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Deliverable 4.3
Requirements definition of the hardware to be deployed

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Deliverable administration										
No & name	D4.3 Requirements definition of the hardware to be deployed									
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Description of the related task and the deliverable in the DoW	Subtask 4.2.1 Definition of requirements • Detailing of the actual requirements for hardware (sensor, actuator, and communication) • Based on the experience with interoperability in previous and on-going projects. • The criteria are looked at from an idealized perspective, with no boundaries or limitations • The development of the criteria is done in an iterative cooperation between the different partners; each partner proposes a set of criteria and the others challenge that, remove or add criteria Subtask 4.2.2 Hardware selection • The market is screened to find the hardware components that best match the criteria from subtask 4.2.1. • A best fit and best price/quality fit is selected for the building, neighbourhood, and district communication in the demonstration sites. • Cooperation with ACT ensures that a wide range of available options is screened and checked against the criteria. • Potential solutions are ranked regarding price/quality for matching the criteria. D4.3 Requirements definition of the hardware to be deployed Market screening to find the hardware components that best match the project defined criteria. A best fit and best price/quality fit is selected for the building, neighborhood, and district communication in the demonstration sites.									
Planned resources PM	VTT	THNK	VITO	VLER	BASN	UL	BEN	EG	VIES	HAW
	-	-	-	-	-	3	-	1	-	-
	B9	LOPT	JR	ACT	PROS	CEN	EXL	UCL	HAW	Total
	-	-	-	5	-	-	-	0,5	-	9,5
Comments	The table above shows the planned resources for ST4.2.1 and ST4.2.2									

V	Date	Authors	Description
0	2015-10-25	UCL Paul V	Very initial draft
0	2016-04-09	UL Franci K	Added UL content to HW selection Chapter
0	2016-06-08	ACT	Restructure report
0	2016-08-28	ACT	Content update
0	2016-09-30	Demos	Feedback on REM + update of demonstration sections
1	2016-10-11	ACT	Final update
1.01	2016-11-03	ACT	Checked and released to the Coordinator for internal QA and subsequent submission to the EC

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1 Publishable Executive Summary

This document covers the requirements for ICT hardware (i.e. computing, sensing, actuating and communicating devices) in the demonstration sites of the STORY project. Here, the criteria are looked at from an idealized perspective, with no boundaries or limitations due to specific technological challenges. Specifically, legacy (already in-place) technologies are considered as such and do not get any credit over more recent competitors.

The document collects the know-how and expertise within the STORY consortium during the hardware selection for the different demonstrations, offering a starting point from which case-specific requirements can be derived, technical discussions are supported and public documents for specific audiences can be composed. The document does this by describing a methodology based on a functional decomposition using a Requirement Evaluation Matrix (REM). The REM gives the relative importance of general hardware requirements for the four considered environments: building, neighbourhood, district and industrial. It is a working document covering a technical area that is changing rapidly; consequently, the discussion incorporates, among others, reflections on invariants and uncertainties concerning the future. Specifically, the tension field between legacy technologies, lacking features to answer today's and tomorrow's needs, and emerging technologies, offering comprehensive solutions but lacking widespread availability and support, is relevant.

A key conclusion concerning hardware is that there is no one solution that fits all applications within the STORY domain, not even for all the STORY demonstration cases. The range of requirements is too broad, often application-specific and the impact of legacy and its variability is too significant. For instance, smart energy and energy storage in private homes have requirements that are poorly addressed by legacy technologies or aren't addressed at all. The lack of an installed base eases the adoption of superior novel technologies, and concerns about safe and proper operations tend to be local or isolated. Nonetheless, solutions that need to co-exist with legacy remain necessary even in this area.

The REM confirms the commonly known requirements for technical installations: robustness, reliability, accuracy, cost-effectiveness, legacy systems integration, security, ease of installation and operation. In addition, low power consumption revealed to be of significance, especially in view of battery-operated devices and Uninterrupted Power Supply (UPS) systems ensuring high availability. Size and weight equally matter in many applications. Scalability is another requirement, as future installations will be large in size relative to today's systems.

Concerns addressed by modern technologies include computational power – processing and storage – at competitive prices as well as a critical user mass (e.g. 32-bit microprocessors with gigabytes of memory and storage supporting mainstream software environments). Likewise, hyper scalability (IPv6) and deep penetration of wireless communication offer scalability, ease-of-installation and state-of-the-art security and reliability, unmatched by legacy systems.

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Overall, every development is likely to face an installed base comprising legacy technologies and human expertise tailored to an existing situation. However, the world has changed and is changing such that novel technologies need to deliver key contributions. This includes adoption of the main features of internet technologies (e.g. IPv6 capable and IP based/interoperable). This ensures scalability, state-of-the-art security, as well as critical mass concerning users, developers, installers, and operators. The blind spots in today's installed base need to be addressed (e.g. wireless communication with deep penetration in building with steel reinforced concrete).

Finally, the REM is used and evaluated by all STORY demonstrations to show the differences between the different environments and the importance of application specific requirements. This exercise clearly showed the value of the REM to communicate the expertise gained during the hardware selection and the similarities between different demonstrations on the same level.

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2 Introduction

The purpose of this document is to detail the actual requirements for hardware (sensor, actuator, and communication) for the demonstration cases within the STORY project. The criteria are looked at from an idealized perspective, with no boundaries or limitations due to specific technological challenges. In particular, legacy technologies aren't treated preferentially vs. more recent competitors except for the need to co-exist with them in their installed base.

Furthermore, this document is about the hardware. Software only enters into the discussion indirectly: hardware platforms typically support a restricted range of software. E.g. PLC and SCADA systems will not offer Linux or Windows with native device drivers towards their inputs and outputs (I/O). In contrast, mainstream computers (e.g. Intel or ARM based) offer a wide range of software options (Linux, Windows, .NET, Python, Java, C++, web servers, soft PLC, soft SCADA, etc.). These are enjoying critical user mass but often need specific solutions to address hard real-time demands. The evolution of technology favours mainstream hardware platforms enjoying large/critical user mass where developments in mechatronics and Internet of Things (IoT) are alleviating the hard real-time issue continuously.

The deliverable fits in the STORY project as a result of the work done on the hardware selection for the different STORY demonstrations. In this way, it contributes to the project by helping the different partners during the selection and communicating best practices based on the experiences gained. The deliverable can be seen as the counterpart or addition of D4.1 which covers the communication requirements.

ACT and UL are the main contributors of this document and assisted the different partners in their hardware selection and together created the REM methodology. THNK has done the selection of all components (hydraulic, electrical, monitoring and communication) for the living lab building in Oud-Heverlee. All WP4 partners and in particular UL and BASN played an important role in the definition of the ideal and real life hardware requirements. Finally, ACT, UL, CEN, B9, VITO and ENER all contributed a detailed overview of the hardware selection and how it fits the REM methodology for their respective demonstration.

3 Proposed requirements

This section gives an overview of the discussions in which the partners involved included their proposed hardware requirements to be discussed, retained or rejected, and revised. It collects the views and the know-how from the participants. Among others, not all elements listed concern hardware or fit within our idealized viewpoint. Some of the requirements proposed were therefore discarded, and only the agreed-upon set of hardware (HW) requirements is retained. Using this process, an ideal set of requirements is composed and presented in Tab. 3.1,

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showcasing the consolidated consensus in the project regarding the ideal hardware requirements.

Tab. 3.1 An ideal set of hardware requirements

Proposer	**Requirement**	**Comments**
UCL	IP-accessible	
UCL	State of the art integrity (e.g. CRC)	
UCL	State of the art security (e.g. AESAP with sufficiently long encryption keys)	Especially suitable for wireless, internet connected devices
UCL	Local computing power and access to sensors/actuators to survive interruptions of communication links	
UCL	Decentralised, distributed software and configuration management and diagnostics	
UCL	24/7 availability with automated (or remotely supported) recovery	
UCL	Restful interface available	
UCL	Full state observability (in function of bandwidth of the energy system)	
UCL	Cycle time for the controls (sense-compute-actuate) 10 times faster than the period of the energy system's natural frequency (i.e. bandwidth)	
UCL	No Hassle connectivity (automated discovery, wireless …)	
UCL	Low cost with large user community (commodity size). Redundancy/robustness must come from mutual support, not expensive h/w options.	Especially important for the residential level
UCL	Code/controls updating without shutdown or rebooting	
BaseN	Ability to cache data during internet outages	
BaseN	Ability to remotely update software & configuration	
BaseN	Modular communications system (Ethernet, WLAN, 3G/4G, radio, …)	
BaseN	The device must be able to cope with low-quality power (short fluctuations) and either completely electronically isolate itself from sensor reading interfaces or make sure that is survives interference from external source (e.g. SD card on Raspberry Pi like cheap solutions are a very weak link).	

