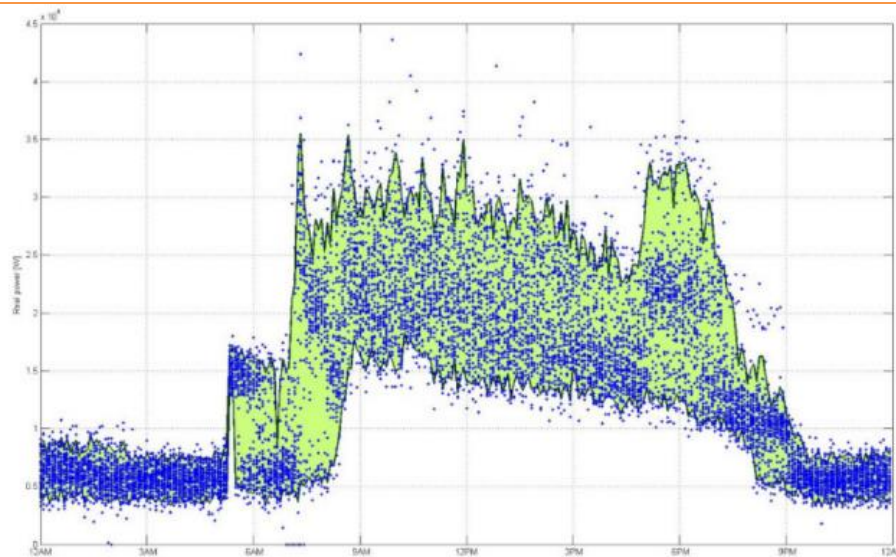
Figure 54: SQS Poller monitoring

A recommender system was developed in ChArGED to process the deviation output and trigger notifications to the game engine in SiteWhere, which can then enable end-users to rectify the undesired deviation.

3. Claim of energy savings from the end-users via the mobile app

Whether triggered by the platform notifications or from their own initiative, end-users will swipe their mobile phone over an NFC sticker to register an energy saving action of their own. They may also move within the floor plan and trigger significant events for the game. These events are communicated to the core component of the platform for immediate feedback to the end-user via the mobile app, and forwarded to the analytics engine for in-depth analysis where the savings achieved are calculated. The output is returned to the end-user for score calculation and feedback to the end-user.

STEP 1: The ChArGED Backends process incoming event from the mobile app and evaluates their in game and power savings progress	
Instruction	The Game backend processes incoming NFC and BLE beacon events to determine the challenge progress for a user. The Energy Analytics backend then combines them with power measurements to validate that energy saving actions claimed or triggered by the users have taken place.
Expected Results:	- The game backend receives events from the mobile app - The game backends processes the events - The Analytics backend receives events from the game engine describing the user actions within the game - The Analytics backend retrieves power measurements for electrical circuits affected by user action - The Analytics backend searches for power drops at the time user events are generated
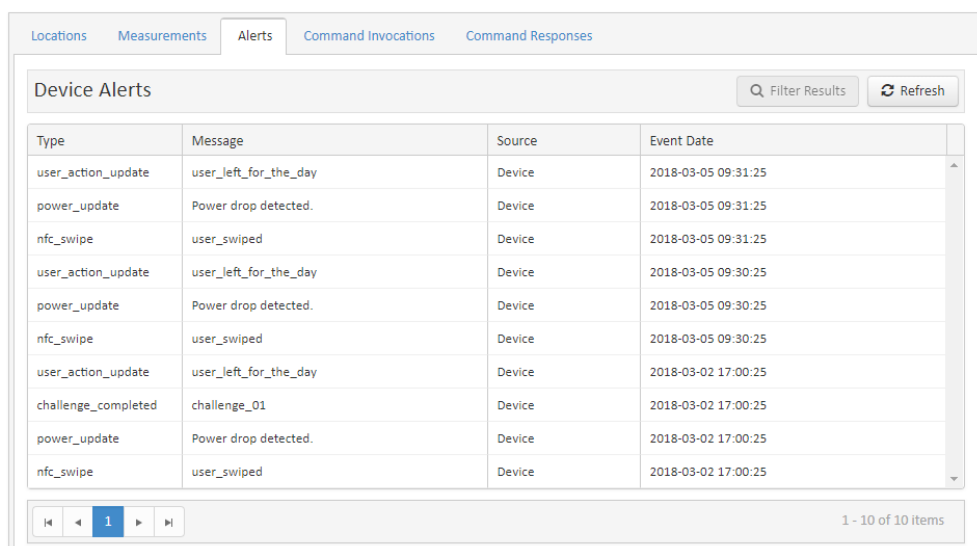
Results

The Game backend is implemented as a Java process which runs on the background and listens for events. All events coming from the mobile app or other IoT devices (except measurements) are firstly processed there. The challenge that is currently being played is then identified and then matched to a user and/or a team. Further information is then retrieved from the Energy Analytics backend regarding the changes in electricity consumption that the user actions achieved.

The analytics engines are implemented as a Ruby background job within the Analytics backend. All events are stored within a processing queue within the Analytics backend, and the background job processes the successive events asynchronously.

If specific time delays are to be respected (wait 2 minutes for the user to switch off the lights), the worker sleeps until analytics are executed.

The Power drop values are calculated and sent to SiteWhere for use by the game engine, These values are then evaluated from the Game backend in order to determine if a challenge was completed successfully.

Figure 55: Messages Exchanges by the backends and store in SiteWhere

4. **Forecast of weather conditions to optimise the use of renewable energy**

The microgeneration analytics engine forecasts the time periods when the solar irradiance will be at its highest. This insight is fed to the game mechanics engine to incentivise the use of energy during such periods, and reduction of energy use outside of said hours. Notifications are passed to the end-

users via the mobile app, and the microgeneration analytics engine monitors the readings for the PV installation to assess the overall response to the insights provided.

<table>
<tr>
<td colspan="2" style="background-color:orange;">STEP 1: The third-party weather data stream (provided by Yr.no a joint service by the Norwegian Meteorological Institute and the Norwegian Broadcasting Corporation) is properly received by the Charged server</td>
</tr>
<tr>
<td>Instruction</td>
<td>To validate that the API of the Plegma module is receiving the needed weather data from the yr.no system, the admin must open the graphic interface (in grafana) in the respective "DAEM Solar Microgeneration Energy" dashboard and check if the "Solar energy forecast" fields are populated up to date.</td>
</tr>
<tr>
<td>Expected Results:</td>
<td>● The Solar Energy Forecast fields (bottom graph - see attached screenshot) must have the hourly forecasted data plotted up to date.</td>
</tr>
<tr>
<td>Result</td>
<td>

The connection with the third party service is up and running and the admin then checks the produced system data (Plegma module forecasts) leading to step 2.

Figure 56: The Plegma forecast (up) and actual production (down), comparison

</td>
</tr>
</table>
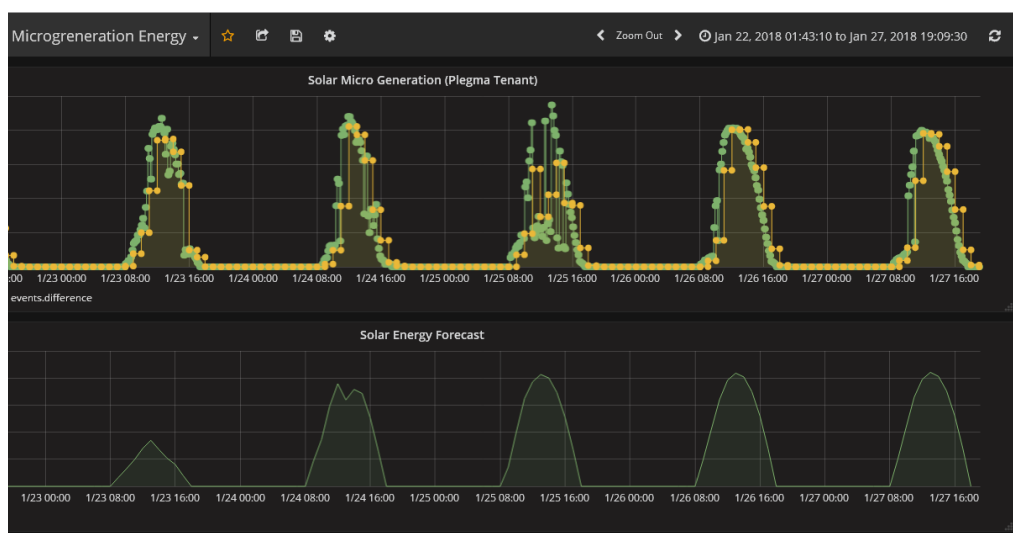
<table>
<tr>
<td colspan="2" style="background-color:orange;">STEP 2: The Plegma Solar Microgeneration Forecast module is properly producing hourly forecast data for the DAEM pilot.</td>
</tr>
<tr>
<td>Instruction</td>
<td>To validate that the Plegma module is producing the needed forecast data for the challenges including forecasted microgeneration data in DAEM, the admin must open the graphic interface (in grafana) in the respective "DAEM Solar</td>
</tr>
</table>

	Microgeneration Energy" dashboard and check if the "Solar Microgeneration" fields are populated up to date.
Expected Results:	● The Solar Microgeneration fields (top graph - see attached screenshot) must have the hourly forecasted data plotted up to date.
Results	The DAEM Solar Microgeneration service is up and running and the module is validated and the data are ready for use in the backend.

Validation Protocol

The integrated system components supporting the game scenarios implemented at each stage of the project is evaluated, and evidence of testing and the process for handling testing failures is documented. The Validation Protocol is constructed to test the four use case scenarios under the test environment, current software component specs and according to the list of test cases relevant at that stage of the project. Test cases will differ depending on which version of the software platform is released, as some use cases will not initially implement all functionality.

The Validation Protocol is central to the Validation Plan, as it defines the execution of test cases, each aiming to verify a specific element of the ChArGED system at each phase of the operation. Collaboration between partners is a requisite for such a fine-grained testing procedure at sub-component level, and the protocol allows all parties to be aligned on what functionality is being tested. Each test case includes the purpose of the test, any pre-requisites that need to be done before testing, and the acceptance criteria for the test. Test validation includes an instruction, an expected result, and the actual result, as well as operational limitations.

The actual validation has been concluded when all the steps of the Validation Protocol are executed to demonstrate the flow of information and processes common to the four scenarios supported by the current version of the ChArGED platform. The results are finally analysed and the new release of the platform can be downloaded in the lind provided above.

