SWitCH 2018 Project

People's awareness about global warming and pure economic sense are powerful drivers for the current change from a centralized electrical grid to the so-called Smart Grid. StudentEnergy.org has a good introduction to the smart grid concept[1] and a very interesting map on energy systems[2]. For further reading, the US Department of Energy has an introductory document[3].

One key element of the smart grid is the Smart Home, i.e. a house/apartment that uses IT and networked devices to improve comfort, safety, security and energy efficiency. TechTarget has an interesting introduction to the smart home[4]. Another important characteristic of many smart homes is that they have electric power generation (e.g. solar panels) and/or storage (e.g. batteries).

The smart home is a key element because the residential sector represents about 25% of the total energy consumption in the EU[5] (2016). With the introduction of electric cars, which most of them will be charged at home, during off-peak hours (e.g. night), residential sector's share of the energy consumption will sharply rise. The consumer management of electrical energy consumption is increasingly important[6].

The objective of this project is to develop a system that allows users to manage the electric energy consumption of a smart home, considering their daily schedule, the weather and energy market prices. The system will gather information about energy consumption/production of devices with energy metering and of the home as a whole. Remote management of devices (turn-on/off, configuration, etc.) would definitely be a plus.

The system should have a web-based, multi-language end-user interface (UI) and a text console for maintenance purposes.

The system should be as vendor neutral as possible regarding home devices and services it can use, thus open for expansion.

For security reasons, home devices should not be freely exposed to the outside world. For each house, one or more gateways will act as the interface between sets of devices and outside systems.

It is a requirement that a service-oriented architecture is used. The system itself may evolve to be a set of cooperating services that may be part of a larger home automation service. Figure 1 presents the conceptual architecture of an IoT stack that may be used as a guideline for designing and implementing the system.

[1] https://www.studentenergy.org/topics/smart-grid
[2] https://www.studentenergy.org/map
[3] http://www.oe.energy.gov/DocumentsandMedia/DOE_SG_Book_Single_Pages.pdf
[4] https://internetofthingsagenda.techtarget.com/definition/smart-home-or-building
[5] https://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_consumption_in_households
[6] http://ambienteonline.pt/canal/detalhe/colunista-david-rua-tecnologia-a-gestao-de-energia-nas-casas-

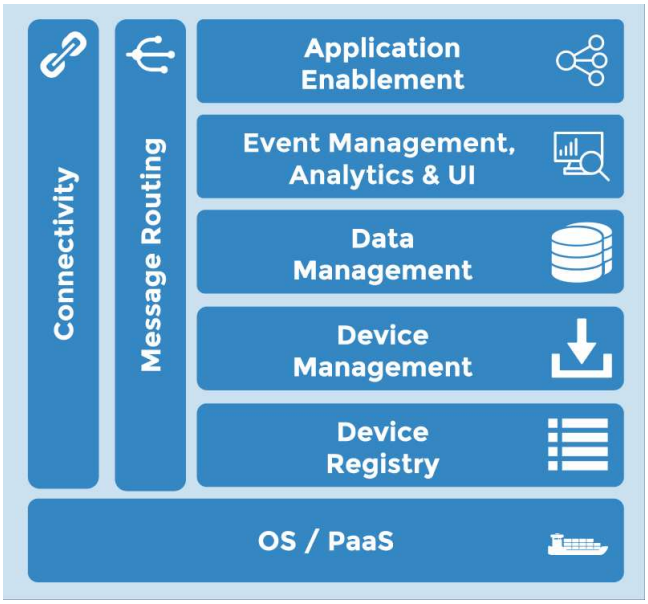

Figure 1 - IoT Cloud Platform Stack[7]

MAIN CONCEPTS

GEOGRAPHICAL AREA

It represents an area of the land with a specific meaning. There are several types of areas: street, place, parish, town/city, district, region, country, continent, urban area, rural area, forest area, etc. A geographical area may be part of another area.

A geographical area has location (centre of the area): GPS coordinates + altitude (polar coordinates). Also has the actual representation of the area that, for the moment, is a rectangle centred in the area's centre. Areas are measured in km2.

HOUSE

A house or apartment that is to be managed. A house may include gardens and other outbuildings that are part of the house (e.g. garage, garden shed, etc.). A house is located in a geographical area and has an address, including ZIP code, and a GPS location.

ROOM

A part of the house that has an independent logical and possibly physical representation (e.g. kitchen, bedroom, corridor, hall, garage, a delimited area in the basement, a section of the garden). A room has a name, house floor and dimensions. For the sake of simplicity, it is assumed a room always have a parallelepiped shape.