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VTT	Devices must support usage of popular Linux distributions, when applicable.	Gateway and actuator devices
VTT	Devices must fulfil predefined environmental requirements (temperature, moisture, etc.).	
VTT	Most critical devices could have ‘watch dog’ feature to enable automatic recovery.	
JR	The device must be compliant and be certified regarding the CE marking.	
JR	The device must have a reasonable noise emission level.	Devices used inside a house or flat
JR	The device should be enabled with a slot to insert a hardware key (e.g. card reader).	
VITO	The device should be capable to work in a dusty environment	Beneens case with waste wood burning
VITO	The device can work in environments with high electromagnetic interference.	
VITO	The device can be equipped with an electrical storage system (e.g. battery) in case of power supply interruption.	
ACT	Real time monitoring of state. Be able to see the measured data in real time.	
ACT	Direct access to IP without installing a separate communication gateway.	
ACT	Automatic registration to the network.	
ACT	Backup connection if the first connection fails.	
ACT	Battery powered sensors and actuators.	
ACT	Deep indoor connectivity. The device should be able to connect in all environments.	
ACT	Low cost sensors, actuators and communication gateways / subscriptions.	
ACT	Easy installation of the sensor / actuator without changing the legacy system in place.	
ACT	High level communication interface for application developers.	
ACT	Unified standard for all smart grid components. API (Application programmable interface) is the same for all smart grid components.	
EG	Increased resistance to potential attackers and unintentional errors.	
EG	Data confidentiality provision and customer data privacy.	
EG	Data backup and disaster recovery availability.	
EG	Guaranteed ongoing support and maintenance.	

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EG	Provision of open industry standards (TCP IP, HTML, ...) for general interoperability.	
EG	Generally accepted vendor standards.	
EG	Real time data exchange, monitoring and service management.	EG, Enersys, Lecale
EG	Remote upgrades, securely updates of software and firmware.	
EG	Mobile approach (GSM/GPRS, ...).	Oud Heverlee, Olen
EG	Backup solutions for communication links (i.e. multiple WiMAX Base Stations).	
EG	Secure communication between grid devices and operator.	
EG	Automatic device registration for remote monitoring and control (AMI counters, etc.).	EG
EG	Time synchronisation.	Vital when obtaining data from different platforms (metering data, quality metering, SCADA data)
EG	Reliable (persistent) data storage.	
EG	Distributed data processing (local level, service level, ...).	
EG	Provision of low level (or possibly not at all) data loss.	
EG	Provision of predefined Quality of Service (QoS) for connectivity (latency, bandwidth, delay, ...).	
EG	Web service enabled technologies for demo sites management.	
EG	End user interfaces to access different demo application functionalities (HMI for smartphones, HMI for desktops, …).	
EG	Large data base provision and management.	
EG	Data integrity provision (truthfulness and timing).	
EG	Metering of different parameters (voltage, currents, powers, quality,..).	EG, Enersys, Lecale
EG	Metering at grid nodes and data transfer to back-end.	EG, Enersys, Lecale
EG	Setting of configuration parameters to field devices (locally and remotely).	EG, Enersys, Lecale
EG	Provision of scheduled actions and conditional control.	
EG	VPN connection provision.	
EG	Protection of system components.	
EG	Security management.	

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EG	Traceability of events, alarms etc…	
UL	Low power consumption.	
UL	Small size and weight.	
UL	Reliable (redundant) internet connectivity.	DSO
UL	Accurate time (NTP protocol).	DSO
UL	Logging system for events (syslog).	DSO
UL	Fault management (Alarm reporting).	DSO
UL	User friendly configuration and management.	DSO
UL	Support for wide range of protocols (modbus, DNP3, IEC60870-5-104, OPC-UA).	DSO
UL	Support for IEC 61850.	DSO
UL	Ease of data mapping between protocols.	DSO
UL	Reliability of SCADA system (redundancy of servers and failover).	DSO
JR	Fault ride-through capability.	Suha, Lecale
JR	Usage of security by design and privacy by design principles for developing a reliable communication gateway.	ALL
BASN	If device has a battery, it must be capable of a graceful shutdown when battery is running low. Otherwise system must be resistant to occasional accidental shutdown/reboot by power loss.	

4 The ideal set of requirements and conclusions

This document takes an **idealized** perspective or stance concerning **hardware requirements** for the STORY project while keeping in mind both the demonstration cases within the project and the future replicability of solutions transpiring from the project. For instance, a ‘’real-world realization’’ may have to provide ‘’wrappers’’ around legacy sensors, actuators and networks to create an installation that complies with the retained hardware requirements from the wrapper interface/connections onward. The wrapped components and systems are considered to be outdated and are to be phased out when decommissioned, replaced or upgraded.

In this Chapter the hardware requirements are addressed from a number of perspectives. We investigate their hyper-connectivity and simplicity, possibility for decentralized system management, robustness, cost level, attained critical user mass, legacy technologies, migration, and control and measurement applications. Finally, we present the final list of HW requirements.

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4.1 Hyper-connectivity and simplicity

The STORY hardware ideally needs to scale and connect on par with the Internet and IP. In today's technical environment, from an idealized viewpoint this translates into ***direct access to IP*** without the need to install a separate gateway. Installation and configuration is easy and highly automated; sensors, actuators, computing nodes are discovered (e.g. plug-and-play), etc. Registration to the network is automated.

This auto-configuration may even include access to technical characteristics beyond the connectivity itself. This would include environmental parameters such maximum and minimum temperature of the surroundings, noise levels, power consumption, etc.). Possibly, this is achieved through Internet/cloud services pointed at by the device.

Low power consumption, allowing for battery-operated devices, is the preferred choice. When not battery-operated, optional UPS must be provided at user's disposal. Likewise, small size and weight, easing physical integration and installation is a requirement. Ultimately, integration on chip-level is to become the first choice; If addressed at integration circuit (IC) design time, electronic control hardware of a heat pump or a climate control could be upgraded adding the required functionality, identified in this report, at a cost less than 5 euro.

Modularity regarding communication technology (wireless, wired, short range, long range) and often supporting multiple modes (e.g. Near field communication (NFC), LoRa and Wi-Fi) is highly desirable. Deep penetration[1] of one of the provided wireless modes is required, allowing for easy, low cost installation of sensors and actuators without causing inconvenience to the users or inhabitants.

State-of-the art security and integrity are to be supported to minimize organizational constraints and hassles needed to ensure proper operations. Finally, minimizing the need for services that require negotiations by humans (e.g. 3G/4G) when cheaper available alternatives exist (e.g. LoRa) further improves the simplicity of the operations and organisational processes.
Overall, the environment of smart systems becomes a homogenous space in which a very low number of mechanisms allow connecting, configuring and operating smart systems. Moreover, this solution scales as needed by the application. It scales at design and installation time, as well as while the system is and remains operational. In the end, the hardware supports a single API for all grid components, differing only to reflect the component in the application dimension and not the ICT dimension. All components exchange information in the same manner but have component-specific information-processing capabilities and requirements. A valve and a flow sensor are able to connect and communicate in the same manner whereas the content and the effect of these communications will differ.

[1] Through steel-reinforced concrete, reservoirs in a brewery or dairy farm, …

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4.2 Decentralized system management

There must be a possibility to manage the systems remotely and in a decentralised manner. Software installation must be enabled and managed from a distance. Logging, diagnostics, etc. are either supported or software is available to do this. The local systems have all the necessary privileges that enable distributed management. Ideally, management does not disturb operations; software updates without restarting the installation, diagnostics is integrated with the operations.).

4.3 Robustness

Smart grid operations demand very reliable hardware, or at least services executing upon the hardware. This involves three aspects: security, component or installation reliability, and system reliability.

Concerning **security**, state-of-the art technology needs to be employed (AES, RSA with long keys). To enable strong security, the hardware platform with the accompanying software platform and user community needs to exhibit the ability to keep up with future developments and to remain state-of-the art concerning security. Failure to do so will result in difficult working conditions and cause the loss of the simplicity and hyper connectivity when e.g. restrictive firewalls and air gaps become necessary.

Supporting security, solutions from banking need to be possible where desired (e.g. out of the loop challenge-response). Moreover, support for very short range and contact technologies is instrumental (e.g. card readers, RFID, NFC). The security features supported by the hardware allow software to ensure privacy as required and desired.

Next to security, the **integrity and reliability of single devices/installations** needs to be ensured. It starts with state-of-the art integrity features ensuring that data is transmitted correctly and, if not, failures are detected. This is a matter of avoiding outdated technologies (e.g. RS232C, using a common signal ground and barely any error detection) and employment of state-of-the art technologies (CRC checks, differential signals, and clock recovery from signal …). In high-demanding cases, expensive hardware will be indicated (e.g. ECC RAM).

