STORY

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Deliverable 4.6
Demonstrated embedment in 3 different controllable devices able to support flexibility of the energy demand

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1 Publishable executive summary

This document describes the developments to make three different controllable devices able to support flexibility of the energy demand smart grid ready for integration in the STORY residential building and neighbourhood demonstrations. The demonstrations use original devices which are extended with communication hardware in order to monitor and control these devices. They serve as a prototype for a potential new product which can be sold including the communication possibilities making them *smart-grid ready* out of the box. A storage tank and a heat pump are equipped with the LoRaWAN communication technology and a battery is connected to the internet using WiFi.

The demonstrations clearly show the added value of adding communication to the storage tank and the heat pump. Integrating wireless LoRaWAN sensors proved easy and possible at low cost showcasing the potential to add this communication technology to existing products. Regarding the innovations on integrating a battery into the overall operational control, the technical limitations of this device and the linked impact on safety and guarantee forced the team to take an intermediate approach. The battery itself can be requested to participate in a charging or discharging modus, but cannot (or not always) be controlled from a higher level.

2 Introduction

Smart energy installations comprise measurement, data gathering and control solutions devised for their own purposes. Usually, these solutions have been designed and implemented such that they effectively and efficiently provide what is needed by the energy installation at hand. However, these measurements and data are valuable – potentially – beyond this “internal usage”.

In other words, measurements and the ability to trigger additional measurements as well as data and services to collect additional data for external purposes all represent potential value. Hence, it makes a lot of sense to offer services, providing access to external systems, allowing to turn this potential value into real value. For instance, data from solar installations might enable more fine-grained, accurate and real-time weather forecasting (i.e. single house, five minutes interval).

Here, state-of-the-art ICT normally delivers a significant margin at no extra cost. Today, the information processing power that will be found in a smart watch offers a 32-bit microprocessor with 512 megabytes of computer memory. And, additional costs will be below 10 euro when adding such information processing power during control hardware design. For example, Wi-Fi, Ethernet and Bluetooth connections have bandwidth to spare. In principle, smart energy installations should be able to use this margin and offer measurement and data gathering services beyond their own usage and purposes.

Nonetheless, the energy domain is facing obstacles. First, there is legacy. Many equipment only support outdated communication interfaces, often at high prices (e.g. 10 times the price of more

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capable mainstream alternatives). Worsening this situation, the manufacturers of the highest quality products – from an energy perspective – experience little or no incentive to improve this situation as their devices are competitive as they are. The answer is to wrap such devices in state-of-the-art ICT as is demonstrated here.

Second, smart energy applications have requirements that are not (yet) served in full by mainstream ICT. Emerging solutions in e.g. wide-area low bandwidth communication offer services addressing significant challenges, which are ill-addressed by the current mainstream. Here, there is no such abundance of bandwidth/capacity. A more explicit handling and managing of the available resources is indicated.

Third, software development approaches commonly used for smart energy installations fail to account for the above. Many devices come with control systems that impose severe limits on how they can be used. This is partly motivated by the complexity involved in proper usage of the devices as well as the severity of the impact of improper usage. Nonetheless, commonly used development approaches aim to fulfilling user requirements, which are to be established up front, without consideration for anything beyond them. The concern to keep the equipment safe and healthy results in an overly constraining device control interfaces.

This development approach implies that embedded contributions to flexible demand often need to be included (e.g. the development team imagined how they will contribute) in the user requirements at the start of the development. This is especially true when moving beyond measuring and data collection into control. Indeed, the ability to offer flexible demand by influencing actuation brings this concern with the proper usage of the equipment (e.g. batteries) to the forefront. In this discussion, the final answer is not yet known; there is not even a common view on the manner in which to improve on the present situation.

Overall, installations need to become aware of their embedded resources and the abilities of those resources beyond the envisaged usage for their own purposes. This awareness has to become explicit, resulting in explicit allocation of rights as well as explicit constraints preventing misuse. Likewise, the trade-offs when using a device in anominal manners ought to become more explicitly documented. Obviously, this can be challenging for novel technologies.

Looking into fundamental answers to interoperate with the power grid at large is addressed in task 3.4. In this task, the in-depth interoperability platform explicitly brings resources and activities on those resources into the picture. It is concerned with real-world resources and their allocation to activities (e.g. allocation of storage in a battery). Concerning the ICT aspects, the unbundled smart meter approach provides suitable guidance.

The remainder of this document covers the WP5 demonstrations in the project, which have used state-of-practice approaches for their software developments and ICT installations. The discussion covers how they contribute to the flexibility of demand, especially concerning data gathering and measurement.

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As indicated in D4.5 (Overview of requirements, challenges and potential for embedding measurements for services on ICT), LoRaWAN was chosen as the communication technology to extend the storage devices. Actility implemented this for two of the three storage devices:

1. Hot water storage tank: Temperature sensors and smart plugs are added to measure the state of charge and control the heating of the water in the tank.
2. Heat pump and building thermal mass storage: Temperature sensors are separately added to the building's rooms and a Modbus converter is build based on LoRaWAN to monitor the state of the heat pump and send control signals.