A room may have a set of owners and all devices in the room have the same set of permissions.

[7] https://iot.eclipse.org/cloud/

HOME GRID

The electrical network of the house. All devices at home are connected to the home grid, which is connected through an energy meter and a power limiter differential circuit breaker to the public power grid. A house may have more than one independent grids (e.g. one for the main house and another for the garden). A room belongs only to one grid.

DEVICE

An active electrical device that consumes electricity in order to fulfil its tasks. About devices:

- Every device has a name, so that the users understand its purpose, a type, a location (room) and nominal power, i.e. the maximum power it can consume;
- A device may be metered, i.e. it has a meter connected to it (e.g. a metering plug) or has an internal meter. One cannot know the actual energy consumption of a non-metered device, so that the device's consumption will be an estimate based on its working profile;
- A device may be switchable, i.e. it is connected to a switchable plug, a switch in the distribution board or itself supports that functionality.
- A device may be programmable, i.e. may be able to run several predefined/user defined programs at a configurable starting hour (e.g. washing machine, dishwasher, etc.).

A device may be "self-managed", i.e. its operation is fully based on internal decisions. That is the case of devices that have a thermostat (e.g. water heater, fridge, etc.). Though these are autonomous, some of these devices may be switchable.

Regarding device types, there aren't many specific requirements at the moment, except that the use of types should help users to understand the purpose of the device, standardize behaviours and also simplify system development and future extension. The client has already identified the following common types of devices that one can find at home:

- Electric water heater
  - Nominal power (kW), volume of water (l), hot water temperature (°C), cold water temperature (°C), performance ratio (typically 0.9)
  - Energy consumption = C*V*dT*PR (kWh)
    - C -> Specific heat of water = 1,163 Wh/kg°C
    - V -> Volume of water to heat (water consumption in litres)
    - Dt -> difference in temperature = hot water temperature – cold water temperature
    - PR -> performance ratio (typically 0.9)
- Washing machine
  - Nominal power (kW), capacity (kg), list of programs (duration, energy consumption)
  - Energy consumption = energy consumption of the program (kWh)
- Dishwasher
  - Nominal power (kW), capacity (in dish sets), list of programs (duration, energy consumption)
  - Energy consumption = energy consumption of the program (kWh)
- Fridge
  - Nominal power (kW), freezer capacity (l), refrigerator capacity (l), annual energy consumption (kWh)

    - Energy consumption (daily) = annual energy consumption / 365 (kWh)
- Freezer
    - Nominal power (kW), freezer capacity (l), annual energy consumption (kWh)
    - Energy consumption (daily) = annual energy consumption / 365 (kWh)
- Wine cooler
    - Nominal power (kW), number of bottles, annual energy consumption (kWh)
    - Energy consumption (daily) = annual energy consumption / 365 (kWh)
- Kettler
    - Nominal power (kW), maximum volume of water (l), performance ratio
    - Energy consumption = C*V*dT*PR (kWh)
        - C -> Specific heat of water = 1,163 Wh/kg°C
        - V -> Volume of water to heat (l)
        - Dt -> difference in temperature = 100 – cold water temperature
        - PR -> performance ratio (typically 0.95)
- Electric Oven
    - Nominal power (kW), list of programs (nominal power of the program)
    - Energy consumption = nominal power of the program * time
- Stove
    - Nominal power (kW), list of programs (nominal power of the program)
    - Energy consumption = nominal power of the program * time
- Microwave oven
    - Nominal power (kW), list of programs (nominal power of the program)
    - Energy consumption = nominal power of the program * time
- Wall electric heater
- Portable electric oil heater
- Portable electric convection heater
- Wall towel heater
    - Nominal power (W)
    - Energy consumption = Nominal power * time (Wh)
- Lamp
    - Nominal power (W), luminous flux (lm)
    - Energy consumption = Nominal power * time (Wh)
- Fan
    - Nominal power (W), list of programs (nominal power of the program)
    - Energy consumption = Nominal power of the program * time (Wh)
- TV
    - Nominal power (W), standby power (W)
    - Energy consumption = Nominal power * time (Wh)

POWER SOURCE

A power source supplies electric energy to the home grid. This may include the public electric grid, photovoltaic panels, wind generator, batteries, etc. Some power sources may be “chargeable”, i.e. the may be used to storage energy for later use.