6 Next Steps and Conclusions

The deliverable presented the description of the 1st ChArGED integrated system, along with an overview of the ChArGED approach, the game concepts, the related use cases and challenges that are addressed with the integrated system. It further described the system architecture and software implementation details for the Data/Core Backend components that are included in the 1st integrated system. The description was accompanied with multiple indicative screenshots of the Mobile App and of an end-end challenge implementation that involved all integrated modules but the integrated system scenario has been demonstrated in real time at the project review meeting in M20.. Finally, the deliverable described the procedure for performing the testing of the ChArGED platform at each validation phase of the project to demonstrate that the ChArGED system implementation meets the requirements established in the technical deliverables.

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8 Annex Deployment plan

H2020 – EE – 11 – 2015

Research Innovation Action

CleAnweb Gamified Energy Disaggregation

Deployment Instructions

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Executive Summary

ChArGED solution is based on a complex architecture and combination of technologies, protocols and sub-systems. This document provides a summarized, simplified overview of the steps required to deploy the ChArGED solution and each specific component.

Table of Contents

1 Introduction

ChArGED aims to develop a framework that will leverage IoT enabled, low-cost devices (NFC or BLE Beacons) to improve energy disaggregation mechanisms that provide energy use and -consequently-waste at the device, area and at end user levels. This energy waste will be targeted by a gamified application that will feed personalized real time recommendations to each individual end user and will thus implement a novel social innovation process based on human incentive factors and will help users to understand the environmental implications of their actions and adopt a greener, more active and responsible behaviour.

This document provides the deployment guidelines for the CHARGED system and each specific component.

2 Hardware components / sensors
2.1 Architecture overview

This figure presents an overview of the architecture to support the understanding of the system topology outlined below. Each of the components are analysed separately.

The system architecture consists of four main groups of functional blocks:

- The Data/Core Back-end group is responsible for providing an environment in which data, assets and users are stored and managed. The Back-end components provide the software infrastructure on which the ChArGED application is developed. That group of components is application agnostic, however it is tuned towards the needs of ChArGED project.
- The Gateway group is responsible for integration of energy use and environmental data to the Back-end system, to determine variations over the energy context within the building.
- The Analytics Back-end component is responsible for delivering insights that will enable the ChArGED application to deliver custom and targeted feedback and incentives to the end-users.
- The Gamification group is responsible for processing field data and insights created from such data and make decisions as to the evolution of the game for each user, i.e. what the next step is towards more energy savings. That group also delivers the mobile app the end-users interact with which acts as an interface between the user and the charged system updating the user with the current game state and also provides information to the system about the users' behaviour towards the energy saving goals set.

The architecture also includes an external system that is utilized to provide a solar power microgeneration forecast based on weather predictions for the specific location. It serves to maximize the building energy savings, increase end user awareness as well as to enable the use of the mobile app to maximize the solar-based electricity consumption during production, avoiding the need for energy storage

Figure 1 ChArGED architectural overview

2.2 SiteWhere Server

The Data/Core Back-end system components and infrastructure were implemented in SiteWhere[1]. The available functionalities are the following:

- Each new asset or entity (i.e. a sensing device, an appliance, a specific location area, a person) is assigned a unique id and can be autonomously monitored via external software. Specifically, a model for standard types of generated event data is provided for each device (which includes measurements, alerts issued and location updated by the device). The logged events are stored in massively scalable time series datastores (InfluxDB).

- Devices (appliances such as printers, air conditioners, a PCs etc) can be assigned to / associated with other entities. A can be associated with a person, a location or another sensor device of our infrastructure thus giving us the ability to establish ownership room/location metadata and establish relationships with device.

- Devices can be grouped together according to a common role they fulfil, something that enhances efficiency by simplifying the way the devices can be retrieved by other backend processing services.

- Every top-level entity is modelled as a tenant and can have a completely different configuration and structure without affecting other tenants. This can be used for modelling infrastructures that are unrelated to each other such as different locations, different buildings, pilot users etc on the same server.

Registration of new or existing devices (building appliances and sensors)

SiteWhere devices can be created manually with API calls, or they can be self-registered. In later case, the device provides a unique hardware ID and a specification token to the system which in turns creates a new device record that can start accepting events. SiteWhere assumes that each device will have a unique ID in the system so it can be independently addressed. The specification token passed at startup indicates the type of hardware the device uses and references a device specification that already exists in the system. Devices send a registration event when they boot or connect to the network and SiteWhere either creates a new device record or finds an existing one.

Registration of electrical circuits (monitored by submeters and smart plugs)

Power measurements retrieved by the ChArGED gateway from the deployed submeters and smart plugs need to be uploaded to SiteWhere and be associated to devices. The type of device depends on the entity being monitored, for example, if a multi-channel submeter monitors 18 single-phase circuits, 18 'Circuit' devices must be registered in SiteWhere to hold the measurements. If a smart plug is used to monitor a specific computer, power measurements will be associated to a 'PC' device.

---

[1] Sitewhere: The Open Platform for the Internet of Things, https://www.sitewhere.org/

Figure 1: List of Sitewhere Device entities that can be created to hold measurements by the metering and IoT infrastructure

Physical electrical circuits feed wall plugs, lighting fixtures and air conditioning equipment within locations of a building, as such 'Circuit' devices registered in SiteWhere must reflect that setup. 'Circuit' devices are therefore assigned to 'Location' assets, see example below.

Figure 2: Illustration of the assignment of SiteWhere Circuit devices to building Locations

The ID used when registering the 'Circuit' device should be globally unique. This is the ID that the gateway will use when pushing data to SiteWhere.

The naming convention chosen when using the 18-channel meter from Accuenergy is to set the ID as <metermacaddress>CHx, with <metermacaddress> to be replaced by the mac address of the meter in lowercase without space, and x the channel number. For example, the screenshot above shows that the ID is ecc38a600c4fCH18.

For Zwave smart plugs, the ID is the device specification token automatically assigned by SiteWhere when device is registered.
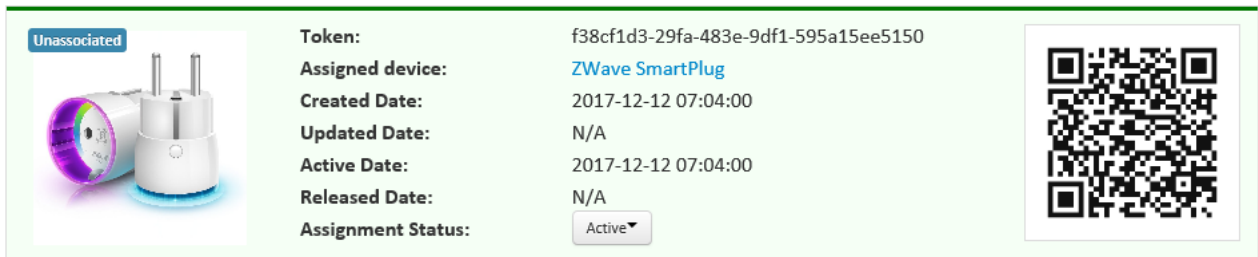
Figure 3: Illustration of Zwave smart plug device registration within SiteWhere

2.2.1 Asset Modules

Assets represent objects in the physical world – people, places, and things. Device specification assets are used to describe the hardware information/configuration for a type of device. Rather than hard-coding a schema for assets in the system, SPIs will be defined for general asset types, allowing asset modules to be plugged in to provide asset definitions. This allows existing identity management systems to be used in providing a list of available person assets. It also allows product catalog systems to be used in defining available hardware assets. The concept of asset categories which reside in the datastore will also be provided.

2.2.2 Object Model

A comprehensive object model captures the relationships between all of the various concepts in tracking device data. The diagram below shows some of the core objects in the model and their relationships:
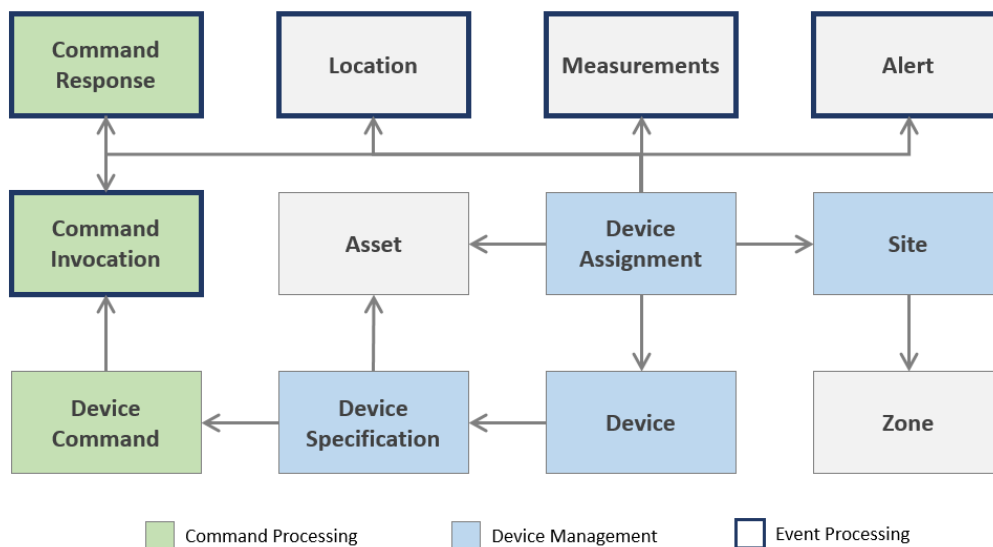
Figure 4: ChArGED entities overview

2.2.3 Sites - Buildings

Sites are used to organize devices that are cross-related so that their events can be looked at from a grouped perspective. The primary use case for sites is in location-aware devices. A site provides a

containing entity to which a map can be assigned so that location data can be viewed in the context of that map.

2.2.4 Zones - Rooms

Another important feature for location-aware applications is the concept of zones that carry special meanings. For instance, in a building, there are areas where certain devices can be used (e.g. photocopy machines) so when a person enters a this zone the energy consumed by those devices can be associated with this person.

2.2.5 Device - Appliance Specifications

Specifications are used to capture characteristics of a given hardware configuration. A device specification contains a reference to a hardware asset which provides the basic information about the hardware including name, description, image URL, etc.