Due to the low time constants of both devices, the limited bandwidth of LoRaWAN largely suffices and all advantages of LoRaWAN integrations can be easily exploited such as easy to embed, install, low cost and more as described in D4.5.

BaseN's contribution to this task were twofold. Initially BaseN looked into converting BaseN's IoT base station to LoRaWAN (see 3.1.3) and when that approach was abandoned, resources were used for providing the necessary software APIs so that data coming from TH!NK-E's system can be accessed by Actility over the interfaces they have specified: this includes both pull interface for measurement data retrieval and push interface for control messages.

UCL investigated TH!NK-E's system as a case study for embedding measurement and data sharing, considering also more advanced services (e.g. influencing actuation). Here, UCL provided the connection to task 3.4 on in-depth interoperability. The insights and lessons learned will be injected in the deliverables of task 3.4 enhancing and maximising the ability to embed services – offering flexibility and other benefits to external parties – beyond the own goals/features of a smart energy installation. UCL focuses on the semantic level, going beyond the syntactic levels that are typically addressed in existing and ongoing efforts in the domain.

Th!nk E's contribution focussed on integrating the batteries communication-wise. The difference with the battery communication platform used in the Beneens demonstration is that the communication needs to allow external commands to either charge or discharge the battery. The set up of the communication is done through the intermediate platform of BaseN, allowing an immediate storing of the data for monitoring and evaluation.

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3 3 different controllable devices able to support flexibility of the energy demand

In the context of the two demonstrations in Oud-Heverlee (Belgium), it has been decided to monitor and control the following 3 devices:

1. Battery
2. Heat Pump Boiler (hot water storage tank)
3. Heat Pump

All three devices can and will be used in the operational control of the neighbourhood to show the added value of storage.

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3.1 Battery – TH!NK-E

Batteries in 2 buildings are to be connected to the Actility ThingPark Energy platform. This is done using the same logic as the large battery set up in the advanced building of the Oud-Heverlee demonstration.

The 2 batteries are connected through the BaseN platform to allow maximal use of the same software set up for all battery types. This set up further allows to immediately integrate the data in the overall STORY measurement database, hosted at BaseN.

3.1.1 Hardware

Two different batteries have been added, both connected with a Studer inverter system, XCOM communication module and a Raspberry Pi. Additional relays were added when 3-phase devices where connected, given that the batteries are connected on a single phase only.

Figure 1: Mercedes set up on the left side, EnerSys battery set up on the right side.

The specifications for the batteries are summarized below.

- Mercedes:
    - 2.5 kW, 5 kWh
    - Maximum system efficiency 97%
    - Depth of Discharge 80%
    - Expected residual capacity after 10 years > 80%

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    - Advanced Li-Ion technology, nickel, manganese and cobalt
- EnerSys:
    - 2 set ups of 9.2 kWh
    - Connected in parallel
    - Pure lead TPPL
    - 2500 cycles with a 35% DOD
    - 1800 cycles with a 50% DOD
    - Roundtrip efficiency 90%

Each of the batteries is connected to an inverter, a Studer XTM 4000-48, i.e. one Studer XTM's for each of the lead acid set ups and one for the Li Ion set up:
- Maximum efficiency of 96%
- Automatic disconnection with 3 time restart
- Accessories:
    - XCOM: communication sets
    - BSP: battery status processor
    - RCC: remote control

The additional hardware connected is a Raspberry Pi that allows all the battery systems to be connected in a single platform.