For more mundane and common installations, it suffices to address the key weaknesses. First, high quality power supply, possibly battery-based UPS, is mandatory. An adequate shielding from interference (e.g. galvanic, optical or wireless) is a second measure. Moreover, high-quality hardware for storage solutions is indicated (flash memory) where proper usage needs to be ensured (e.g. avoid overwriting the same part of flash memory, raid).

The individual installation needs to survive service interruptions in its environment. Local computing and storage is indicated (e.g. caching). The possibility to survive power outages needs to exist, leaving the decision to provide the capability to the specific cases.

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Next to individual installations, redundancy at the **level of the overall system** provides robustness. Both data storage and running operations benefit from multiple options to perform what is required. The hardware needs to allow the software, executing on top of it, to provide such functionality. Basic hardware functionality includes watchdog timer and heartbeat signals, among others. This robustness provided at an overall system level is indicated in high-value installation and applications and in ‘’massive’’ low-end systems in which ‘’neighbours’’ mutually assist each other. Obviously, the software plays a key role in the latter.

4.4 Low cost and high critical user mass

Depending on the application environment, cost plays a decisive role. Critical user mass is the most important factor in keeping costs low. However, it has an even more critical role in this discussion. Critical user mass determines the quality of the solution, the speed at which the solutions adapt to a continuously changing environment and, most importantly, the upper limit on the complexity these solutions will cope with. Industrial automation lacks critical user mass in this respect to support applications that are more complex than currently existing applications in industry. Analogously, graphic cards in CAD (Computer aided design) systems have been developed for gamer not for industry.

STORY research and application domain ranges from interoperation with the distribution system operator (DSO) to home automation. At the DSO end, industrial automation legacy systems will shift the balance towards expensive, low user mass hardware, which will be required in small numbers executing relatively simple protocols. On the other hand, home automation, integrated at internet scales, will be highly cost-sensitive and enjoy large user masses provided mainstream computing technologies are selected (e.g. Python, C and not IEC61499). In spite of the perception of a shortage of ICT professionals, there is no alternative to employing them when the solution complexity moves beyond a rather low threshold. Industrial automation remains competitive in providing access to sensors and actuators (with upcoming IoT competition and mechatronics) but is ill equipped to compete in providing application-level services.

On another level, the embodiment of the hardware has an impact on the cost. Ideally, small, lightweight, low consumption is demanded. Battery operation (10+ years on a battery) is a plus. Embedment in an IC that is anywhere present is highly desirable in long run.

4.5 Migration

In practice, the *ICT-hardware* selection may be constrained by the *energy-hardware* selection. The best and thus preferred choices for solar charge controllers, battery monitors, compressors, pumps, valves, etc. may fail to support our preferred ICT-hardware technologies. Unsurprisingly, such limitations, originating from the application in the energy domain, mostly

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have priority over our demands for a future-proof scalable ICT-hardware selection (e.g. supporting hyperconnectivity).

With migration in mind, an idealised hardware selection – but nonetheless realistic and pragmatic – comprises a “wrapper” around the devices that fail to support future-proof technologies. Typically, a computer node communicates with the energy device in a manner supported by this device (e.g. RS232C) and renders all device functionality available through future-proof technology (e.g. IPv6). Note: the recurring hardware cost for such a wrapper (e.g. a 32-bit CPU with ½ GByte RAM) is low and decreasing.

4.6 Applications of energy control and measurement

The nature of the envisaged applications translates into hardware requirements. Timing is a first aspect. Support for NTP is indicated but providing the basic capabilities for PTP is a truly general purpose feature (e.g. hardware time stamping of outgoing data packets). Hard real-time data processing and communications are on the list of many but not all applications. Because mainstream computing has no need for it yet, this requirement remains tricky, as it is difficult to achieve critical mass, forcing applications to remain simple. Often, soft real time as needed by on-line computer games like counterstrike in combination with software and hardware able to survive interruptions will be the preferred solutions. Indeed, requiring fully reliable hard real-time services will remain both risky and resource hogging for the foreseeable time.

An example of different timings in the electricity grid is the balancing mechanisms of a Transmission System Operator (TSO). Primary or frequency control has to react automatically on a 30 second basis to maintain the frequency whereas Tertiary control is often manually activated and balances the power in 15 minutes.

Next to above generic features, control specific requirements belong on our list. Observing a system at a frequency 10 times greater than its natural frequency and being able to issue commands at similar frequency facilitates control greatly. It is worth noting that going to a high frequency almost always means lower latency putting additional requirements on the network such as bandwidth. Furthermore, especially in the presence of legacy technology equipped with suitable ‘’wrappers’’, the ability to access all sensors and actuators is necessary. Such access must not suffer from unduly delays, jitter, etc.

4.7 Final list of requirements

The above discussed requirements are summarized in the table below. For each requirement, a proposed *ideal* value is given.

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Table 4.1 The summary of the final requirements.

Requirement	Description and examples
Ease of installation and operation, scalable and supporting hyper connectivity.	IPv6 based while being able to cope with “constrained resource environments” (cf. CoAP, LW-M2M) where relevant.
	Single/same API for similar/identical functionality (or straightforward conversion)
	Minimal dependence on service contracts from third parties (e.g. telecom operators). Hassle-free and uniform/standard services at most.
	Automated discovery, registration and configuration (cf. universal plug and play).
	Where relevant/useful/needed possibility for battery operated components (with e.g. 5-10 years of autonomy)
	Physical integration requirements/efforts/costs are minimized/modest/proportional to non-expert users.
Integrity, security	Using state-of-the-art, best in class technologies; e.g. AES secret-key encryption, CRC, RS error detection and correction, … Key management with public key encryption, e-banking technologies, … and/or physical proximity (e.g. NFC, USB).
Decentralised system management	Basic operation from a remote site supported.
Robustness	Possibility of UPS when/where needed.
	Monitoring and handling of battery charge depletion or battery malfunctioning (note: battery for the ICT, not the STORY application).
	Redundancy adapted to the application (e.g. high but costly versus cost-effective). E.g. mutually supportive installations must be possible.
	Ability to cache data during connectivity outages
	General-purpose ICT capability to handle unforeseen demands from the test case at hand
Cost effective	Linux based
	Critical user mass (maximized, large margins)
	API accessible to software in a common language
	Mainstream computing (not industrial automation specific) with isolated components handling (if needed) hard real-time demands (which currently are not expected or identified)
Legacy technology handling, integration	Quarantined/isolated by providing a mainstream computing platform (Linux based) to connect (over Ethernet, USB, …) to the project’s ICT infrastructure.
	Current list of legacy technology: - ModBus, - KNX, - DNP3.0

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5 Hardware selection

This Chapter discusses relevant hardware components needed for the different demonstration cases within their respective levels. Hardware selection will be done in four levels: building, neighbourhood, district and industrial level.

The ideal requirements from Chapter 4 are interpreted in more concrete and tangible criteria that can be used to evaluate hardware components. In the second step, these requirements are used to construct a *Requirement Evaluation Matrix* (REM). The REM consists of a functional decomposition of hardware components for each level where each requirement is weighted for its importance depending on the level.

Finally, the evaluation of some examples using the REM is shown for hardware components used in the demonstrations.

For communication gateway requirements, we refer to the Deliverable 4.1: “Structured Overview of Communication Standards for Smart Grids” (cf. reference 1).

5.1 Requirement Evaluation Matrix

The goal of the hardware *Requirement Evaluation Matrix* (REM) is to share the experience of the hardware selection within the STORY project in the form of a selection methodology. While STORY does not want to give a comparison between hardware from different manufacturers, the REM still allows sharing our expertise in a usable and informative format.

What follows is a description of the REM methodology, explanation of requirements and their weights for each application and finally an evaluation of practical examples of hardware components used in the demonstrations.

5.1.1 Methodology of hardware components evaluation

Error! Reference source not found. shows the REM which is used to evaluate the different hardware components on the different levels in the STORY demonstrations:

- Building (Home area network HAN).
- Neighbourhood (Neighbourhood area network NAN/FAN).
- District (Wide area network WAN).
- Industrial (Local area network LAN).

Requirements are grouped into *General requirements* and *Connectivity requirements* and are based on the idealized requirements from Chapter 4. Every requirement is weighted in accordance with the importance for the type of application environment. The relevance of each criteria is presented as requested value, where it must be better than presented value to receive

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100 % score, or as importance of different levels. For example, low power consumption is less important in the industrial environment, but is very important for in building battery operation. The sum of values in each level is normalized and thus equal to 1.