2.2.6 Devices - Appliances

Devices are a representation of connected physical hardware that conforms to an assigned device specification. Each device will be addressable by a unique hardware ID that identifies it uniquely in the system. A new device can register itself in the system by providing a hardware id and device specification token.

2.2.7 Device - Appliance Groups

Device groups allow multiple related devices or subgroups to be organized into logical units. The groups can then be used for performing operations collectively rather than performing them on a per-device basis. Each group can have zero or more roles assigned to it, allowing arbitrary groupings based on application needs. Devices may belong to multiple groups and may be assigned zero or more roles within the group

2.2.8 Device Assignments

Events are not logged directly against devices, since a given device may serve in a number of contexts. For instance, a visitor badge may be assigned to a new person every day interacting with appliances and their energy. Rather than intermingle event data from all the people a badge has been assigned to, the concept of a device assignment allows events to be associated with the asset they relate to. A device assignment is an association between a device, a site, and (optionally) a related asset. Some assignments do not specify an asset and are referred to as unassociated.

2.2.9 Device - Appliance Events

Device events are the data generated by connected devices interacting with system with types of events such as **Measurements.** Measurement events send measured values from a device to the core system. Measurements are name/value pairs that capture information gathered by the device. For instance, a smart plug sensing device will send measurements for total energy and instant power.

2.3 Solar Microgeneration Inverter

Figure 5: ChArGED solar inverter - Kaco blueplanet 5.0 TL3

ChArGED system takes advantage of a solar energy generation net metering solution in one of the pilot sites, maximizing the building energy savings, increasing end user awareness and also maximizing the solar-based green electricity consumption during production, avoiding the need of energy storage.

The solar solution is based on the solar inverter (Kaco blueplanet 5.0 TL3) which provides rich energy metadata information via both modbus TCP communication and web based / dsv export capability, enabling the detailed monitoring of the generated electricity assisting production forecasting mechanisms.

Solar inverter is connected via the gateway and its gateway middleware IoT integration software mBS SH. Through the device abstraction of the mBS SH the data are prepared for the ChArGED backend and sent via MQTT to the ChArGED core platform and distributed to all other system components.

2.4 Multi-channel smart meters

Public buildings are supplied with three-phase power to be able to deliver power to both single-phase end-loads e.g. lighting and wall-plug appliances, and three-phase end-loads e.g. air conditioning.

Three-phase meters are generally used in non-residential settings to measure electrical energy consumption of an entire distribution board using three current transformers (CTs), each clamped to a different phase of the supply line.
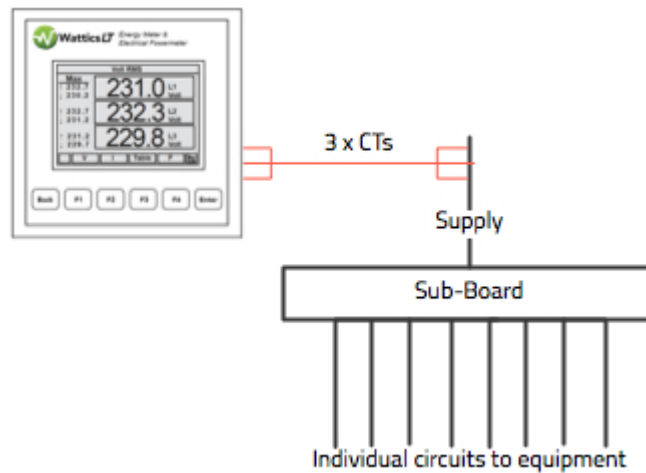
Figure 6: Illustration of a three-phase meter monitoring the electrical supply of a distribution board with three current transformers clamped to the three phases of the supply line

Because small loads are widespread in public buildings, e.g. lighting units and plugs for computers and office equipment, electrical panels are generally made of many single-phase circuit breakers, feeding lighting fixtures and plugs individually.
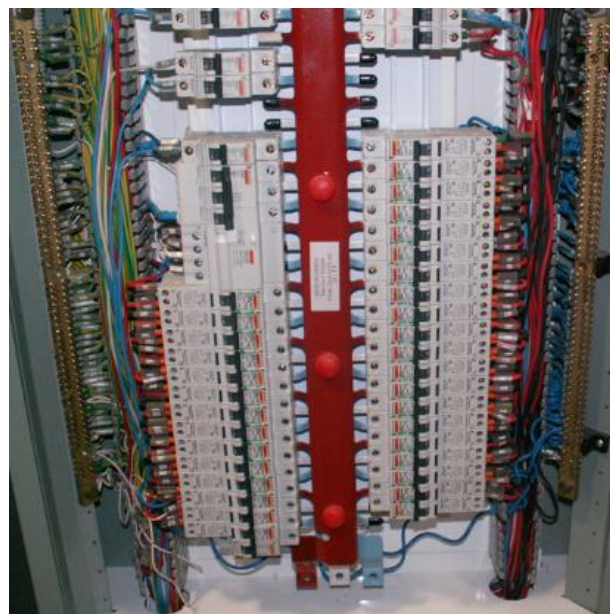
Figure 7: Example of office building electrical panel, showing many single-phase circuits feeding equipment on the floor plan

In that setup, all circuits must be monitored individually with dedicated CTs in order to measure energy use and demand variation for equipment fed by such circuits. Multi-channel meters offer a cost-effective solution for monitoring multiple circuits, by allowing many CTs to be connected to a single meter.

Figure 8: Photo of the Accuenergy AcuREV2000 18-channel meter used for monitoring single-phase circuits in public building environments

Accuenergy offers with their AcuREV 2000 series a 18-circuit power metering system that monitors kilowatt-hour (kWh), power, energy, demand, peak demand and time-of-use (TOU) in high-density applications. It is best used for tenant submetering, commercial facilities and branch circuit monitoring where multiple circuits require monitoring.

2.5 Gateway and zwave controller

2.6 zwave smart plugs

Zwave smart plugs are installed into any power outlet and that outlet is instantly smarter that captures the energy that is used through this outlet. This information is sent through the zwave network to Sitewhere in the CHARGED system.

Figure 9: Zwave plugs

2.7 zwave window contact sensors

Door window sensors serve a simple purpose: they capture events related to a door or a window opening or closing. When connected to Z-Wave network this information can is captured in Sitewhere.

Figure 10: Zwave window sensors

2.8 zwave 4in1 sensors

This is a 4in1 sensor which monitors motion, temperature, humidity, and light level and transmits those to the Sitewhere.

Figure 11: zwave 4in1 sensors

2.9 NFC tags
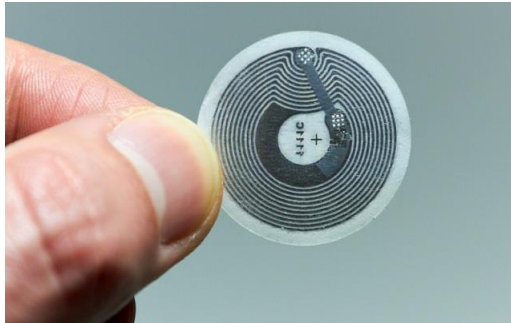
Figure 12: NFC sensor tag

NFC sensors **NTAG213** at 38mm diameter provide the lowest-cost while keeping a very fast reading speed and long range. ChArGED mobile app is designed to capture the NFC events and trigger the verification of a user action, through the energy disaggregation mechanism, ie. if a user swaps the phone over a turned-on computer, means that he turns it off, and this is confirmed by the analysis of the energy comsumption measurement in the energy disaggregation engine.

2.10 BLE beacons

Figure 13: BLE Beacons

Estimote Proximity Beacons are used for indoor localization. Battery life time is 2 years by default. The estimote mobile app can be used to "lock" the write ability of the BLEs.

2.11 Smartphone

Figure 14: Samsung K8 Smartphone-CHARGED recommended

Recommended and tested smartphone for Charged application is the Samsung Galaxy K8 2017 are used due to their low cost, Android 7, and BLE/NFC capability.

3 Installation Guide

3.1 Overview of deployment steps – high-level

The following presents an overview of the steps that are needed to install and deploy the CHARGED components, which are further detailed in the following chapters:

1. Setup RPi gateway as the ChArGED gateway and configure according to Prosyst's 10 page instructions (is included from chapter 3.2 following)
   a. Linux admin or developer skills required
2. Open Prosyst web console (e.g http://192.168.1.25:81/system/console/hdm)
   a. go to zwave controller (node1) change mode to "adding"
      i. Repeat as needed
3. Power up new every zwave device, one by one
   a. Triple click to pair (or follow manufacturer's instructions)
   b. Add a paper sticker with node id given to device by controller (visible in /system/console/hdm)
   c. Repeat with all plugs, 4in1, window contacts
4. Place new plug/4in1/contact in appropriate location, keep note on a document* for later update in SiteWhere
5. Program each NFC sticker using ChArGED app in admin mode (or NFC TOOLs app)
   a. Make a node of the UUID of each NFC on a document*
6. Place every sticker on appropriate location and keep notes on a document* for updating SiteWhere later
7. Identify BLEs and record their Mac Addresses on a document, as they will be registered later to SiteWhere. The identification of the BLEs can be done by using ChArGED app in admin mode (or Estimote app) identify each BLE.
   a. Take all BLEs away a few meters from the smartphone, keep one close and read it's Mac Address(Estimote app requires BLE owner to be logged in)
   b. ALTERNATIVE approach: scan the internal NFC of the beacon and via the estimote cloud find out the BLE Mac Address
8. Place every BLE on appropriate location and make a node on document* for later update in SiteWhere
   a. Select locations that maximize variation of distance between users / and differentiate
9. Install multi-channel meters at electrical panels to monitor circuits feeding plug-load, lighting and air conditioning equipment of the floor plan
   a. Registered electrician will need to be contracted to conduct the installation wrk
   b. Labeling work will be required before installation to identify which circuits to monitor for the needs of the ChArGED application

*keeping notes of Mac Addresses on document makes deployment slower, cumbersome and prone to errors. These actions should be fully automated and be part of the game process even if the end-users will not perform the deployment.