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3.1.2 Software

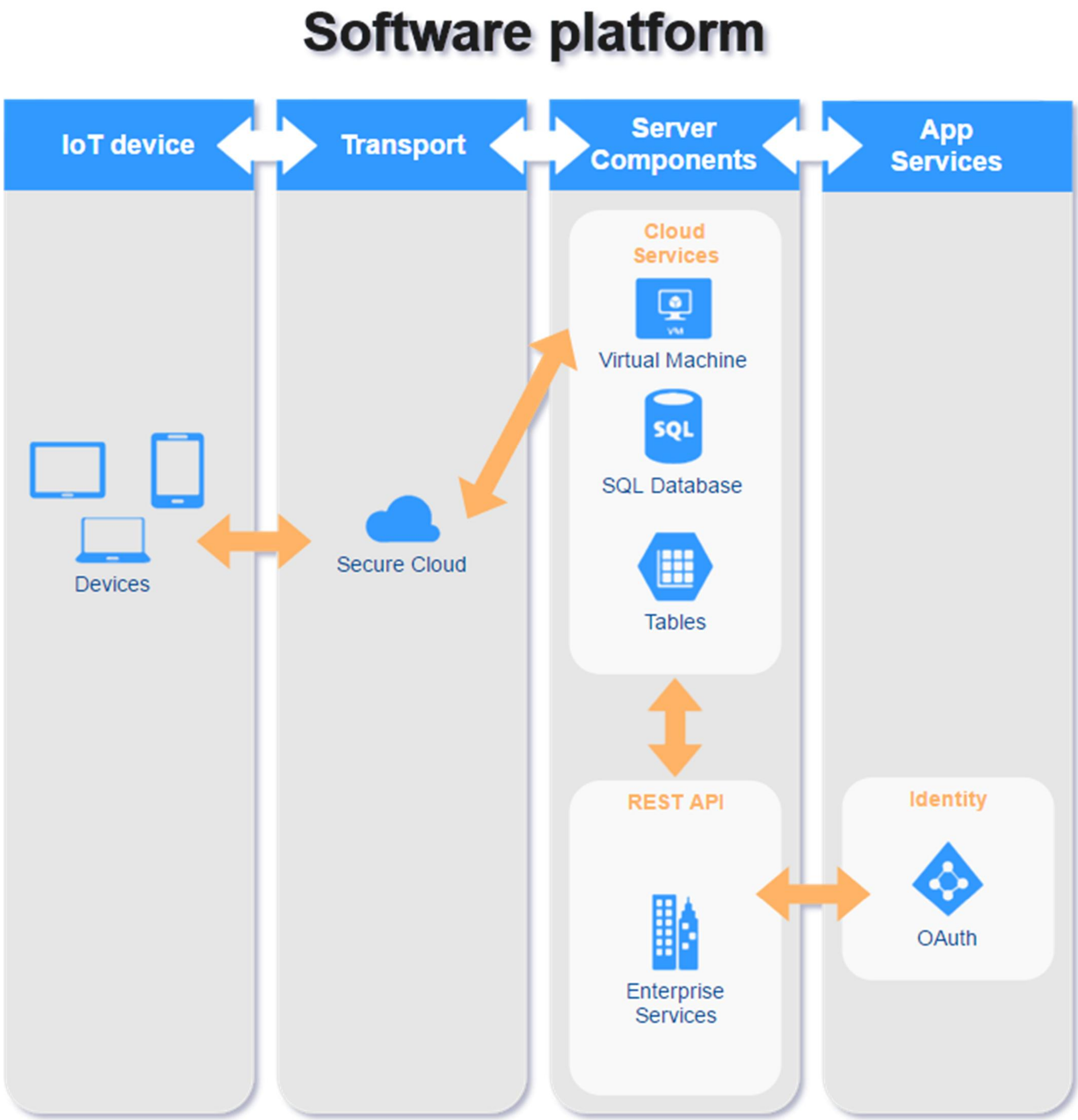

Figure 2. The software solution controlling the batteries.

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The software solution presented in Figure 2 consists of two parts:

- The Raspberry Pi contains a C++ application guarded by a supervisor to keep it running at all cost. The application communicates with the Studer and Power Meters. The gathered data is being sent to the cloud every 2 minutes using secure communication. Nevertheless the application will gather all data every second or every 5 seconds depending on the priority of that key/value. The data over 2 minute intervals and an average value is send to the cloud. The security measures regarding the IoT device to cloud communications and vice versa are following the next security levels
    - Endpoint security
        - TLS/SSL encryptions
    - Network Encryption
        - AES for data streaming through the cloud solution network
    - No Open Ports
    - Reactive Routing
        - Thwart regional attacks with automatic data routing
    - Legislative Compliance
        - Cloud solution is HIPAA compliant and conform with EU privacy regulations
- The server component subscribes to the messages from the IoT and are processed and stored in an Azure Sql Database. All server components are also hosted in the Azure cloud. This to ensure the best possible uptime and guards against failures at any level.
  A REST API has been created to make the data from the different IoT devices publicly available. The API also provides the possibility to enable or disable the connection to the grid by using the 2-way communication being integrated in the IoT device and the cloud server components.
  The API is protected by OAuth2 access tokens, this to protect the data from prying eyes.

Layer 2 (Raspberry Pi) software collects the measurement data from the battery and acts as a gateway to external control signal. This data is then routed to Th!nk E's system, which handled local control and offers an authenticated (OAuth2) API for fetching the measurement data and passing control messaged. BaseN's platform connects to this API, collecting data to the project's measurement storage and offering an access to the system for the third layer high level control. External API is implemented as a HTTP(S) REST with JSON payload for ease of integration.

3.1.3 IoT Base station

One of the initial potential LoRaWAN integrated devices in Story was the BaseN IoT base station (BaseN Spime Enabler). This device is used to connect to various local bus devices (modbus, knx, pulse counters, RS232, etc.) for both data collection and control. A typical industrial installation monitors PV panels and energy meters, providing 50-100 measurements per minute, while a smart home installation connects to HVAC, heat pumps, relays and energy pumps, providing 200-300 measurements per minute, in addition to control functions by relay switching.