Scoring option definitions indicate quantitative requirements for an application which helps to score hardware components according to their characteristics in the REM. Scoring option definitions are very case specific (e.g. the criteria *low power consumption* will equivalent to mAh for sensors on batteries whereas Ah could be used for sensors connected to the power grid) and therefore only slightly elaborated upon here and in a general manner.

A hardware selection with the REM then consists of the following steps:

1. Defining the scoring options for each criterion based on the application needs
2. Multiplying the assigned weight with the designated score of each requirement.
3. Calculate the sum of all multiplied values for each group separately (general + connectivity).
4. Calculate the weighted sum for each group and define an importance factor between the general and connectivity group. The sum of separate group requirements is multiplied with assigned importance of each group.
5. Divide the score by the price of the hardware equipment to represent a cost/value result. The result is a quotient that provides some baseline form evaluation and comparison of future and legacy equipment.

As mentioned, weights, scoring options and designated values of requirements of levels can be adjusted accordingly to the application needs.

Result of REM evaluation and calculation provides a good indication of quality of legacy and potential new hardware components. Overall ranking of potential solutions could be prepared by dividing the price with result of REM score.

5.1.2 Table of weights for every requirement for the different levels

Table 5.2 The requirement evaluation matrix for the different levels.

Network Level (environment)	**Building (HAN)**	**Neighbourhood (NAN/FAN)**	**District (WAN)**	**Industrial (LAN)**
General requirements (sum of weights = 1)				
Low power consumption	0.09	0.09	0.05	0.03
Size and weight	0.09	0.09	0.02	0.03
Ease of installation	0.13	0.13	0.09	0.05
Simple operation	0.13	0.13	0.11	0.08
Reliability	0.06	0.06	0.13	0.12

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Modularity	0.06	0.06	0.08	0.11
Accuracy	0.06	0.06	0.11	0.10
Scalability	0.10	0.10	0.07	0.08
Computational power	0.05	0.05	0.06	0.07
Memory RAM	0.05	0.05	0.07	0.08
Disk storage	0.05	0.05	0.03	0.10
Configurable	0.06	0.06	0.10	0.11
Time synchronisation	0.04	0.04	0.09	0.05
Connectivity requirements (sum of weights = 1)				
Remote connectivity (via the internet)	0.17	0.17	0.17	0.00
Fibre connection	0.04	0.04	0.10	0.12
Wireless connection	0.20	0.20	0.17	0.07
Deep penetration	0.15	0.15	0.12	0.03
Bandwidth	0.09	0.09	0.08	0.02
Allowed delay	0.07	0.07	0.09	0.29
Redundancy (communication)	0.07	0.07	0.12	0.26
Security	0.22	0.22	0.15	0.06
Importance of group of requirements for levels (environments) (sum of weights = 1)				
General requirements	0.6	0.6	0.5	0.6
Connectivity requirements	0.4	0.4	0.5	0.4

5.1.3 Description of requirements and example scoring options

This section gives a description of the requirements and scoring options for the hardware criteria based on the expertise gained during the hardware selection for the STORY demonstrations. For some requirements, an indication of an optimal value is given as an example as these values can be very application specific. This section can be seen as an extension to Chapter 4, incorporating the expertise gained during the hardware selection to transform the *ideal* criteria in *real* criteria.

General requirements

Low power consumption is generally an important requirement in all cases. It is important in applications with power delivery interruptions. A system must be resistant to an occasional accidental shutdown or a reboot due to power loss. The only area where the power consumption is not the most critical requirement is on industrial (LAN) level where usually an alternative power supply is available. For the building, neighbourhood and district level good power consumption is below 10 W.

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Low power consumption is especially important for battery-operated hardware and UPS systems. If device has a battery, it must be capable of a graceful shutdown in case of battery running low. The second, alternative solution is UPS operation.

Size and weight often depends on the use case of the required equipment. It is not unusual that the size and weight is limited with the mounting capabilities of the equipment or available space. Integration on the IC level enables small dimension of the devices and higher reliability. An example on the industrial level would be to score the weight of the device at 100 % if the weight is below 5 kg.

Level of ease of installation and set-up has a significant importance. It can be measured in amount of special and dedicated tools required, the amount of time that is required for installation or the required installation expertise. At the industrial level, installation can be more complex and therefore it has a lesser influence on the score.

The devices should have user-friendly and simple operation that saves time during the installation and operating time. In addition to simple management, the devices should support remote management for more convenient operations of the system, remote configuration and diagnostics. Remote management saves time, money and other resources, as operators do not need physical contact with the device. Operator and technicians can improve and secure the devices or system from a distance with remote software upgrades which is important for neighbourhood and district levels where it is difficult to ensure the physical accessibility of equipment.

Reliability is one of the most important requirements in all cases. Equipment malfunctions are a regular appearance with working systems. One of the solutions to detect and recover from malfunctions is a watchdog timer. A system can regularly restart this timer when the system and devices are working as designed, but in case of a malfunction, the timer runs out and forces the recovery of the system. This is very important for neighbourhood and district levels.

Modularity is the most essential for industrial level. It enables joining and combining different devices and module. Modularity allows industrials to build their own application using hardware components from different manufacturers and thus optimizing the cost. For example, a modular communication system consists of Ethernet, WLAN, 3G/4G and has open API connections. This can refer to meters, communication equipment and software.

Accuracy is important for meters and is highly application-specific.

Scalability is the capability to cope and perform under an increased and expanding workload. This functionality provides future proof systems with constant level of performance and efficiency. The importance of scalability greatly depends on the application and the amount of hardware components needed.

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Computational power is important in systems where a local computation will take place. In the building and neighbourhood level, most of computational calculations and forecasts will be done on remote servers.

Memory RAM should suffice to all of the CPU requirements and other system and communication requirements.

Disk storage enables redundancy in case of unreliable communication link with occasional interruptions. Additional storage space provides storage space for temporary storage of measurement results for up to a year. Solid-state disk is reliable alternative to hard disk and are typically more resistant to physical shock, run silently, have lower access time, and less latency. Devices should be configurable.

Accurate real time should be ensured with a local timer or real time clock (RTC) and time synchronization. The network time protocol (NTP) assures clock synchronization between computer systems over packet-switched, variable-latency data networks.

Connectivity requirements

Remote connectivity provides direct access to internet without installing a separate communication gateway and serves as the convergence level for all communications in modern systems. Through open standards (TCP, HTML, etc.) it provides general interoperability. IP connectivity is important to all area levels equally as it offers high-performance communication in comparison to traditional fieldbus networks. Direct connectivity enables new requirement of simple installation of devices and setup of connectivity. Only at industrial level, we can accept more complex installation processes.

Fibre optical connection is a next available technology for connecting different area levels, neighbourhood, district and industrial areas. Fibre can be used in harsh environments with high electromagnetic interference and represents a bonus in comparison with other communication technologies.

Wireless connection is important on all area levels with the exception at the industrial level where for reliability purposes most data is communicated hard-wired. It bypasses the limitation of buildings and setting up wired connections. Connections must be secured with authentication and encryption with sufficiently long encryption keys.

Deep penetration of wireless signal through walls and steel-reinforced concrete is required for easy, low cost installation in neighbourhood and district level.

Bandwidth is dependant of the system requirements for full state operation of the energy system and applications. Nevertheless, it should fulfil required needs for all area levels. However, the building area requirements are not the same as district requirements where bigger bandwidth is

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required. A delay must be set appropriate to different area levels thus delay settings are stricter at industrial and district level than building level.

Redundancy of communication path is required for assuring delivery of transmitted data to its destination. Redundancy can be ensured in several ways. An additional communication path with a different technology, e.g. wireless communication connection in addition to wired one is a straightforward method to ensure redundancy. Another approach is using several paths inside one technology. Support for multiple communication protocols allows devices to be more flexible and used in more cases. Such systems are prepared for potential future upgrade. This parameter is most important for district level.

5.2 REM weights for each level and corresponding technologies

The most important difference between the environments levels is described here based on the experience gained by selecting the required hardware for the different STORY demonstrations. A detailed description of each demonstration can be found in STORY deliverable **D4.1 [1].** The demonstrations are classified as followed:

1. Residential building scale (Oud-Heverlee, Belgium) – **Building**
2. Residential neighbourhood scale (Oud-Heverlee, Belgium) – **Neighbourhood**
3. Small scale battery to reduce peak power (Navarra, Spain) - **Industrial**
4. Residential district (Lecale, Northern Ireland (UK)) - **District**
5. Flexible and robust use of medium scale battery
    - Medium scale battery in Enersys-Hawker factory, Hagen, Germany - **Industrial**
    - Flexible and robust use of medium scale battery – **District**
    - Medium scale battery in EG headquarters, - **Industrial**
6. Roll out of private multi-energy grid in industrial zone (Olen, Belgium) - **Industrial**

5.2.1 Building level

Communication hardware found currently on the building level is often limited to personal devices such as smartphones, tablets and computers and is often not used for monitoring or control of devices, with the exception of smart devices such as smart thermostats or some smart appliances. Communication is done almost solely over Wi-Fi and the mobile network. The implementation of detailed monitoring hardware remains limited for now, as cost and set-up complexity have proven to be major bottlenecks.