3.2 Gateway preparation

3.2.1 Required Hardware

1. Raspberry Pi 3 Model B / SD card / PSU / Enclosure.
2. USB ZWave controller attached to the one of Raspberry Pi USB ports (serial controller http://www.vesternet.com/z-wave-me-razberry-2-pi-gpio-daughter-card-gen5 is supported also).
3. ZWave Smart Plug with Power Metering http://www.vesternet.com/z-wave-fibaro-wall-plug-schuko-gen5 http://www.vesternet.com/z-wave-aeon-labs-smart-switch-6-gen5, optional.
4. ZWave Window contact sensor http://www.vesternet.com/z-wave-fibaro-universal-door-window-sensor, optional.
5. ZWave Motion 4-In-1 sensor http://www.vesternet.com/z-wave-fibaro-motion-sensor-gen5, optional.
6. Modbus Power meter AcuRev 2000, optional.
7. Modbus Solar Inverter Powador 12.0, optional

3.2.2 Required Software

1. ProSyst runtime installation file
2. Oracle ejre on Raspberry
3. cdc_acm module on RaspBerry. Check if available with 'lsmod | grep cdc_acm'. If the ZWave USB stick is attached 'ls /dev' should show one /dev/ttyACMx (e.g dev/ttyACM0) device.
4. SSH Client program like Putty https://www.chiark.greenend.org.uk/~sgtatham/putty/latest.html
5. SFTP client like WinSCP for Windows https://winscp.net/eng/download.php]

3.3. Installation

1. The installation archive is called com.prosyst.clients.funded.charged.image.runtime-x.x.x.tar.gz, where x.x.x is the installation version.
2. The archive has to be copied into the Raspberry PI to a temporary folder, for example '/home/pi/mbs-install'. For file transfer from Windows machine it could be used WinSCP.
3. Login in Raspberry PI with your client application (Putty) and extract the archive from the respective directory with the command:

        tar xvzf com.prosyst.clients.funded.charged.image.runtime-1.0.2.tar.gz

4. After extracting, you have to make the script 'install.sh' executable and to start it:

        chmod +x install.sh
        sudo ./install.sh

        output:
        Executing pre-install script...
        Executing pre-install script... done!
        MAC Address: b827eb45fe87
        Serial Number: 00000000fc45fe87

Configuring stack with:
Provisioning SPID: b827eb45fe87
PRM Manager URL: ssltcp://35.157.248.28:2443

insserv: warning: script 'mbssh.setenv.sh' missing LSB tags and overrides
Executing pre-install script...

Note: When using serial USB devices ensure that usb-to-serial modules are available for this kernel

The stack will start automatically after reboot
Manual start via:
 /etc/init.d/mBSSH.sh start

Installation complete.

Executing post-install script...
Executing post-install script... done!

5. Warning may be printed like:
   insserv: warning: script 'mbssh.setenv.sh' missing LSB tags and overrides

   The installation will produce following folders:

   /mbs - program location
   /mbs-data - data location for storage and logs

   It is using 'update-rc.d' command with 'defaults' parameter for auto starting runtime after reboot of the system.

   Manual start or stop is possible via several ways:

   'sudo /etc/init.d/mBSSH.sh start' or 'sudo /etc/init.d/mBSSH.sh stop'
   or/and
   'sudo /mbs/mbsa/bin/mbsa_start.sh' and 'sudo /mbs/mbsa/bin/mbsa_stop.sh'

6. Configure the system as shown in section 4.
   Modify the SiteWhere siteToken as descibed in section 4.1. (If not modified the devices will be attached to ProSyst site.) Define Modbus devices as shown in section 4.2)

7. Reboot the system via:
   sudo reboot

8. The runtime will be started automatically after reboot.

3.4 Pairing of Zwave devices

1. Read the ZWave device vendor instructions first.
2. Set the ZWave Controller in Adding mode:
   a. open http://<RPi-ip>:<port>/system/console/hdm (port should be 80, 8080 or 81)
   b. click on icon 'i' (right) of the ZWave Controller
   c. find Device Class ZWaveNetworkController table
   d. set **mode** to Adding
   e. click 'set property value' button (right arrow)
3. Set the end device in pairing mode via the vendor instructions. (It is popular to be quick triple click of a button)
4. After a few seconds the ZWaveNetworkController **mode** property should change to Normal and at http://<RPi-ip>:<port>/system/console/hdm should appear new end device with Online Status.

If the end device was paired to another network before it must be removed from this network first. This is ZWave protocol specifics. If this is the case set ZWaveNetworkController **mode** to Removing and follow the vendor instructions.

Figure 15: Photo of ChArGED 4-in-1 sensor deployed in ICAEN office floor plan

3.5 BLE placement

BLEs are used to capture the location of users. This is particularly necessary for offices with many rooms and areas for example DAEM where one BLE is placed per room. In the case of big spaces with a lot of desks one BLE will be placed for small groups of desks (for example every 4 desks). The local administrator will need to log in at the account of the BLE provider at google play (where there is ESTIMOTE app   https://play.google.com/store/apps/details?id=com.estimote.apps.main&hl=en) (the email and password used when buying the BLEs is required) and configure each BLE. In the configuration screen disable all options except for the IBeacon protocol which is the one used in CHARGED. Set the the Advertising Interval = 300ms. Also set in the same tab:

     a. if the BLE covers a whole office, Transmit Power (Tx) = Weak (-20 dBm) (coverage radius~3.5m)

     b. if the BLE covers a small area of around four desks close to each other in the same room, Transmit Power (Tx) = Weak (-40 dBm) (coverage radius~0.25m).

The MAC address of the BLE is then retrieved through the ChArGED app and mapped to all the users it corresponds to in a separate document which should be then sent to ED to integrate in the SiteWhere. In case of a common area (for example kitchen) or elevator the same process can be followed with Transmit Power (Tx) = Weak (-20 dBm) is the BLE is placed in a room or Transmit Power (Tx) = Weak (-40 dBm) for an elevator.

3.6 NFC placement

Each NFC should be placed according to the map on the building as follows: An NFC is placed at each desk, one for each room (towards the exit of the room) and one in the middle of each flight of stairs, one for each shared device. Each NFC is empty in the beginning. Using the ChArGED Deployment app (see below in the app section) each NFC is registered to SiteWhere with specific metadata that will

be needed to identify it during the actual game. The NFC will also be automatically locked by the app so it cannot be further modified.

It is recommended to first design and number the NFCs on the map so that all of them are well representing the devices in the building. The guidelines detailed below present the process to be followed for the NFC configuration in the SiteWhere and CHARGED system.

Figure 16: Photos of NFC stickers deployed at ICAEN officefloor plan near lighting control switches

Figure 17: Photos of NFC stickers installed near computing and kitchen equipment at ICAEN office to allow users to inform the system when equipment is switch off for energy saving purposes

3.6.1 Password protect the NFC tags

Upon (or before) placing the NFC stickers use the ChArGED Deployment app (See below) to pre-configure the URI Package so that only ChArGED app will handle the tags and password protect NFC stickers to ensure no tampering is possible.

3.7 ChArGED Deployment App

3.7.1 Overview

The app can be downloaded at

https://drive.google.com/file/d/1Q1fv2TMuXSQz4YAHeZjnC9ZR9Pao93B-/view)

The app supports the deployment in order to easier gather the NFC and BLE IDs. It is capable of reading/writing NFCs, listening to BLEs and storing the data in the smartphone in two separate csv files. The files can then be emailed through the app.

The data are stored in the following format

1,<NFC_id1>,NFC

2,<NFC_id2>,NFC

3,<NFC_id3>,NFC

the same for bles.

We also need to have a map of the building where we will note the NFC/ble number 1,2,3,4 etc. Then we can then find the corresponding id from the mapping.

3.7.2 Description

1. The app has two tabs one for the NFC and one for the BLE IDs to support the configuration of NFC and BLEs respectively. In the NFC tab one can scan NFCs that have already been written by the app. On the BLE tab the app will identify and display the closest BLE to the smartphone.
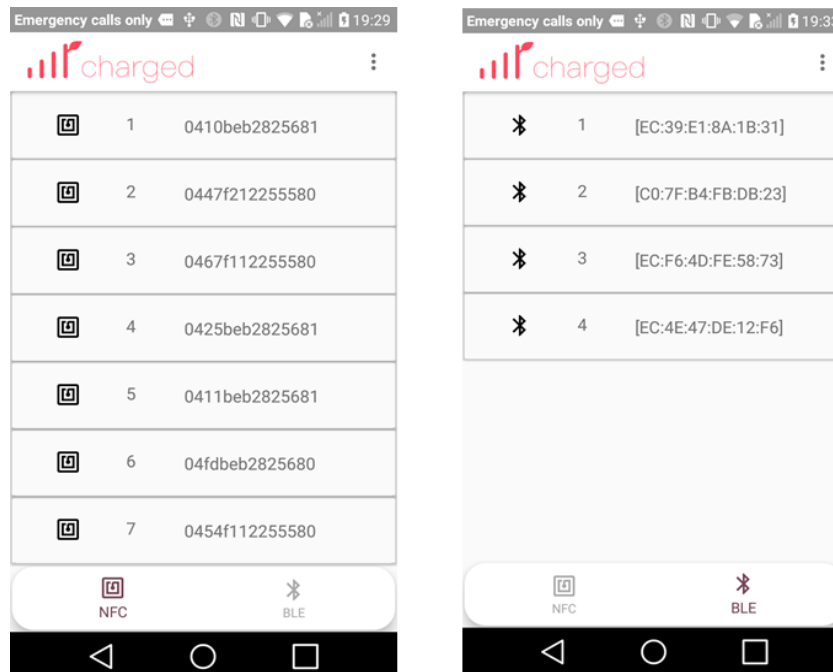

Figure 18: Screenshots of the ChArGED Deployment App showing how NFC stickers and BLE beacons deployed on the floor lan can be registered and assigned a unique ID for mapping to floor plan location and use for the game application

2. All the data are written in the Document/Charged folder in the ble-mappings.csv and NFC-mappings.csv files. The files aree visible for most devices through the File Manager but in some they may marked as private and hidden. In either case you will be able to send them via email through the app.