A single measurement consists of identifier, millisecond timestamp and measurement value, so combined with device identifier, a single measurement is upwards of 32 bytes, as each individual field is 8 bytes. (In practice much more, as some measurements are of string format.) This means

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that each base station has a constant outbound data stream of 1.5-9kB, before factoring in any encryption. Smart home installations in newly built areas or apartment complexes are also often clustered such that single area has multiple installations, in range of at least 10-50 installations within a square kilometre, meaning that channel congestion can be a problem if bandwidth is limited. For example [https://www.thethingsnetwork.org/forum/t/universal-lora-wan-gateway-limitations-because-physics/1749] shows a LoRaWAN packet collision situation when a single LoRaWAN gateway is handling hundreds of messages per minute. For research purposes, all this data is relevant and useful for analysis and thus based on these calculations it was decided that LoRaWAN is not the optimal data transfer technology for devices producing hundreds of measurements per minute. For example, an ad hoc wlan mesh network with few internet connection points gives much better performance in these situations. However, as soon as the solution is well identified, a much smaller subset of data can be communicated allowing the communication hardware company to take advantage of LoRaWAN as described in D4.5.

3.1.4 Other

Freedom of control in the case of batteries is limited as a battery has a maximum number of cycles and the actual definition of what is considered as a cycle is often not detailed.

Additionally, batteries are electrical devices that need to be operated with care to avoid damage and safety issues. In STORY, it was agreed to allow Actility as aggregator to demand a certain flexibility and for Th!nk E as integrator of the batteries to evaluate whether this could be delivered.

In the Th!nk E/OH case there are multiple different batteries, control of which is managed via the platform developed by Th!nk E. These correspond to layers 1 and 2 in STORY modelling. As the interface offered by the initial design was not compatible with the Actility supplied layer 3 control system, the BaseN platform is used to as a go-between offering a suitable API for communication between layers 2 and 3. While the solution, considering the final rest API offered to Actility, is probably over-engineered, it shows how a 3rd party platform (BaseN) can be used to abstract away the underlying APIs (Th!nk E) so that the 3rd layer solution provider (Actility) sees only one unified API.

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3.2 Heat Pump Boiler - Actility

A 270-liter heat pump boiler has been added in one of the demonstration site houses as an energy storage system. Besides the heat pump (air/water), it also contains an electrical heating element (boost). The boiler is placed in series and upstream to an existing domestic hot water boiler to ensure a comfort level for the residents at all times. The new boiler potentially 'pre-heats' the water for the existing boiler – creating a buffer for storing energy while final comfort temperature is managed by the downstream boiler. The upstream boiler is monitored and SW controllable for charging thermal energy. Discharging happens through normal consumption of domestic hot water. The downstream boiler is not controlled but monitored such that maximum flexibility remains for the house owners. The 'State Of Charge' (SoC) of the boiler is calculated by an online service provided by VITO based on three temperature measurements.

Figure 3. The 270-liter heat pump boiler controlled through LoRaWan.

3.2.1 Hardware

The solution consists of a number of hardware components:
- a LoRaWan monitor box with three thermal sensors:
    - one measuring the bottom temperature of the boiler,
    - the second measuring temperature at level of the electrical heating element
    - and the third one measuring on the top of the boiler)
- a LoRaWan power plug for controlling electrical power to the heatpump
- a LoRaWan power plug for controlling electrical power to the electrical heating element

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- two Kamstrup calorimeters to check energy flows of the first and second boiler, both of them equipped by NKE LoRaWan pulse counters.
- the heatpump boiler
- a LoRaWan base station

Figure 4. The realisation of the external control required installation of variety of equipment.

In order to install the temperature sensors on the heat pump boiler, specific expert knowledge was needed to ensure the sensors are able to measure the temperature of the hot water storage tank. This is mainly due to the sensors being added **after the manufacturing process of the storage tank.** As an expert is involved, the business case for implementing this solution is highly limited as the hourly cost of this installation can exceed the added value of the service offered using the new potential energy services. However, if the communication can be embedded from the start, the cost can be severely lowered transforming these implementations into positive business cases.

3.2.2 Software

3.2.2.1 Temperatures

The sensor data is transmitted over the public LoRaWan network. Figure 5 below shows logging of the data packets of the temperature sensor box (Smartlog). LoRaWan provides two levels of encryption: a first level at Network Operator and a second level on Application layer. A packet of the monitor box is presented; it is decrypted at the Network Operator level, but the data is still encrypted at the Application level.