A power source has a maximum power output and, if it has storage capabilities, the maximum amount of storable energy and the maximum power it can provide in continuous operation (the peak instant power it is not relevant, for the moment).

PASSIVE HEAT SOURCE

A device that supplies or absorbs heat from a room. When designing a house, the architect should give special care to the use of passive sources (e.g. windows) in order to reduce active energy consumption, thus reducing the house's carbon footprint. A house that requires little or no active heating/cooling is called a passive house[8].

Passive heat sources may be truly passive (e.g. window) or active devices with little electric energy consumption regarding their overall heat production (e.g. window with electric blinders, ventilation fan).

SENSOR

The virtual representation of a real sensor that provides information on the house environment. Thus, in the context of the system, a sensor is not a physical device (see above). The power consumption of the sensors is deemed negligible.

In order to further simplify the system's management and extension, a sensor is a virtual entity that represents a set of operations related to a single physical quantity[9] (e.g. air humidity sensor) or a condition (e.g. presence detection). A sensor belongs either to a location in the house, i.e. a room (see the extended room definition above) or to a geographical area (e.g. outside temperature sensor, solar radiation sensor, etc.). Sensors in geographical areas have a location (latitude, longitude, altitude).

A sensor has a name, a start operation date, a stop operation date (optional), its readings and a type. Some common sensor types :

- Air humidity;
- Air speed;
- Atmospheric pressure;
- Human presence;
- Light intensity;
- Solar radiation;
- Rain;
- Temperature.

USERS

Inhabitants of the house (permanent or guests) or someone who uses it regularly (e.g. house staff) with access to the system, which must be granted by an Administrator (c.f. User Roles).

[8] https://passivehouse.com/

[9] Wikipedia contributors. (2018, September 26). Physical quantity. In Wikipedia, The Free Encyclopedia. Retrieved 20:29, December 1, 2018, from https://en.wikipedia.org/w/index.php?title=Physical_quantity&oldid=861312166

User roles

A house has at least 3 types of roles:

- Administrator, which is used only to manage the system;
- Regular users, the default user;
- Power user(s), a regular user with the ability to override all other permissions regarding regular house operation;
- Room owner(s), a regular user with "power user like" abilities in a room, but whose commands/setups can be overridden by a power user.

User comfort

EN 15251:2006 provides recommendations for acceptable indoor temperatures for design of buildings without mechanical cooling systems. The following formulas are given in annex A.2

Category I	Upper limit	$t_{i\,max} = 0.33t_o + 18.8 + 2$
	Lower limit	$t_{i\,min} = 0.33t_o + 18.8 - 2$
Category II	Upper limit	$t_{i\,max} = 0.33t_o + 18.8 + 3$
	Lower limit	$t_{i\,min} = 0.33t_o + 18.8 - 3$
Category III	Upper limit	$t_{i\,max} = 0.33t_o + 18.8 + 4$
	Lower limit	$t_{i\,min} = 0.33t_o + 18.8 - 4$

Electric power

Instant electric power[10] available at a power source or consumed by a device.

Electric energy consumption/production

Total amount of energy produced/consumed[11] during a certain period. Energy is measured in KWh, the basic trade unit of energy.

Energy price

The price of 1 KWh of electric energy. The price of energy changes over time according to market needs and the energy produced. The basic period of pricing is 15 min. Energy prices are obtained from a service provided by the utility. Regarding energy sale prices, they may be provided by the utility or by other services, e.g. provided by the area's energy market.

Electric energy meter

A sensor that measures the amount of electric energy that travels through it at a certain point of the grid. By convention, energy consumption is a positive value and energy production a negative one. Though many meters can provide almost continuous readings (e.g. one every second), there is no real interest in that. It is assumed that the average energy consumption for a period of 5 minutes is detailed

[10] Wikipedia contributors. (2018, November 25). Electric power. In Wikipedia, The Free Encyclopedia. Retrieved 16:02, November 29, 2018, from https://en.wikipedia.org/w/index.php?title=Electric_power&oldid=870593204

[11] Wikipedia contributors. (2018, November 18). Electric energy consumption. In Wikipedia, The Free Encyclopedia. Retrieved 16:32, November 29, 2018, from https://en.wikipedia.org/w/index.php?title=Electric_energy_consumption&oldid=869428110

enough for energy monitoring and consumption planning purposes. Thus, the system will receive readings with that period. Nevertheless, this period may change in the future or even be configurable by the Administrator.

GRID METER

An electric energy meter that measures the electric energy consumption/production of the grid relative to the public power grid (outside). Every house has at least one.