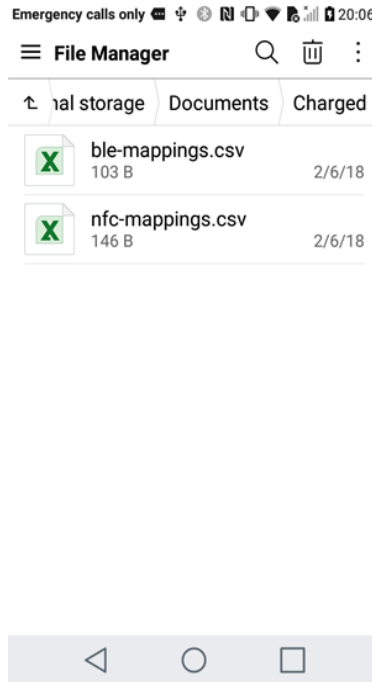*Figure 19: Screenshot showing the CSV files created by the ChArGED Deployment app to export the registered NFC stickers and BLE beacons for configuration of SiteWhere*

3. From the menu select Write/Lock NFC. The app will ask you to scan, the NFC and write on it the CHARGED metadata (the given name/number you have selected from the map). The NFC will also be locked by the app so it can't be modified later.
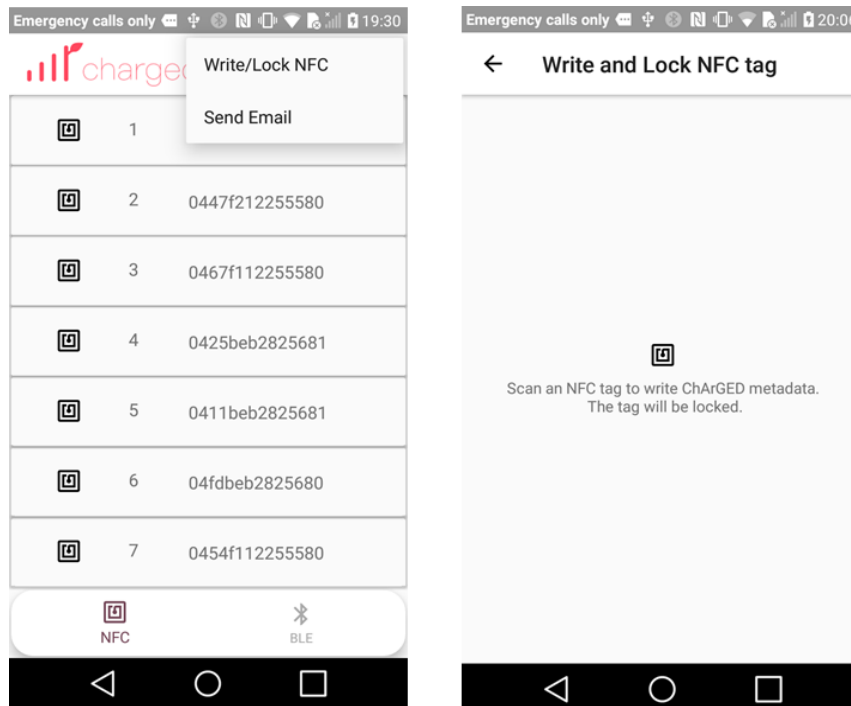
Figure 20: Registration of NFC stickers starts by writing the ChArGED metadata using the Write/Lock NFC feature

4. Each NFC and BLE ID can only be stored once. If an ID has already been stored a message with its details is provided.
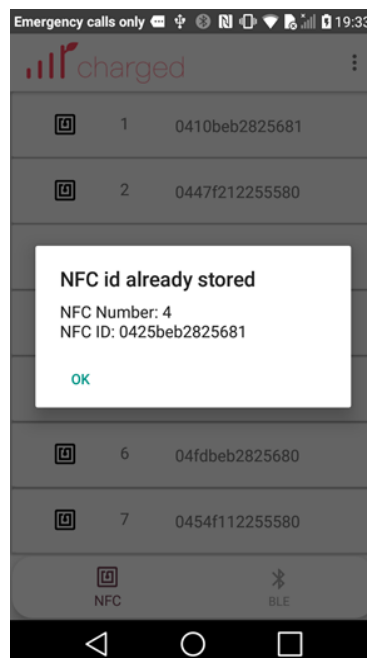
Figure 21: Screenshot showing that duplicate NFC sticker registration is prevented

5. When the deployment is finished select Send Email from the menu to send the files via email. For the beginning they can be sent to the default email preconfigured.
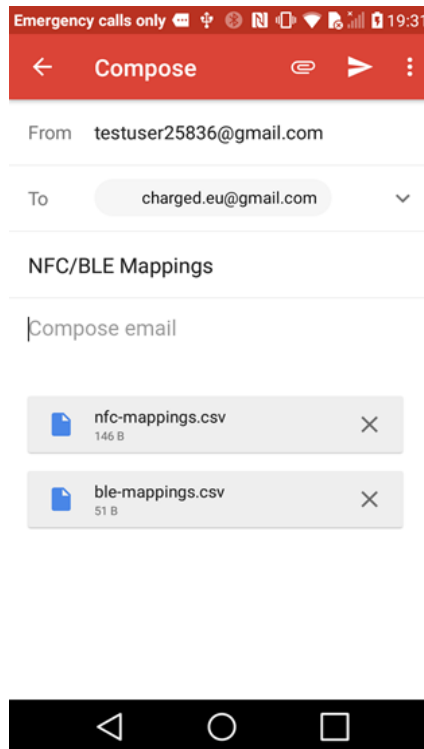
Figure 22: Screenshot showing how lookup tables for NFC stickers and BLE beacons can be exported by email

3.8 Multi-channel meter installation
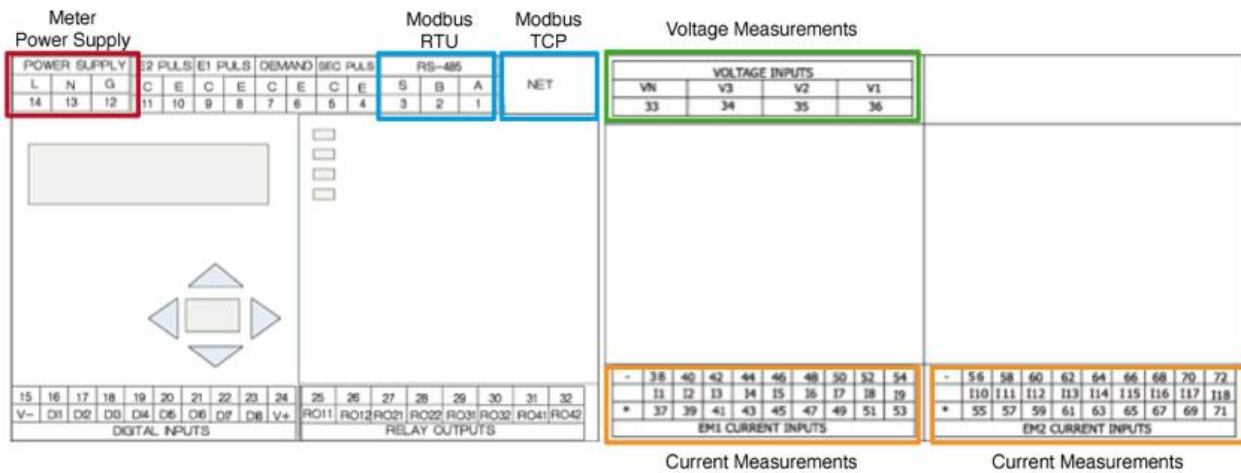
Figure 23: Schematics of the Accuenergy AcuREV 2020 18-channel meters showing the terminals used for voltage and current measurements, as well as power supply lines and Ethernet port for Modbus TCP communication with the ChArGED gateway.

Installation of the meters must take place according to the steps below, using suitable equipment and tools. Be careful to consider the following advises in this process:
● Devices must be installed without voltage applied and by qualified personnel.

- General safety regulations and nationally applicable accident prevention guidelines must be observed.
- Electrical installation must be carried out according to the relevant safety guidelines

STEP 1: Prepare the meter installation report

The meter has 18 terminal inputs (I1 to I18) to connect 18 CTs that will monitor 18 monophase circuits. Before the actual electrical wiring starts it is good practice to plan and document which CT will be used for which circuit, and how they will be connected back to the meter.

- The first step is to choose CTs with the most suitable primary rating for the circuit being monitored (e.g. a CT with a 300A primary rating for a circuit fed through a 250A circuit breaker).
- You can then label all the CT heads to facilitate deployment and not get mixed with all the CTs around (e.g. a CT head labeled S3 will be clamped to circuit called S3).
- The labeling of the CT leads is also useful to avoid getting the leads mixed when pulling them through the distribution board, and to quickly identify where to connect the CT leads back at the meter terminals (e.g. a CT lead labeled S3-15 will be clamped to the meter input terminal I15).

Important: it is necessary that the following is respected:

- All circuits fed from L1 (phase A) must be connected to inputs I1, I2, I3, I10, I11 and I12
- All circuits fed from L2 (phase B) must be connected to inputs I4, I5, I6, I13, I14 and I15
- All circuits fed from L3 (phase C) must be connected to inputs I7, I8, I9, I16, I17 and I18

For example, a single-phase lighting circuit fed from L2 can be clamped with a CT wired back to meter terminal input I4, I5, I6, I13, I14 or I15. Similarly, a three-phase circuit fed from L1, L2, L3 can be clamped with three CTs wired back to meter terminal inputs I1, I4 and I7 for example.

The table below shows how 18 monophase circuits can be wired based on their supply phase.

		CT inputs																	
		I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14	I15	I16	I17	I18
Supply phase	L1	1	2	3							10	11	12						
	L2				4	5	6							13	14	15			
	L3							7	8	9							16	17	18

Figure 24: Mapping table showing how monophase circuits can be wired to the 18 terminal inputs of the Accuenergy AcuREV 2020 meter based on their supply phase.

Now that the wiring setup is pre-configure, fill in a meter installation report.

Wattics	Wattics Limited	31-33 The Triangle, Ranelagh, Dublin 6, Ireland Tel. +353 1 532 7875 e-mail: support@wattics.com					
Customer Name	WATTICS LTD						
Site Name	HEAD OFFICE						
Site Address	RANELAGH, DUBLIN, IRELAND						
Electricity Supplier Name	AIRTRICITY						
Installation Date	01/03/2016						
Area Name	Circuit monitored	Meter input (I1..I18)	Phase monitored	CT size (A)	Parent circuit	Meter serial number	
1st Floor	C5	I1, I4, I7	1,2,3	250		ecc21f21045	
1st Floor	C1	I2, I5, I8	1,2,3	250	C5	ecc21f21045	
1st Floor	C2	I3, I6, I9	1,2,3	250	C5	ecc21f21045	
1st Floor	C3	I10, I13, I16	1,2,3	250	C5	ecc21f21045	
1st Floor	C4	I11, I14, I17	1,2,3	250	C5	ecc21f21045	

A WattREV-6 Meter Installation Report template is available for download **HERE**.