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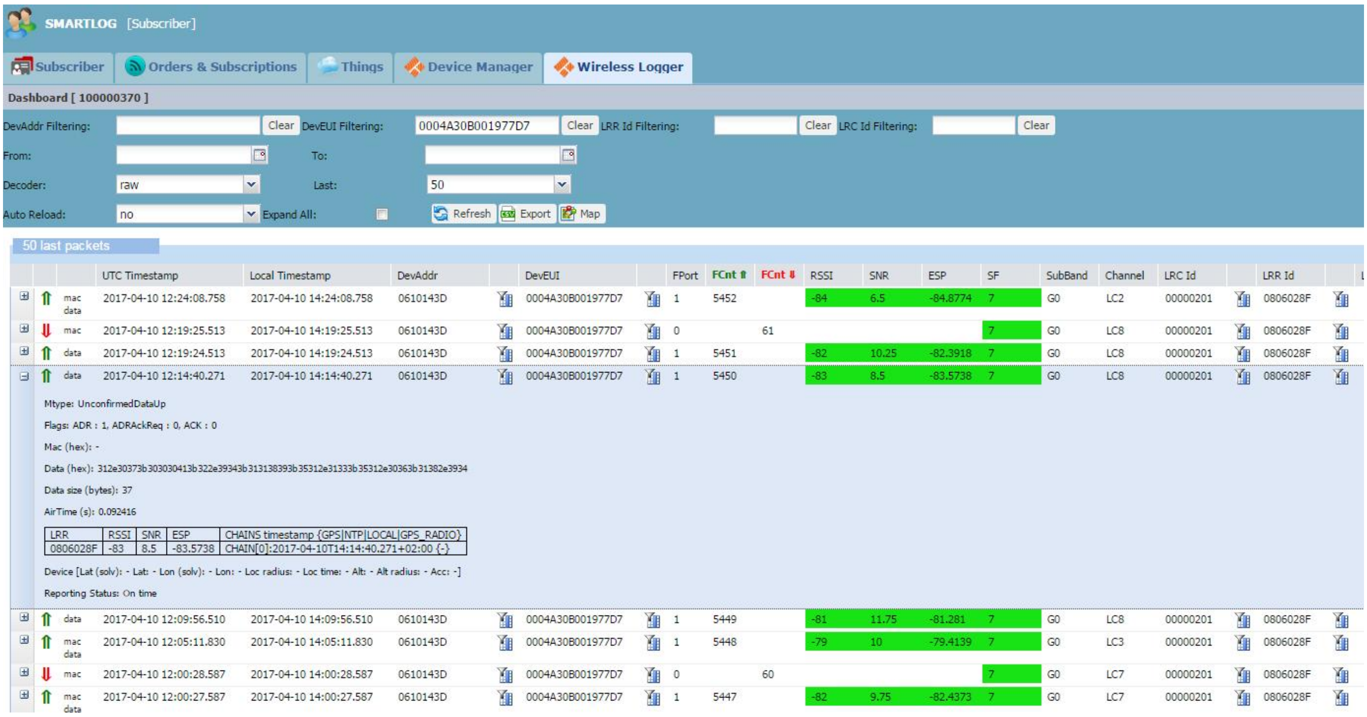

Figure 5. Logging of the data packets of the temperature sensor box (Smartlog).

The data packets are forwarded to the Application Server of the device manufacturer where third parties (Actility in this case) can collect the data through an Application Programmers Interface. The pictures below show a quick test program written in Node-Red to test this API.

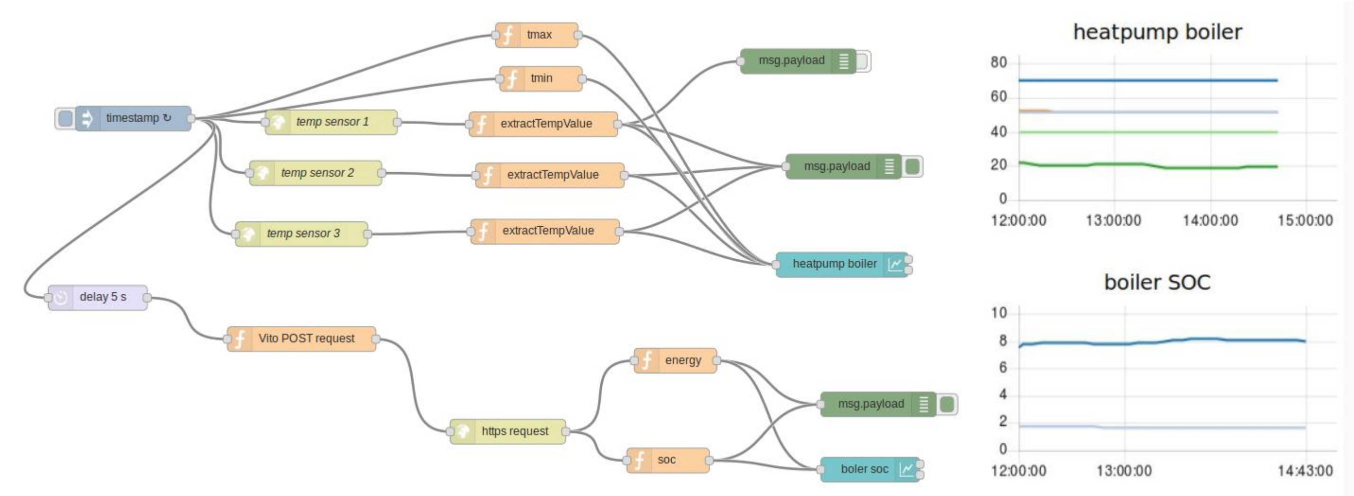

Figure 6. A quick test program written in Node-Red to test the API for temperature data.