The **most important requirements for the building level are the cost and the ease of installation** as customers often do not want to pay much and do not like to read complex manuals to install monitoring equipment. Complex installations require expert knowledge and thus heavily increase the cost. This is mostly because monitoring on the building level is seen as a *nice-to-have* and does not provide the same benefits as on the other levels for now.

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Therefore, the accuracy of the measurements remains less important. Furthermore, the energy quantity remains limited.

In order to cope with the above, successful building level monitoring systems use a proper home gateway to facilitate the device provisioning and avoid connecting to the local Wi-Fi network (e.g. Smappee, Ecobee, Google Home, …). Often, these devices have one central gateway connected to Wi-Fi and setup an individual radio network. Monitoring hardware is usually **non-intrusive** and thus easily set-up by the customer itself. Additionally, appliance providers are including monitoring features in their devices, which often connect to Wi-Fi or a LPWAN.

Compared to proper gateway solutions such as Smappee (cf. reference 2), LPWAN solutions avoid installing a home gateway and can thus reduce the cost in exchange for a lower bandwidth, which is often not essential for building level applications.

5.2.2 Neighbourhood level

The neighbourhood level tackles the communication between residential buildings using the same communication technology. As this level also copes with the building level, most of the same weights apply. The largest difference lies in the **additional security required when several customers communicate over the same gateway** and the additional accuracy needed for some measurements as done on the access point of the neighbourhood (e.g. An electrical feeder, heating network entrance of a neighbourhood). Furthermore, **when using the data for a clearinghouse application between the customers in the neighbourhood, the accuracy should suffice to the applications requirements.**

For neighbourhood connectivity, the use of LoRaWAN sensors will significantly optimize the costs, as installation does not require multiple access point or repeaters. Typically, a whole residential area of several square kilometres may be covered by a single access point, using Ethernet, 3G or 4G backhaul to the Internet, secured by IPsec. Antenna coverage density may be augmented in case of specific battery life requirements or need of large uplink traffic, as LoRaWAN implements a dynamic data rate feature (ADR), which decreases airtime when the network density increases.

Note that LoRaWAN Pico cells are also available, to cover smaller areas, typically radius of ~500m, with less expensive indoor access points.

5.2.3 District level

Communication at residential district level must ensure connectivity of residential users (consumers, producers) and substations with the control centre. The automation of substations relies on remote supervision and control and thus reliable and secure connections are of great importance. For equipment at the end user sites, the cost is of great importance, while the price of equipment on control and management side (substation, control centre) is less important.

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Substations often contain legacy intelligent devices such as IED, RTU or a PLC connected to a SCADA system. Therefore, **modularity** is very important, as these components must support multiple communications protocols such as DNP3, OPC UA or latest IEC 61850 to be prepared for potential future upgrades. Electrical meters must measure many parameters with requested **accuracy and reliability** as requested in IEC standards for substations.

If measurements are used for billing and/or clearing house functionality, then **smart meters** must be used which are connected to an advanced metering infrastructure (AMI) system. Smart meters must comply with the requested accuracy, reliability, privacy and data retention. Connected smart meters must be certified and in accordance with requirements defined in IEC standards, DSO and regulatory rules.

A private IP network could provide communications if necessary security wise and separated in private VLANs secured with firewalls. Connections are preferably via an optical network or via wireless network such as **WiMAX** with AES encryption to provide the necessary latency. With proper positioned base stations, WiMAX enables good coverage also in rural mountain regions. WiMAX might be replaced with LTE-M.

It must be possible to **remotely manage** devices at residents and substations – configuration, operation, diagnostic and also software installation and update, possibly without operation disturbance.

5.2.4 Industrial level

For the industrial level, **modularity** is a key requirement to be able to use hardware components from different manufacturers. These different components should be easily integrated in the present industrial communication and measurement system. The industrial requirements focus more on **reliability, speed and performance** with respect to ease of installation and cost, especially due to the large implications a faulty measurement can have on a large energy process. TSO often use a dual high performant monitoring system for their large industrial clients to measure their electricity offtake on the access point to avoid any error.

Large industrial sites often have all the required **expertise for installation** of equipment in-house as monitoring and exploiting their energy assets is their core business (contrary to a house owner with a flexible heat pump). Furthermore, **the size and weight** of the components matter less as the equipment should be sturdy and once installed often does not need to be relocated.

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5.3 REM in the STORY demonstrations

This section describes the hardware choices made in the different STORY demonstrations as well as alternatives where possible. The REM provides a useful tool to select new hardware when needed and gives a good qualitative indication of the requirements for each demonstration (based on level) as described above. **For most demonstrations, the REM and its demonstration specific weights can be found in the appendix with additional comments.**

5.3.1 Residential buildings (THNK, Oud-Heverlee, Belgium)

The demonstration consists of the individual optimization of 5 buildings. Of these buildings, building 1 is considered as a living lab where innovative technologies will be tested whereas the other 4 buildings are normal buildings with some storage equipment (e.g. batteries) are added.

The main hardware devices found in the buildings which already have existing instrumentation use separate communication gateways and communicate using the main protocols: Modbus and KNX, the market leaders in that segment. It is noted that for the building level these technologies require expert knowledge to set-up and are used here for demonstration purposes. These technologies are used in building 1 where a multitude of sensors is being set-up, justifying the choice of this technology.

In both cases, the controllers already in place can, by means of relatively inexpensive options, export the data over IP networks using ModBus/TCP or KNX/IP. In that case the hardware components that need to be put in place will need to bridge the KNX or ModBus local area network with cloud applications. Two architectures may be envisioned:

- Using a local gateway.
- Using direct WAN bridge to the cloud.

As the ModBus and KNX protocols are not natively meant to be conveyed over WAN, in case there will be multiple sensors, the optimum choice is that of a local gateway. Ideally this gateway implements a standardized Local area to cloud protocol, as the ETSI M2M standard (GSC to NSC interface, mId). Such implementations exist in open source, including drivers for KNX/TCP and ModBus/TCP. Therefore, the hardware required in only a small industrial PC, with Linux.

In case of single ModBus sensors, when the traffic is small, there is also the possibility to use ModBus to LPWAN bridge, e.g. using the LoRaWAN protocol. Such a sensor is being developed by companies such as NKE and may become available during the project.

For new sensors, not already in place, the use of LoRaWAN sensors will significantly optimize the costs, as the installation does not require multiple access point or repeaters. Most common sensing needs are covered by the LoRaWAN ecosystem:

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- Pulse metering detectors and sensors may be provided by companies Adeunis RF or NKE **and in combination with existing pulse output meters, be used to report any kind of measurement**
- Temperature sensors,
- Binary sensors and actuators,
- Remote controlled relays are also available from NKE, using familiar ZigBee ZCL ontology transported over standard LoRaWAN MAC layer.

For applications where no LoRa alternatives exist yet, custom integrations over the HAN have to be provided. Examples of these hardware components are:

- Smart Thermostats, and
- Modbus interfaces.

A good example of the power of a LoRa connected hardware component is a smart plug. A simple smart plug is plugged into a socket connected to an electric car, which allows an application to control the charge of this car. By simply installing the smart plug, the component is immediately connected to the internet (without going over Wi-Fi) and can be used for smart grid applications.

5.3.2 Residential neighbourhood (THNK, Oud-Heverlee, Belgium)

The biggest difference between the building and neighbourhood level is **the need of a central system, which has access to all information.** A remote connection to the local installed hardware has to be in place.

As described above, the most common sensing needs are covered by the LoRaWAN ecosystem: pulse metering detectors and sensors may be provided by companies Adeunis RF or NKE (and in combination with pulse output meters, be used to report any kind of measurement), temperature sensors, binary sensors and actuators, remote controlled relays are also available from NKE, using familiar ZigBee ZCL ontology transported over standard LoRaWAN MAC layer.

In the case of non-standard or prototype equipment installed in the neighbourhood, typically these systems will implement a serial ModBus interface. Serial ModBus to LoRaWAN adapters are being developed by company NKE, and we believe they will become industrially available during the course of the project. Other vendors are likely to offer similar products during the timeframe of the project; a final election will be made at the time of purchasing.

If possible, measurements from the local DSO will be used for the access point of the neighbourhood feeder. These measurements can be collected locally using pulse or ModBus interfaces or via the SCADA platform of the DSO.