STEP 2: Provide voltage references to the meter

Wire the meter voltage reference inputs to a Type C 6AMP 3P breaker to provide voltage reference for power calculation. Make sure the breaker is in the OFF position.
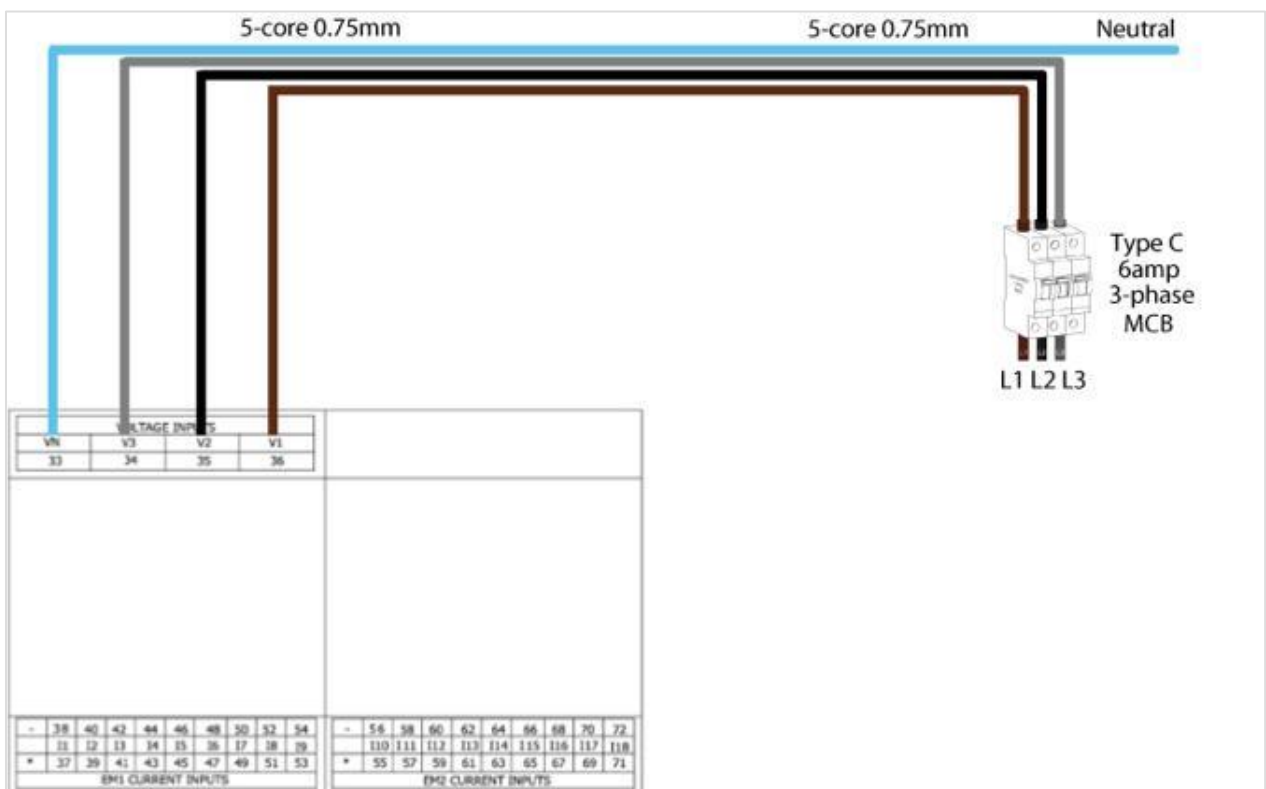

Figure 25: Illustration showing the way voltage reference should be provided to the Accuenergy AcuREV 2020 meter via a 3P Type C breaker

Note: the breaker must be fed from the same transformer as the circuits being monitored to ensure that the correct voltage references are applied for power calculations.

STEP 3: Supply power to the meter

Wire the meter L and N voltage supply inputs to the breaker L1 and N output terminals or short the V1 and VN reference voltage lines to the L and N voltage supply lines as shown in the figure below.
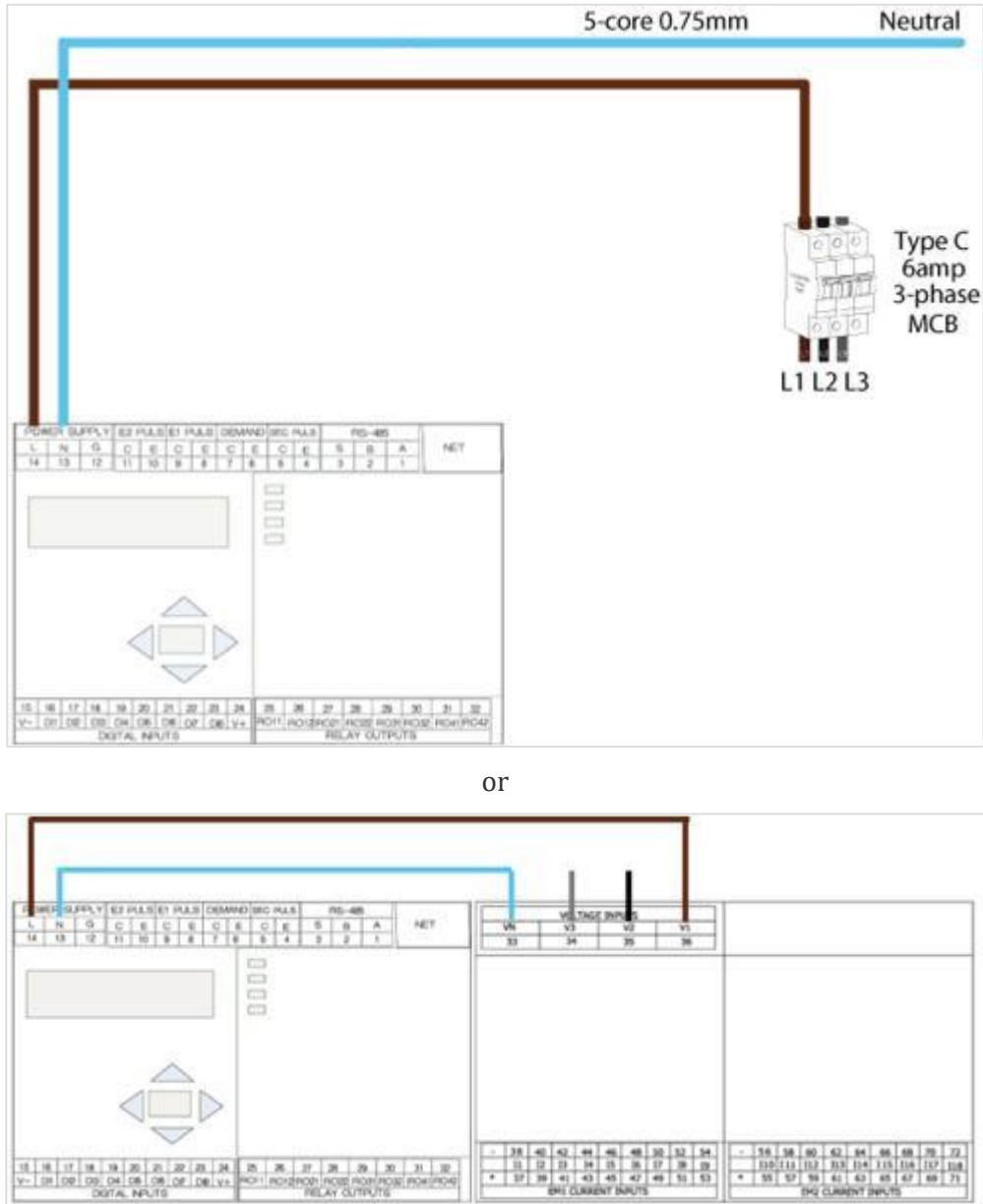

or

Figure 26: Illustration showing how the power supply line of the Accuenergy AcuREV 2020 meter can be wired, either from a circuit breaker or by creating a loop from the voltage reference lines

Figure 27: Photo showing the wiring of the voltage reference and power supply lines of the AccuenergyAcuREV 2020 meter deployed at the ICAEN pilot site

STEP 4: Prepare the meter for Rogowski coil or CT connections

Carefully attach the meter to din rail pre-mounted within the meter compartment or enclosure. This process can also be done once all the Rogowski Coils and CTs are wired in the case wiring is made easier with the meter outside the meter compartment.

Figure 28: Electrician adding an enclosure to locate the meter outside of the electrical panel compartment

Now remove the two current measurements terminal blocks from the meter (see below cover and terminal). The left terminal block has 9 inputs (I1 to I9, left to right), and the right terminal block has 9 inputs (I10 to I18, left to right).
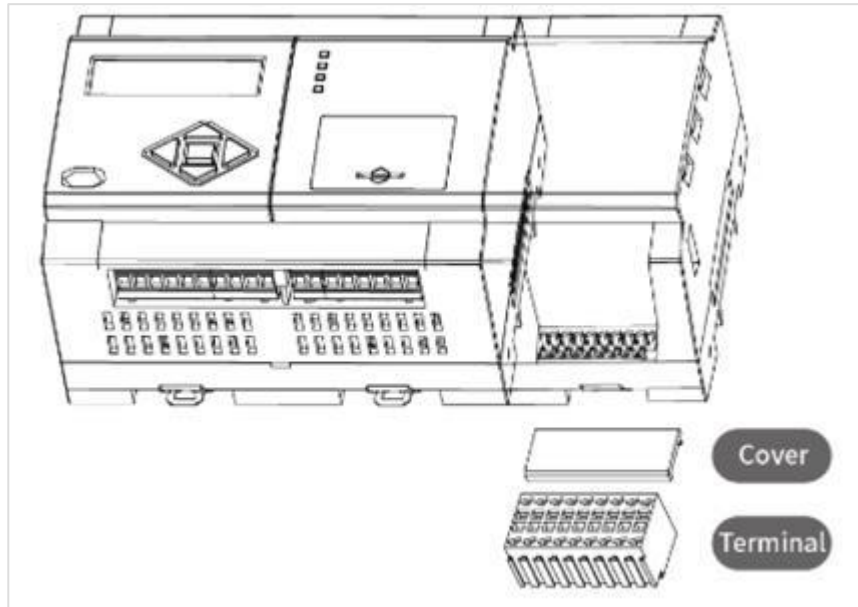

Figure 29: Diagram showing how the current terminal block can be removed for easy wiring of the CT end cables to the AcCuenergy AcuREV 2020 meter.