The measured temperatures and the characteristics of the boiler are successively stored in the Actility cloud application ‘Datalogger’ and some parameters are sent to a server of Vito which calculates the State Of Charge of the boiler (see bottom branch of the graph in Figure 7, after 5

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sec delay). The Energy cloud platform of Actility models the daily use of the boiler and foresees an extrapolation on future use (see graph in Figure 7).

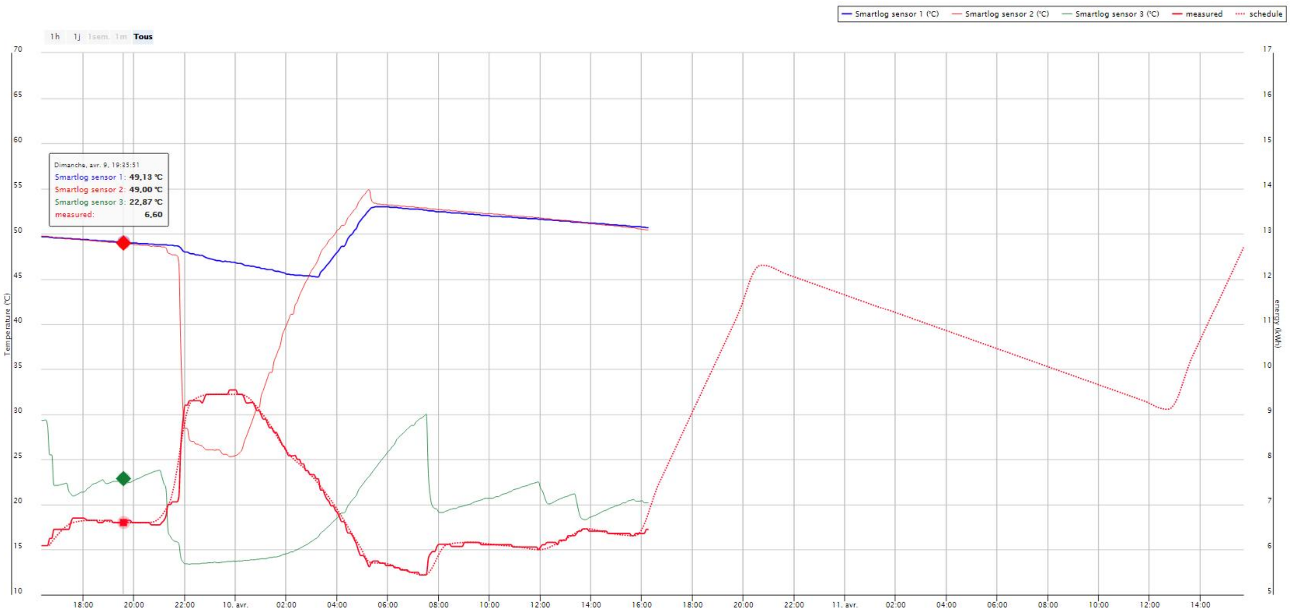

Figure 7. The measured and forecasted temperatures of the heat pump and storage.

3.2.2.2 Calorimeters

The calorimeters are connected with NKE pulse counters; these send the pulse values over the public LoRaWan network to the Actility application server. The server stores the values into the Actility cloud application 'DataLogger'.

3.2.2.3 Smart Plugs

As mentioned, both the heat pump as the electrical heating element can be controlled via the public LoRaWan network. Moreover, the Smart Plugs also measure the actual power consumption and report this over LoRaWan.

3.2.3 Control

Thanks to the calculation of VITO based on the LoRAWan temperature sensors, an optimal control can be developed to choose the best moments to heat the heat storage. A model is developed to predict the SoC variation and used to optimize the electric consumption of the heat pump and the electric resistance.

This demonstration shows how a pre-connected boiler could be used to valorise the flexibility of the heat pump with minimum effort. Sensors can be pre-embedded and a valorisation service can run on a company's platform (as is the case here with Actility). The LoRaWan connectivity provides a high plug-and-play level for these applications.

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3.3 Heat Pump -Actility

A high tech Danfoss heat pump (soil grid / water) was installed in one of the demonstration site houses as a central heating unit and for providing domestic hot water (Figure 8). The heat pump provides heat for floor heating circuits that use the heat capacity of the concrete of the building. The Danfoss heat pump can be controlled and monitored via a standard ModBus interface (wired, serial connection) and Danfoss also provides the details on the API to read and write the necessary registers. Initially we intended (and spent a lot of effort) into a Cocoon gateway (see: http://cocoon.actility.com/) with a modbus interface to read-out and control the Danfoss heat pump but this requires the use of the internet connection of the owners and was not preferred (it was also not clear if it was allowed). Later, Smartlog, an external company (www.smartlog.com), came up with a solution by providing a ModBus to LoRaWan converter – which is then finally implemented.