CONTRACTED MAXIMUM POWER

The maximum electric power the public grid can provide to a house grid. This is enforced by the grid's power limiter circuit breaker.

NON-FUNCTIONAL REQUIREMENTS

System development will use an agile approach.

The system shall be implemented using the Java programming language using a Test-Driven Development (TDD) approach regarding code development. A minimum of 95% of code coverage and mutation coverage of tests is required. UI and IO packages are not included in this coverage requirements.

All code, comments and documentation will be in English. System's documentation will be on the project's Bitbucket wiki.

There will be a text console UI for local system management by the Administrator. In the early stages of development, the other users will also use a text console to interact with the system.

The UI will be in English.

All data exchange between controller and UI classes should use DTOs, in order to improve application's serviceability

USER STORIES

HOUSE CONFIGURATION

ID	User story	Sprint
US001	As an Administrator, I want to add a new type of geographical area, in order to be able to create a classification of geographical areas.	S0
US002	As an Administrator, I want to get a list of existing geographical area types.	S0
US003	As an Administrator, I want to add a new geographical area.	S0
US004	As an Administrator, I want to get a list of existing geographical areas of a given type.	S0
US005	As an Administrator, I want to define the sensor types.	S0
US006	As an Administrator, I want to add a new sensor and associate it to a geographical area, so that one can get measurements of that type in that area.	S0
US007	As an Administrator, I want to add an existing geographical area to another one (e.g. add city of Porto to the district of Porto).	S0
US008	As an Administrator, I want to find out if a geographical area is included, directly or indirectly, in another one.	S0

US010	As an Administrator, I want to deactivate a sensor in a geographical area, so that it will no longer be used. It can be reactivated later.	S05
US011	As an Administrator, I want to remove a sensor from a geographical area, so that it will no longer be used.	S05
US015	As an Administrator, I want to import geographical areas and sensors from a JSON file.	S04
US015v2	As an Administrator, I want to import geographical areas and sensors from a JSON or a XML file.	S05
US020	As an Administrator, I want to import geographical areas sensors' readings into the application from a CSV file. Data outside the valid sensor operation period shouldn't be imported but registered in the application log.	S04
US020v2	As an Administrator, I want to import geographical areas sensors' readings into the application from a CSV or a JSON file. Data outside the valid sensor operation period shouldn't be imported but registered in the application log.	S05
	As an Administrator, I want to export the readings of a sensor to a JSON file.	
US050	As an Administrator, I want to define the metering period for energy-metered devices (in minutes) using a configuration file. It is assumed the first metering period starts at 00:00. Devices' metering period must be a multiple of the grid metering period and the sum of all periods in the day must be 24:00.	S3
US051	As an Administrator, I want to define the metering period for grids (in minutes) using a configuration file. It is assumed the first metering period starts at 00:00. The sum of all periods in the day must be 24:00.	S3
US060	As an Administrator, I want that whenever there is more than one sensor to choose from to get readings, the nearest one should be used. A fall-back selection criterion is the one with the latest readings (to the instant/period in analysis).	S3
US061	As a Product Owner, I want that no duplicate information to be created when importing data. Equality criterion should be based on business rules.	S06
US063	As a Product Owner, I want that sensor data import of large datasets (num. of records>1000) to be fast, i.e. t < [num of records]/200	S07
US070	As an Administrator, I want to configure the available device types for each instance of the system (i.e. each house) using a configuration file, so that the types of devices can be updated without compilation and redeployment of the software.	S3
US080	As an Administrator, I want the data related to geographical areas, including sensors and their readings, to be persisted in a relational database, so that this data is available whenever the application is run.	S05
US080v2	As an Administrator, I want the data related to geographical areas (including sensors and their readings) and to the house (including grids, rooms and sensors) to be persisted in a relational database, so that this data is available whenever the application is running.	S06
US100	As an Administrator, I want to configure the house from a file containing basic house information, grids and rooms.	S06
US101	As an Administrator, I want to configure the location of the house.	S1
US105	As an Administrator, I want to add a new room to the house, in order to configure it (name, house floor and dimensions).	S1
US108	As an Administrator, I want to have a list of existing rooms, so that I can choose one to edit it.	S1
US130	As an Administrator, I want to create a house grid, so that I can define the rooms that are attached to it and the contracted maximum power for that grid.	S1
US135	As an Administrator, I want to add a power source to a house grid, so that the produced energy may be used by all devices in that grid.	S1
US145	As an Administrator, I want to have a list of existing rooms attached to a house grid, so that I can attach/detach rooms from it.	S1
US147	As an Administrator, I want to attach a room to a house grid, so that the room's power and energy consumption is included in that grid.	S1