STEP 5: Deploy the CTs

The next step is to clamp the CTs to the electrical circuits and wire them back to the meter current measurements terminal blocks. This procedure must be conducted as follows with extreme precautions:

● Power the circuit down temporarily (working with live circuits may be possible if all safety precautions are taken and under agreement from the customer)
● Position the CT next to the circuit to be clamped, but do not clamp them until the CT lead has been wired to the meter to avoid major safety risks (this is valid for CTs with 1A or 5A output, however 333 mV CTs do not require shorting blocks or prior connection to the meter because they have a burden resistor built into the CT that limits the output voltage to a safe 333mV under all conditions.)
● Pull the CT lead back to the meter via pre-mounted cable glands, trunken and other covers.
● Wire the two CT lead wires to the correct meter terminal input. Take the positive (white or red) lead wire and insert it into the lower circular opening of the current measurement terminal (e.g. I1 37, I2 39, etc). A tiny screwdriver should be inserted into the upper square opening and pressed down to allow the lead wire to be inserted properly.
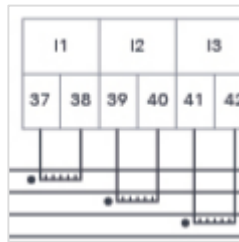
White/Red wire = + (positive)

Black/Brown wire = – (negative)

- Repeat for all CTs you plan on deploying and place the terminal block back into the meter module when the wiring is complete.
- Clamp the CT heads to the circuit paying attention to the labels to ensure that you clamp the correct circuit and to the direction in which you clamp the circuits.

  The red/white leads will be your positive wire and the black will be the negative wire. Also, on the CTs there is an arrow which dictates the polarity. The arrow should be facing the load. If you have the arrow towards the load and the red/white lead and black lead in the correct positive and negative terminals of the meter's CT input channels then the kWh will accumulate correctly.
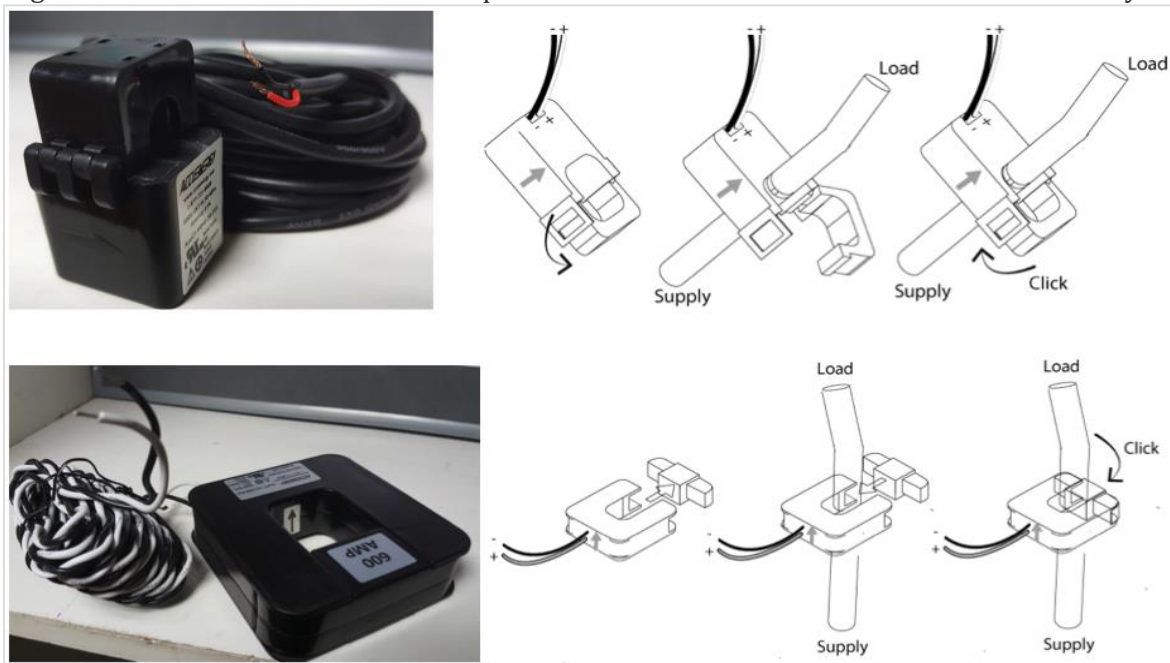

Figure 30: Illustration showing how different types of current transformers should be clamped to an electrical circuit

- Power the circuits back up after all Rogowski Coils or CTs have been deployed
- At this stage, the meter is wired to the circuit breaker and all CTs are clamped and wired back to the meter.
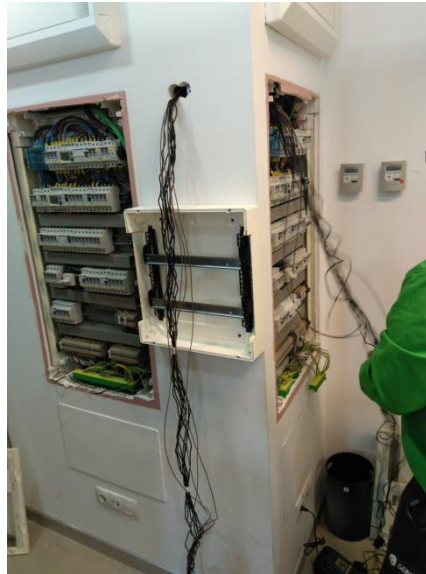
Figure 31: Photo showing the current transformers end cables being pulled from the electrical panel to the meter enclosure where they will be wired to the meter current terminal block

Figure 32: Photo showing the current transformers heads clamped to the electrical circuits

**STEP 5: Switch the breaker on to power up the meter**

Switch on the breaker to supply power to the new meter. The meter will power up and will after a few seconds emit a red LED light (L1).

STEP 6: Configure the meter

The meter has a total of 18 current measurements terminal inputs called channels (I1 to I18), that are connected to up 18 CTs used to monitor 18 single-phase circuits or a mix of single-phase and three-phase circuits. You must now configure your meter terminal inputs to the correct primary

rating size of the CTs wired to them (e.g. if a 300A CT is wired to the channel I1 then I1 must be configured to 300A). This procedure is executed via the meter display:

- Press the meter display's left and right arrows together to go back to top menu
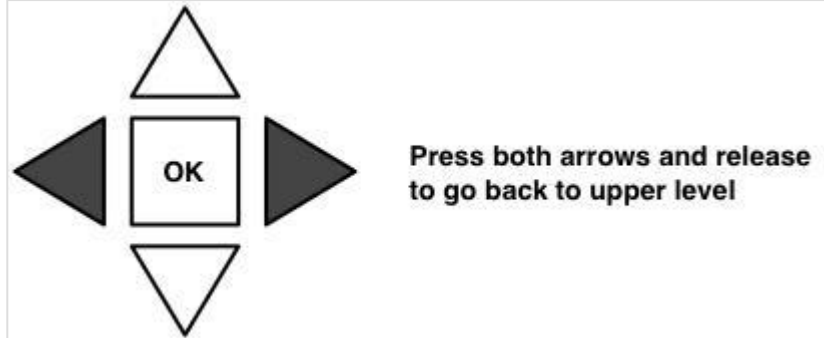
- Select the Settings menu, enter the password 0000, then press the cursor left until you reach the CT TYPE submenu. There you need to set the correct AMPERE size for each terminal input, one by one. For example, if you used a WattRCT16-2500 Rogowski Coil to monitor the three phases of your circuit 5, you need to set a value of 2500 for the meter channels I11, I14 and I17.
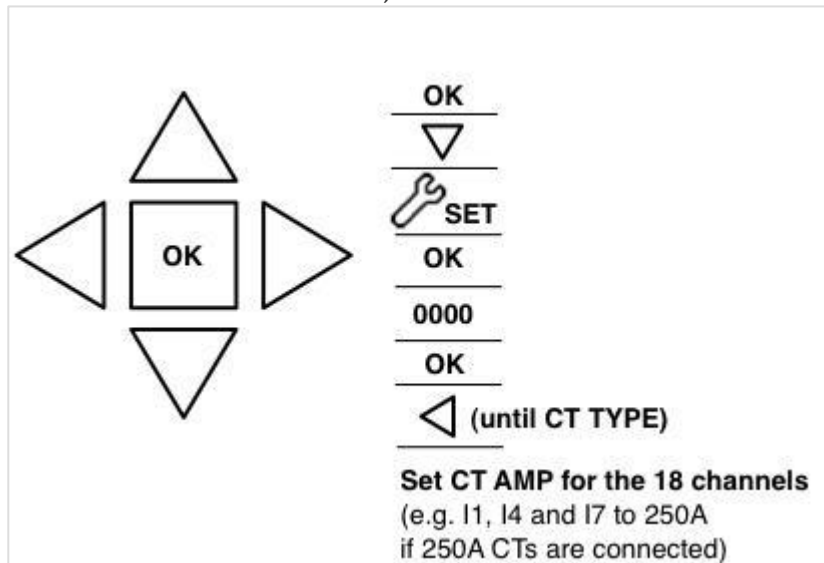
- Press the OK button to register each AMPERE value, and move on to the next channel until you are done. At the end verify that all channels are configured properly in case you didn't save correctly, this is extremely important as you will otherwise get incorrect readings.

STEP 7: Provide network access to your meter

- Connect an Internet cat5 cable to the meter's Ethernet port.
- Press the meter display's left and right arrows together to go back to top menu
- Select the NET menu, enter the password 0000 and press OK. Then press OK to enter the DHCP Setting configuration.
- You must either enable DHCP (so the meter gets discovered and is assigned an IP address automatically), or change its IP address to be within the correct IP range. To

enable DHCP, set the DHCP Setting tab to AUTO and press OK to save it. If you want to assign a static IP address, follow the steps below:

- ○ Press the right cursor until you reach the DHCP Setting tab, press OK and set to MANU. Press OK to save.
- ○ Press the right cursor until you reach the IP ADDRESS tab and register the IP address to be used.
- ○ Press the right cursor until you reach the SUBNET MASK tab and register the IP address to be used.
- ○ Press the right cursor until you reach the GATEWAY IP ADDRESS tab and register the IP address to be used.