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5.3.3 Industrial zone (EXC, Navarra, Spain)

The Exkal demonstration is an industrial scale facility with photovoltaic power generation and storage with Li-Ion Batteries. The loads considered for the demo, are the loads already present at the facility. It is an interconnected installation without the ability of isolated operation.

The load consumption power measurements will be performed by wattmeters. The device chosen for such task is the PowerLogic PM5320 (Scheneider Electric). At the facilities, there was already a legacy wattmeter (Carlo Gavazzi EM24, AV9), in the Point of Common Coupling (PCC). However, the PowerLogic PM5320 has substituted it because it offers wider communications options and thus increases the modularity.

On the generation side, the inverter for the PV array is an Ingecon Sun Power. It was already installed before the facility incorporated storage assets. Internal measurement devices are present in the inverter that allows electric measurements. This way, no extra measurement devices are required for monitoring the performance at this point. Communication with it is possible through a customized Ingeteam MODBUS TCP/IP protocol that was available by default in the device.

For the storage assets a bidirectional Power Converter Unit (PCU) has been selected, Cinergia Microgrid manager MM60. It incorporates an internal measurement device and it provides electric variables. As the PV inverter case, no extra measurement devices are required at this point. Communications port is included in the device allowing the use of MODBUS TCP/IP. Batteries selected are SAFT Intensium Mini-M composed by Lithium-Ion Synerion 24E modules. The SAFT batteries include a Battery Manager System (BMS). The BMS shares with the batteries PCU, the necessary data for the safe and right system operation. The communication between both devices is possible through MODBUS TCP/IP protocol.

A Programmable Logic Controller (PLC) and a Workstation that integrates the SCADA and the Energy Manager System (EMS) compose the general controller system.

The PLC communicates with the required devices of the facility through MODBUS TCP/IP. It implements the second level control, guaranteeing the integration of all devices and the correct operation of the plant. The PLC also acts as gateway between the primary control layer, which is integrated by the individual hardware assets, and the SCADA software installed on the Workstation. The Workstation includes an OPC server that provides an easy path to communicate with the PLC. The SCADA system performs data acquisition, supervisory control, database, and internet gateway tasks.

5.3.4 Residential district (B9, Lecale, Northern Ireland (UK))

Lecale, Northern Ireland uses two electric current measuring sensors: Power Sensor PAN-10 and Power Sensor PAN-12. The two sensors are similar by design and functionality with the only real difference in max out-air outer diameter size and different current measurement range.

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The two sensors have low power consumption as they harvest all the needed power from induction. They are small in size and weight with simple way of installation and ability to discover and form the wireless mesh network. Remote management is all done through the accompanying gateway. The meters use standard wireless communication but do not provide additional wired connection capabilities like fibre or Ethernet or they do not have redundancy in communication. The CPU, memory and operating system capabilities are not that important as the meters only measure and transmit the data to the gateway but do not process the data.

The Power Bridge PAN-2-E Bridge is a simple gateway for transmitting the data from the meters to the cloud platform. It has the connection redundancy in WiFi and 3G mobile communication module. The bridge has sufficient computing and memory capability to transmit data in under 10 second intervals. Its installation and operation is meets the connectivity requirements.

Meters like Satec PM 135 or Schneider-electric PowerLogic PM 5000 can be used as substitute meters based on the requirement matrix. The meters are similar by design with comparable functionalities. The presented meters are more complex in functionality than required in Lecale use case. They are not as easy to install and have not energy harvesting. However, they do support multiple connection protocols.

The Lecale demo installation is a combination of a smaller on-shore wind power energy gathering facility and a large-scale isothermal compressed air storage site. Described installations help to fulfil the required energy needs of a dairy farm, a fish factory, a housing facility and other objects. Installed wireless sensors transmit data through the bridge to the solutions cloud-based analytics platform. Aggregated and analysed data helps to optimize operations, processes and maintenance resources. For measuring purposes, power sensor Panoramic Power PAN10 or PAN12 are used. Sensors are attached to the circuit and data are wirelessly transmitted to the Power Bridge PAN-2-E Bridge. The Power Bridge transmits measured data from the sensors to the cloud over WiFi, cellular or Ethernet connection. Although the system is primarily developed to serve electrical applications, the system will support other utility types and various operational parameters as part of the reporting and alarming process.

Power Sensor PAN-10 and Power Sensor PAN-12

Description: Power Sensor PAN-10 and Power Sensor PAN-12 are two variations of sensors for measuring current. Sensors differ in max hot-air outer diameter size and different current measurement range. They are attached to the electrical outgoing wire from the circuit breaker and used for real time metering of power. Sensors harvest enough energy from the circuit they measure so that they are able to connect to its fellow devices in a wireless mesh network. Energy consumption is reported in 10-second intervals. Sensors create a wireless mesh network that connects to Panoramic's P3E cloud-based analytics platform.
The communication between sensor and bridge uses Radio EN-ETSI 300220-1, 300220-2 standard and communication between the bridge and the cloud uses WiFi or Ethernet, depending on the supported infrastructure.

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Power Sensor PAN-10 specification:

- Current Measurement Range: 0-63 A
- Current Measurement Accuracy: Typically 2 % at I>1A
- Minimum Operating Current: 0.3 – 0.45 A

Power Sensor PAN-12 specification:

- Current Measurement Range: 0-225A
- Current Measurement Accuracy: Typically 2 % at I>10A
- Minimum Operating Current: 0.5 – 0.8 A

Power Bridge PAN-2-E Bridge
Description: Bridge collects data from the sensor network mesh and transmits it to the cloud service of the service. Data is transmitted at sub-minute intervals.

Power Bridge PAN-2-E Bridge specification:

- Supported Communication protocol (Sensor to Bridge): Radio EN-ETSI 300220-1, 300220-2
- Supported Communication protocol (Bridge to Cloud): Wi-Fi protocol 802.11 b/g with Wi-Fi security protocol WEP64 / WEP128 / WPA / WPA2 or Ethernet communication depending on the supported infrastructure
- Sensor reception sensitivity: -105dBm

5.3.5 Industrial environment electrical storage (HAW, Enersys-Hawker factory, Hagen, Germany)

The demonstration consists of a factory on grid level with medium voltage supply and low voltage transformation. A medium scale battery energy storage system BESS is used for peak shaving and optimization. The measurement of many electrical parameters including power quality at MV power entry used for control algorithm of battery storage

The equipment used in the industrial environment of EnerSys HAWKER production site is selected to fit into the building automation environment that was installed with the Combined Heat and Power Generator (CHP). The Factory's Energy Management is operated with SIEMENS ADVANTAGE NAVIGATOR where Data is managed locally on the DESIGO Terminal Server V5.1 and remote (over VPN-Router CRSP) in Energy monitoring EMC.

The **Energy Counter Landis&Gyr E650** from DSO Enervie at the MV Power Entry of the factory is an existing equipment. It will provide pulse signals for active energy consumption and provision plus a 9 s pulse for the end of the measuring period for peak power calculation. This signal is collected by the automation station DESIGO PXC12 ED and transmitted over BACnet

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over Ethernet / IP to the Site Control. This signal is the master signal for the peak shaving algorithm.

For monitoring purpose, a **SIEMENS SENTRON measuring device and power quality recorder PAC5200** is installed at the MV Power Entry. It measures a wide range of signals including apparent, active and reactive energy, cos phi, harmonics (2^{nd} to 40^{th}) and THD; Cl. 0.5 (acc. to IEC61557-12) or Cl. 0.5S (IEC62053-22). These values are transmitted over MODBUS TCP via a **Modbus Gateway** Welotech/**ATOP MB5404D-TB-X** (MODBUS TCP to MODBUS RTU Slave) to the Site Control. The additional measurements on the factory incoming power are as additional input to the peak shaving algorithm and the reactive power control of the BESS.

A **SIEMENS automation station DESIGO PXC 001-E.D** operates as the Side Management Control on the 2^{nd} Layer of Control. It provides connectivity over BACnet, MODBUS RTU and Ethernet/IP. The system gathers information about the electrical power flow at the factory input and operates the BESS by controlling and commanding active and reactive power flow to the storage over MODBUS IP. It also collects energy and power quality measurements from the PLC in the BESS and from a power monitor (**SIEMENS SENTRON measuring instrument PAC4200**) in the power line to the BESS. This monitoring data is accessible in the building control system and stored as historical data in the SIEMENS Server. From there the data will be available to the STORY Database.

PLC at Power Conversion Unit PCU for Battery Energy Storage System.
Description: PLC unit is to control the PCU with its internal units (main switch, inverters, buck boost converters, isolation monitoring, HMI devices). The PCU is operating as a Storage device on the 1^{st} Layer of Control and ensures the safe and secure operation of the PCU and the Battery Bank Unit (BBU). It communicates with the site control over MODBUS IP and receives commands for the operation (LOAD or GENERATOR for active and reactive power) and provision of monitoring data.
BACHMANN PLC unit CPU MC210 connected to Sipronika network control server via Ethernet connection using DNP3 protocol; incoming surge protection device: PHOENIX D-LAN-CAT.5-HC.