Figure 8. The Danfoss heat pump controlled through the ModBus- LoRaWan solution developed in the project.

The final solution consists of a single piece of hardware which connects to the heat pump *transforms* the device into a smart-grid ready device. The installation of the device only consists of plugging the converter into a serial input making it possible for end-users to do the installation. Contrary to the boiler implementation, the embedment of the sensors during the manufacturing process is not required to obtain a positive business case as the converter could be sold as a cheap and simple upgrade to the heat pump.

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3.3.1 Hardware

The components for this solution are:

- A Smartlog ModBus to LoRaWan converter
- A 'LoRaWan gateway' or 'IoT base station'
- A Danfoss heat pump controllable via a modbus interface

3.3.2 Software

The Smartlog ModBus to LoRaWan converter reads out a number of critical temperatures (condenser, evaporator, domestic hot water, central heating water, environmental temperature) and some critical set points (minimum and maximum temperatures of boiler, 'gears' of the heat pump engine demand control of the room controller, operational state of the heat pump system) and sends these parameters over the public LoRaWan network to the SmartLog cloud application server. From there, Actility fetches it through the API of Smartlog and stores it into the Actility Datalogger cloud application for further modelling treatment by the Actility Energy platform. In the reverse direction, it is possible to send commands over the LoRaWan public network to change the state of the heat pump (On, Off, …) or to change the gears of the heat pump engine (actually, the 'gears' parameters are supposed to be used for throttling the power of the installation) – enabling Demand Side Control of the electricity grid.

The Node-red graphical program to test the read-out of the parameters up to the level of the Smartlog API is presented in Figure 9, and an example of the temperature measurements is presented in Figure 10.

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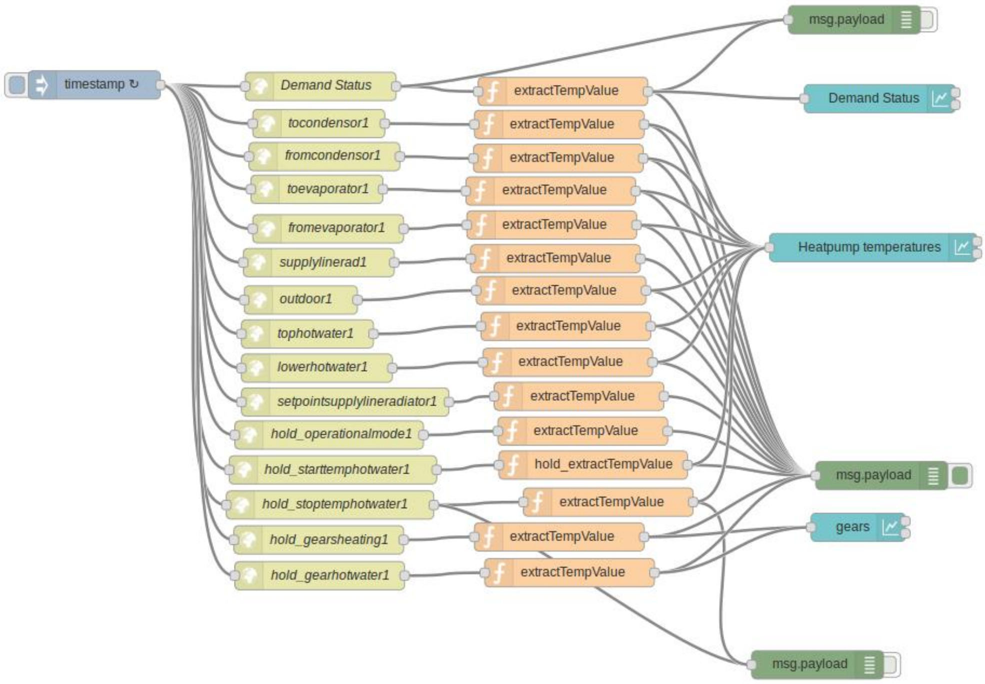

Figure 9. The node-red graphical program to test the read-out of the parameters up to the level of the Smartlog API.