- ● The meter network interface must be rebooted to enable the new network settings. Turn the meter off via its MCB circuit breaker for 5 seconds and turn it back on.
- ● Press the meter display's left and right arrows together to go back to top menu
- ● Select the NET menu, enter the password 0000 and press OK. Press the right cursor until you reach the IP ADDRESS configuration.
- ● Write down the IP address of your meter, you may need it to access the meter's webserver configuration page.

STEP 8: Configure the meter time clock

Set the meter time clock to your local time via the meter display menu:

- ● Press the meter display's left and right arrows together to go back to top menu
- ● Select SETTINGS at the main screen and press 'OK'.
- ● Enter the meter password (default is 0000) and press 'OK'.
- ● Press the left cursor until you reach the TIME SET tab.
- ● Set the local time and press 'OK'
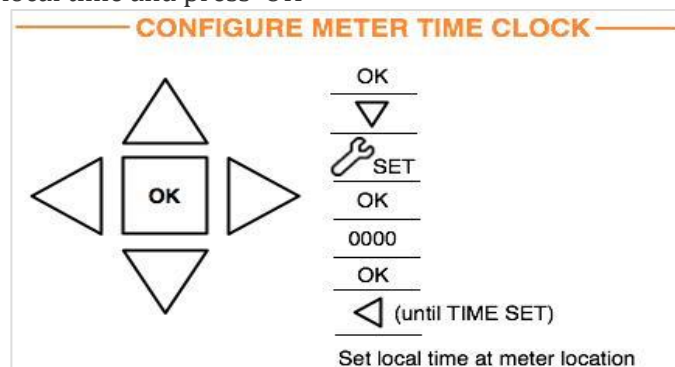
3.9 SiteWhere entities

After the deployment we need to model all the entities of our system. An entity is created inside sitewhere in the following way.

We navigate to the devices tab and there click create new device. We give the device id a unique identifier and a specification (which denotes the type of the device for example pc,NFC,ble,hvac etc).
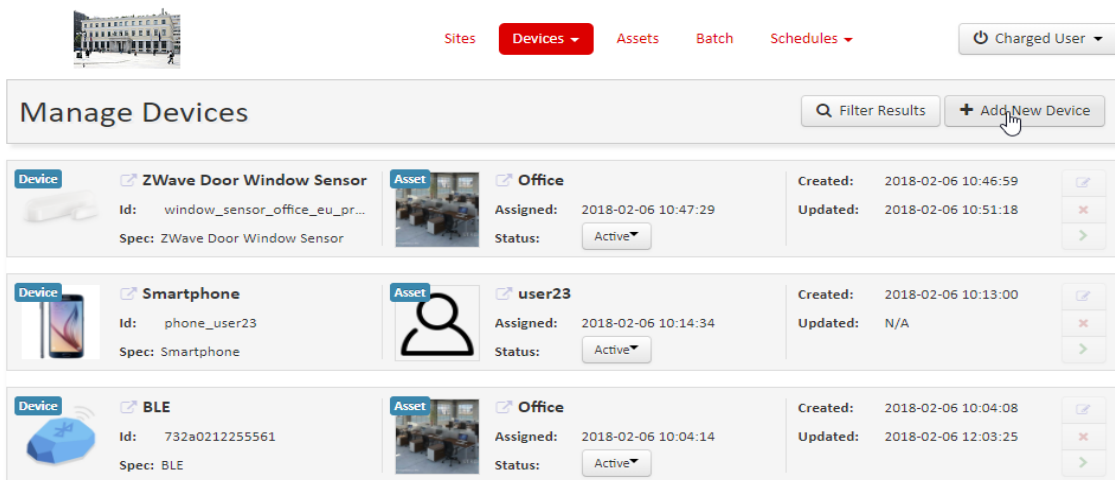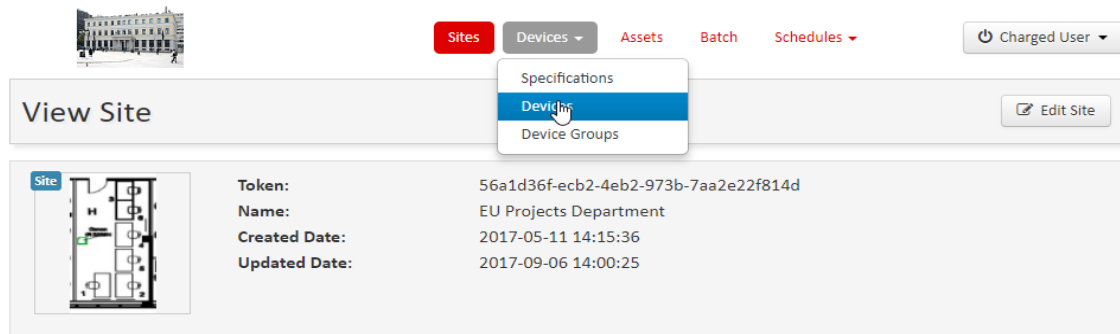
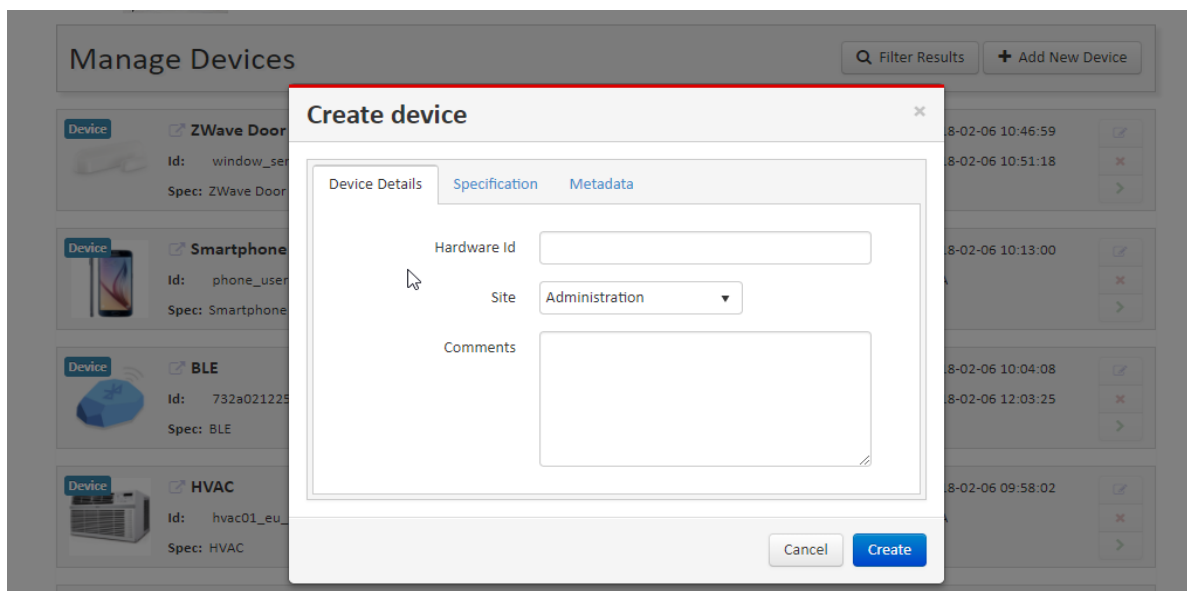*Figure 33: Manage devices screen in SiteWhere*

Figure 34: Create Devices screen in SiteWhere

When the device is created we also associate it with another asset. For example an NFC can be associated with a pc if it is on a desk, with a room if it is placed close to a light switch, with a common place like stairs etc.

Figure 35: Configured devices in SiteWhere

4 Maintenance and support guide

4.1 Zwave Battery monitoring

Battery liefetime should last the pilot time. If battery powered device isn't sending any updates anymore, battery should be changed. No battery watchdog was implemented during the project.

4.2 Zwave battery types to replace

Battery Types of Window Contacts and 4in1 Sensors an be checked in the vendors manual.

4.3 Troubleshooting

4.3.1 Multi-channel meter

KW values shown are wrong

It is very likely that the CTs have not been wired correctly at the meter. Check that the CTs of the circuit with incorrect kWh values are connected meter inputs with the correct phase lines, i.e. CTs connected to first three current inputs of the meter (I37/I38, I39/I40 and I41/42) should monitor the L1 phase of three different three-phase circuits, etc). When using 333mV CTs, white wires will go into 37 and black to 38, white to 39 and black to 40 etc. When using Rogowski Coils RCTs, white wires will go into 37 and brown to 38, white to 39 and brown to 40 etc.

kW values are negative

The voltage and current may not be aligned. Make sure your voltage references V1. V2 and V3 come from L1, L2 and L3, and that CTs wired to L1, L2 and L3 current inputs are clamped to L1, L2 and L3 circuits.

The CTs may be mounted in the reverse direction or the CT leads are wired to the meter in the opposite direction. Make sure the P1/S1/H side of the CT faces the utility/source and that the black and white leads of the CTs are connected in the way specified by the CT manufacturer.

Power Factor values are very low

This indicates an incorrect wiring, either of the voltage lines or the CTs. Check wiring of the meter's V1, V2, V3 and VN from circuit breaker, and wiring of the circuit breaker from main supply, to ensure no cables were switched or fed from incorrect voltage line which would lead to incorrect voltage references. Check that the CTs of the circuit with incorrect kWh values are connected meter inputs with the correct phase lines, i.e. CTs connected to first three current inputs of the meter (I37/I38, I39/I40 and I41/42) should monitor the L1 phase of three different three-phase circuits, etc).

Both kW and kWh values are wrong

Check that the electrical system is the same as the one specified in the project specifications. It may be that the system is in reality different (e.g. Delta instead of Wye), meaning that the meter must be reconfigured for the correct system.

Voltage values are wrong

Check wiring of the meter's V1, V2, V3 and VN from circuit breaker, and wiring of the circuit breaker from main supply, to ensure no cables were switched or fed from incorrect voltage line which would lead to incorrect voltage references.

AMP values are wrong

Verify that the size of the CTs used is equal to the CT rating mentioned in the project spec and pre-configured in the meter (see CT TYPE setting).

If not the same, CT ratio must be modified via the meter's web interface using laptop, see AcuREV user manual.

AMP values are zero

Confirm that the CTs are closed properly around the circuit cables

Confirm that the wiring of CTs at the meter is good and not loose. Pull on CT cables and check that no wire comes out.

kWh are zero

Confirm that the CTs are wired in the right direction (arrow facing the load) as per installation manual.

Data holes

Identify if the meter could be powered off by staff or during ongoing works