In the Battery Bank Unit BBU of the BESS the battery strings are monitored and balanced by the **GENEREX BACS Battery analysing and Care System**. For each string, the 48 C20 modules for 12V 7-600Ah lead acid batteries are connected to the BACS Webmaster Budget controller with a proprietary controlled serial bus. The Webmaster is accessible over Ethernet IP, where the 6 controllers are connected via a local switch. The collected data of the Battery Monitoring System is collected as 3^{rd} party data by EnerSys as battery supplier. Additional collection of the data in the STORY Database has to be defined.

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5.3.6 Residential district electrical storage (EG, TP Suha, Slovenia)

A residential district grid with high penetration of PV generation is connected to a low voltage substation TP in Suha. The demo site is already sufficiently equipped with meters, controllers and communications. The medium scale battery storage will be integrated into the grid for peak shaving and optimization. The application requires measurement of many electrical parameters including power quality at houses (consumers and PV producers) used for control algorithm for optimization of battery storage. Therefore, new meters and controllers for storage are required and will be interconnected locally and to control centre.

At the residential grid and substation at TP Suha, the Iskra Network Power Quality Meter MC750 and MC760 are used. The two meters measure input current and voltage, nominal frequency, power consumption, active, reactive and apparent power. **They allow easy installation, scalability and reliability.** The installation and scalability is more complex than in the case of Power Sensor PAN-10 but still meets all the requirements for installation and scalability for residential and industrial area. The meters support remote management and remote software update. Modbus and DNP3 protocol enabled via Ethernet communication provide first-rate connectivity requirements options with above average communication redundancy over multiple communications protocols and multiple physical connectivity options. This version of meters does not support fibre connectivity but all the other available connectivity options do provide more than sufficient connectivity options. CPU power, memory and available storage space for measurements are sufficient.

Adequate substitutions for Iskra Network Power Quality Meter MC750 are Hoyt N100 and Satec PM135 meters. Both meters are similar in functionalities to aforementioned Iskra meters. The requirements are graded similarly to Iskra meters. Hoyt N 100 is more difficult to install and has greater weight than Iskra meters. Connectivity requirements and processor system requirements criteria are similar to Iskra meters. Satec PM135 is heavier than Iskra meters and has higher power consumption. It supports even broader variety of communication protocols than Iskra meters. Otherwise, all meters have evenly matched requirements criteria.

Photovoltaic elements are installed on the premises of Suha residential homes. At the location of TP Suha a medium scale storage unit will be additionally installed. The main purpose of this demo installation is to explore system control and data acquisitions. All electrical parameters are measured with Network power quality meters MC750 and MC760. Electrical meters are directly linked to Quality power server with the help of Remote terminal unit (RTU). At the central control site Sipronika network control server provides all control functionalities. Measurements of electrical parameters are aggregated with switch and sent to the control centre over the WiMax network of EG. WiMax might be replaced with LTE-M as technology matured.

Network Power Quality Meter (NPQM) MC750 and MC760 (Iskra) measures all electrical network parameters and is directly linked to Power Quality Server as a part of network power quality measurement system. Two communication protocols Modbus and DNP3 protocol are

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enabled via RS232, RS485 or Ethernet communication. Communication is provided by private EG WiMax broadband system using AES encryption. Access to NPQM is secured by implementing next generation firewall, which enables secure operation of devices. MC750 and MC760 meters more than satisfy requirements of the evaluation requirement matrix for electrical power meters for district area. Both meters allow easy installation, scalability and reliability. Meters support DNP3 connection protocol for communication among meters, RTU and servers.
MC750 specification is the following:

- Input parameters (current, voltage):
  - Nominal frequency: 50, 60 Hz
  - Measuring frequency range: 16 2/3 – 400 Hz
  - Nominal value (In, Un): 5A, 500VL-N
  - Maximal value: 12A, 750VL-N
  - Rating: 1-5A 57.7 – 500VL-N
  - Consumption: <0.1VA, <0.1 VA
- Accuracy:
  - Active power: 0.5 (optional 0.2)
  - Reactive power: 1.0 (optional 0.5)
  - Apparent power 1.0 (optional 0.5)

Remote Terminal Unit (RTU) collect data from on-site sensors, add data from off-site sources, and use this aggregated data to make decisions regarding how the process is operating. Changes to the local process may be made; messages may be initiated that send data elsewhere to influence the operation of off-site equipment. The communication with the control centre is based on the DNP 3.0 protocol, however, optionally other protocols can also be implemented, according to the customer's requirements and specifications. The signalling and control are possible also by means of SMS messages.

Network Control Server (Sipronika) is used at the central control site to provide a two-way path to the communication system and the distant RTUs. It is the heart of the system and provides all control functionalities required. Besides typical local SCADA functionalities, it also serves as a powerful communication platform enabling communication between different distribution devices. With this support for multiple communications protocols, it provides required communication redundancy. Different protocols enable Sipronika RTU to communicate with different intelligent devices and provide modularity and scalability capability. Server provides connections to EG Power Quality server, RTU installed in TS, transformer AVR unit (PLC) and EG DCC SCADA.

WiMaxSS switch serves for connection to WiMAX broadband system built on IEEE 801.16e – 2005 Wave 2 standard. Air interface is encrypted vith AES encryption. Traffic from applications (RTU traffic, metering traffic, network management, ...) are separated in different VLANs. All VLANs are terminated on the corporate Next Generation firewall.

Storage PLC at Power Conversion Unit for Battery System. BACHMANN PLC unit is connected to Sipronika network control server via Ethernet connection using DNP3 protocol.

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5.3.7 Industrial environment electrical storage (EG, DSO, Slovenia)

The equipment used in the industrial environment of Elektro Gorenjska Slovenia is identical as used in the residential grid and substation (EG, TP Suha, Slovenia). Description of the requirement matrix is therefore identical as in the Chapter 5.3.6 for Residential grid and substation.

5.3.8 Industrial zone thermal storage (BEN, Olen, Belgium)

Olen demonstration case uses Multical 602 meter/calculator for thermal energy. The meter supports installation of additional flow or temperature sensors in accordance with the need of the demonstration case. This provides modularity and scalability not only on the level of the meter but also the modularity and scalability requirements of the network. The meter is designed for reasonably easy installation, as this is needed in this demonstration case because the sensor and meter must be installed in pipework of the site. Weight and size is appropriate. It can be fitted with several data modules and communication protocols. Its communication protocol versatility makes this meter an appealing device. The meter can be used for different cases, heating or cooling, depending on the site needs. This is possible with meter's simple and remote management and substitution of sensors. In proper configuration, the meter can record data for more than 10 years if needed. CPU power, memory and storage space are adequate for this use case.

The possible replacement meter is Landis+GYR ULTRAHEAT T550 meter. The meter has bigger dimensions and is heavier than Multical meter. Therefore, it is not as easy to install as the comparison meter. Other requirements criteria regrading simple and remote management, remote software management modularity and scalability are on comparison with the Multical meter. In the field of the Connectivity requirements, it sometimes ever surpasses the Multical meter. It supports more communication protocols and provides greater communication path redundancy. CPU power, memory and storage are on par with the chosen meter.

6 Conclusion

This report served a triple purpose: (i) give an overview of idealized hardware requirements without limitations, (ii) create a methodology for hardware component selection based on realistic requirements based on a Requirement Evaluation Matrix and (iii) give a description of the hardware components used in the STORY Demonstrations and how they related to the REM.

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All involved partners created a list of the idealized criteria from which the following requirements where retained in an ideal world:

- Ease of installation and operation, scalable and supporting hyper connectivity,
- Integrity and security,
- Decentralised system management,
- Robustness,
- Cost effectiveness,
- Ability to cope with legacy components.

The result of this exercise shows the importance of performance but also focuses on connectivity and modularity. In the world of today, hardware components should be connected to the internet without much effort and be able to work with different systems to avoid a technological lock-in.

A methodology was developed to effectively communicate the expertise gained in the selection of hardware within STORY. This methodology consists of a general functional decomposition of the most important real world hardware requirements and translates to a requirement evaluation matrix, (REM) which uses weights to indicate the relative importance of a requirement. The requirements used in the REM are derived from the ideal requirements as stated above but relate to the real world. The REM is more a mean to communicate the expertise gained in a qualitative and quantitative way then it was used for the hardware selection, it should be seen as a result of the expertise gained during the hardware selection.