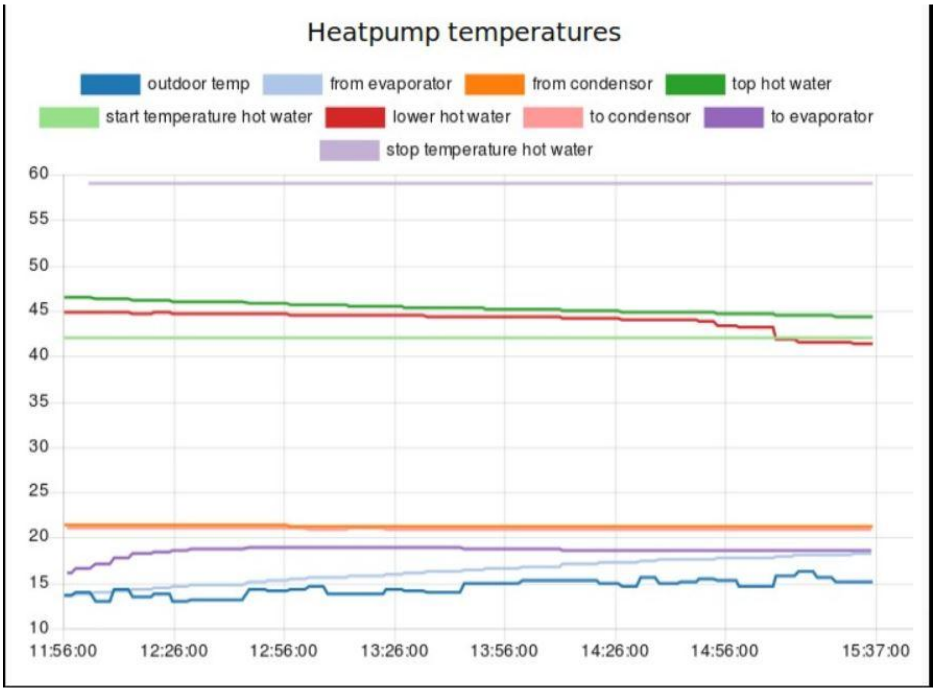

Figure 10. An example of the temperature measurement data received from the heat pump.

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3.3.3 Control

Due to the ModBus connection, all necessary variables are present to know the state of the heat pump and to control the heat pump. Together with distributed temperature measurements in a house, this enables the creation of a (self-learning) model for the building which can be used for optimal control, similar to the boiler. Such a configuration is given in Figure 11 below in a schematic fashion.

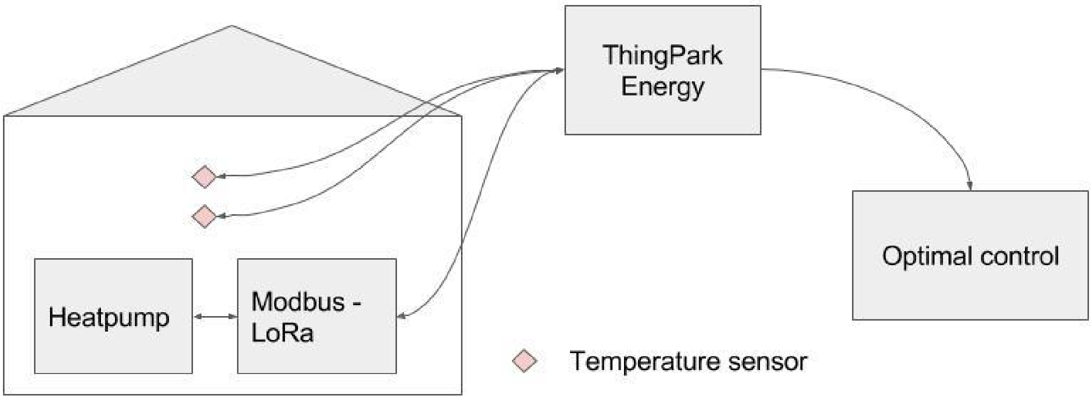

Figure 11. A schematic presentation of a configuration that enables optimal control of a heat pump from external command point.

This demonstration shows how a LoRaWan connected heat pump can be used to valorise the flexibility of a building with minimum effort. Heat pumps with Modbus connectivity can even be easily extended to support this connectivity. Temperature sensors can be distributed in the house or the temperature can be acquired through a smart thermostat.

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4 Conclusions

The embedded measurement and control system of the battery have been successfully integrated and will further be followed up regarding efficiency and effective flexibility. How the selected operational mode influences the battery round-tip efficiency is an additional aspect that will need be considered in the monitoring and evaluation phase.

The integration of both the hot water storage tank and the heat pump have been very successful and clearly show the power of a pre-connected device using LoRaWAN. Furthermore, the choice for LoRaWAN made it easy to do the communication hardware embedment as the cost stay low and no configuration is needed from the resident's side (such as a WiFi connection).

The heat pump boiler connected to the hot water storage tank can now be fully monitored and controlled and will be used as an excellent example of how a connected storage device can be used to create additional value by providing a service which is was initially not build for. However, the business case will most likely only stand when the embedment is done during the manufacturing stage.

The ModBus integration of the heat pump shows the potential of connecting a device after it is built. The heat pump is connected via a ModBus LoRaWAN converter and instantly transforms the heat pump in a *smart-grid connected* device. The manufacturing cost of this device will be low and in any case smaller than the potential gains created by the additional services which can be supplied by the heat pump after connecting to the cloud.

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5 Acronyms and terms

API	Application Programmers Interface
LoRa	Long range, low power wireless platform
WAN	Wide Area Network
RP	Report
SoC	State of Charge (of the thermal storage)

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