US149	As an Administrator, I want to detach a room from a house grid, so that the room's power and energy consumption is not included in that grid. The room's characteristics are not changed.	S1
US160	As a Power User [or Administrator], I want to get a list of all devices in a grid, grouped by device type. It must include device location.	S2
US172	As a Power User [or Administrator], I want to know the total nominal power connected to a grid, i.e. the sum of the nominal power of all devices in all rooms in the grid.	S2

1

2 Room configuration

ID	User story	Sprint
US201	As an Administrator, I want to get a list of all devices in a room, so that I can configure them.	S2
US210	As an Administrator, I want to add a new device to a room from the list of available device types, so that I can configure it.	S2
US215	As an Administrator, I want to edit the configuration of an existing device, so that I can reconfigure it.	S2
US220	As an Administrator, I want to remove a device from a room, so that it is no longer used. Its activity log is also removed	S3
US222	As a Power User, I want to deactivate a device, so that it is no longer used. Nevertheless, it should be possible to access its configuration and activity log.	S3
US230	As a Room Owner [or Power User, or Administrator], I want to know the total nominal power of a room, i.e. the sum of the nominal power of all devices in the room.	S2
US250	As an Administrator, I want to get a list of all sensors in a room, so that I can configure them.	S2
US253	As an Administrator, I want to add a new sensor to a room from the list of available sensor types, in order to configure it.	S1
US260	As an Administrator, I want to import a list of sensors for the house rooms. Sensors without a valid room shouldn't be imported but registered in the application log.	S06
US265	As an Administrator, I want to import a list of sensor readings of the house sensors. Data from non-existing sensors or outside the valid sensor operation period shouldn't be imported but registered in the application log.	S06

3

4 House management

ID	User story	Sprint
US440	As a Power User or as a Room Owner, I want to have a list of the instants in which the temperature fell below the comfort level in a given time interval and category (annex A.2 of EN 15251).	S07
US445	As a Power User or as a Room Owner, I want to have a list of the instants in which the temperature rose above the comfort level in a given time interval and category (annex A.2 of EN 15251).	S07

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6 House monitoring (sensors)

ID	User story	Sprint
US600	As a Regular User, I want to get the current temperature in the house area. If, in the first element with temperature sensors of the hierarchy of geographical areas that includes the house, there is more than one temperature sensor, the nearest one should be used.	S1

US605	As a Regular User, I want to get the current temperature in a room, in order to check if it meets my personal comfort requirements.	S1
US610	As a Regular User, I want to get the maximum temperature in a room in a given day, in order to check if heating/cooling in that room was effective.	S1
US620	As a Regular User, I want to get the total rainfall in the house area for a given day.	S1
US623	As a Regular User, I want to get the average daily rainfall in the house area for a given period (days), as it is needed to assess the garden's watering needs.	S1
US630	As a Regular User, I want to get the last coldest day (lower maximum temperature) in the house area in a given period.	S4
US631	As a Regular User, I want to get the first hottest day (higher maximum temperature) in the house area in a given period.	S4
US633	As a Regular User, I want to get the day with the highest temperature amplitude in the house area in a given period.	S4

1

2 Energy consumption management

ID	User story	Sprint
US705	As a Power User, I want to know the total nominal power of a subset of rooms and/or devices of my choosing connected to a grid.	S2
US720	As a Power User [or Administrator], I want to know the total metered energy consumption of a device in a given time interval, i.e. the sum of the energy consumption of the device in the interval. Only metering periods full contained in the interval will be included. One cannot know the exact energy consumption of devices not connected to an energy meter.	S3
US721	As a Power User [or Administrator], I want to know the total metered energy consumption of a room in a given time interval, i.e. the sum of the energy consumption of all energy-metered devices in the room in the interval.	S3
US722	As a Power User [or Administrator], I want to know the total metered energy consumption of a grid in a given time interval, i.e. the sum of the energy consumption of all energy-metered rooms in the grid in the interval.	S3
US730	As a Power User [or Administrator], I want to have the data series necessary to design an energy consumption chart of the metered energy consumption of a device/room/grid in a given time interval	S3
US752	As a Regular User [or Power User], I want to estimate the total energy used in heating water in a given day, given the cold-water temperature and the volume of water produced in each water heater.	S2

3