The document concludes with an overview of the hardware components in each STORY demonstration and an evaluation of the REM. This exercise clearly shows that the general ideas of the different levels apply but also indicates the importance of application-specific hardware selection and shows that each application is different and will have its own application specific requirements. In general, the building and neighbourhood level have stricter requirements concerning ease of installation and operation as the installation cost often greatly outranges the hardware costs. Therefore, hardware that can be installed by the residents themselves is easily accessible and implemented. Furthermore, the direct added value of this hardware is often minimal for the resident, thus limiting the effort and price a resident is willing to give for the hardware and the installation. This is a lesser concern on the district and industrial levels where performance such as accuracy and reliability are more important. In addition, communication becomes essential on this level to enable real time applications and advanced algorithms.

7 Acronyms and terms

ADR	Automatic data rate
AES	Advanced encryption standard
API	Application programmable interface
CAD	Computer aided design
CHP	Combined heat and power

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CoAP	Constrained application protocol
DSO	Distribution system operator
EMS	Energy management system
FAN	Field area network
HAN	Home area network
HW	Hardware
IC	Integrated circuit
IOT	Internet of Things
LAN	Local area network
NAN	Neighbourhood area network
NFC	Near field communication
NPQM	Network power quality meter
PCU	Power converter unit
PLC	Programmable logic controller
QOS	Quality of Service
REM	Requirement evaluation matrix
RFID	Radio frequency Identification
RTC	Real time clock
RTU	Remote terminal unit
TSO	Transmission System Operator
UPS	Uninterrupted Power Supply
WAN	Wide area network

8 References

[1] Savolainen, P.; Kyntäjä, T; Vallant, H.; Marksteiner, S.; Aertgeerts, A.; Van HaleWeyck, L; and Valckenaers, P. (2016) Structured Overview of Communication Standards for Smart Grids , 2016. STORY, Deliverable 4.1

[2] Smappee: http://www.smappee.com/be_nl/energiemonitor (In Flamish)

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9 Appendices

9.1 Demonstration specific REM Weights

This appendix gives an overview of the different weights for the demonstrations. The weight is evaluated based on a score from 0-10 and normalized in a second step.

9.1.1 Oud-Heverlee, residential neighbourhood

Weights of requirements	Weight	Comment	Normalized
General requirements			
Low power consumption	7	Important for battery sensors	0.09
Size and weight	7		0.09
Ease of installation (set-up)	10	Crucial for low costs	0.13
Simple operation	10	Crucial to avoid installation by an expert	0.13
Reliability	5		0.06
Modularity	5		0.06
Accuracy	5		0.06
Scalability	8		0.10
Computational power	4	Less important for residential applications. These applications are often an add-on/not a "core business"	0.05
Memory RAM	4		0.05
Disk storage	4		0.05
Configurable	5		0.06
Time synchronization	3		0.04
Sum	77		1.00
Connectivity requirements			
Remote connectivity (via the internet)	8		0.17
Fiber connection	2		0.04
Wireless connection	9	Easy to install	0.20
Deep penetration	7		0.15
Bandwidth	4	Sent amount of is often small	0.09
Allowed delay	3	No real time control necessary	0.07
Redundancy (communication)	3	Data which is lost is not a disaster	0.07
Security	10		0.22
SUM	46		1.00

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9.1.2 Navarra, industrial site

Weights of requirements	Weight	Comment	Normalized
General requirements			
Low power consumption	4		0.04
Size and weight	5		0.05
Ease of installation (set-up)	7		0.08
Simple operation	8		0.09
Reliability	8		0.09
Modularity	8		0.09
Accuracy	6		0.07
Scalability	7		0.08
Computational power	9		0.10
Memory RAM	9		0.10
Disk storage	8		0.09
Configurable	9		0.10
Time synchronization	3		0.03
Sum	91		1.00
Connectivity requirements			
Remote connectivity (via the internet)	8		0.22
Fiber connection	3		0.08
Wireless connection	0		0.00
Deep penetration	0		0.00
Bandwidth	7		0.19
Allowed delay	5		0.14
Redundancy (communication)	3		0.08
Security	10		0.28
SUM	36		1.00

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9.1.3 Hagen, industrial site

Weights of requirements	Weight	Comment	Normalized
General requirements			
Low power consumption	1		0.01
Size and weight	1		0.01
Ease of installation (set-up)	4		0.05
Simple operation	8	(need for remote management, configured by professionals)	0.10
Reliability	10		0.12
Modularity	8	(choose for one purpose)	0.10
Accuracy	8		0.10
Scalability	8		0.10
Computational power	6		0.07
Memory RAM	6		0.07
Disk storage	6		0.07
Configurable	8		0.10
Time synchronization	10		0.12
Sum	84		1.00
Connectivity requirements			
Remote connectivity (via the internet)	6		0.14
Fiber connection	6		0.14
Wireless connection	4		0.09
Deep penetration	2		0.05
Bandwidth	8		0.18
Allowed delay	6		0.14
Redundancy (communication)	4		0.09
Security	8		0.18
SUM	44		1.00

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9.1.4 Suha, residential neighbourhood & EG headquarters, industrial site

Weights of requirements	Weight	Comment	Normalized
General requirements			
Low power consumption	4		0.05
Size and weight	2		0.03
Ease of installation (set-up)	5		0.07
Simple operation	8		0.11
Reliability	10		0.13
Modularity	6		0.08
Accuracy	8		0.11
Scalability	6		0.08
Computational power	6		0.08
Memory RAM	6	Temporary storage of results	0.08
Disk storage	0		0.00
Configurable	8		0.11
Time synchronization	6		0.08
Sum	75		1.00
Connectivity requirements			
Remote connectivity (via the internet)	10		0.18
Fiber connection	6		0.11
Wireless connection	10	WiMax	0.18
Deep penetration	4		0.07
Bandwidth	6		0.11
Allowed delay	6		0.11
Redundancy (communication)	6		0.11
Security	8		0.14
SUM	56		1.00

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9.1.5 Lecale, residential district

Requirement	Weight	Comment	Normalized
General requirements			
Low power consumption	4	Site dependent. Wind turbine needs communication when no generation.	0.05
Size and weight	1		0.01
Ease of installation (set-up)	8	Yes, wiring, cost of installation.	0.11
Simple operation	9	Yes, for problems fixed remotely	0.12
Reliability	9		0.12
Modularity	6		0.08
Accuracy	8	EU standards compliant for operation.	0.11
Scalability	4		0.05
Computational power	3		0.04
Memory RAM	5		0.07
Disk storage	5		0.07
Configurable	7		0.09
Time synchronization	7	seconds	0.09
Sum	76		1.00
Connectivity requirements			
Remote connectivity (via the internet)	9		0.16
Fiber connection	5	Wireless to GW, fiber from GW to center	0.09
Wireless connection	9	Optionally LoRa (test)	0.16
Deep penetration	9		0.16
Bandwidth	3	Little	0.05
Allowed delay	4	For compressed air seconds or less	0.07
Redundancy (communication)	7	According to EU Regulation (n+1 for some sites)	0.13
Security	9	Private and public network. Must be secured.	0.16
SUM	55		1.00

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9.1.6 Olen, industrial site

Weights of requirements	Weight	Comment	Normalized
General requirements			
Low power consumption	2	Industrial site, so less important, unless for energy efficiency reasons. But even then, the power sizing of the entire system is so large a few W more or less is negligible	0.03
Size and weight	1	Industrial site	0.02
Ease of installation (set-up)	1		0.02
Simple operation	4		0.06
Reliability	9		0.15
Modularity	9		0.15
Accuracy	9		0.15
Scalability	4	Potential expansions at the Beneens site are limited	0.06
Computational power	2	All complex operations are executed by the central PLC system	0.03
Memory RAM	5		0.08
Disk storage	8	measurements must be buffered in case of failing communications, and stored to overcome power interruptions	0.13
Configurable	8		0.13
Time synchronization	0	All devices are connected directly to the PLC controller, who collects all data, puts a time stamp on it and hence ensures synchronization of data.	0.00
Sum	62		1.00
Connectivity requirements			
Remote connectivity (via the internet)	0	All devices are connected wired to the central PLC system, using Lon-Bus, Modbus, etc.	0.00
Fiber connection	0	no fiber used	0.00
Wireless connection	0	no wireless used	0.00
Deep penetration	0	no wireless used	0.00
Bandwidth	10	Hard real-time requirements on getting all data and commands around, wired busses ensure this	0.50
Allowed delay	10	Hard real-time requirements on getting all data and commands around, wired busses ensure this	0.50
Redundancy (communication)	0	no communications redundancy provided, as the used communications	0.00

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		buses are reliable enough	
Security	0	All operational data stays within the Beneens site	0.00
SUM	20		1.00

9.2 List of alternative hardware components

In the following tables, possible electrical meters and analysers for residential and industrial environment with electrical storage are presented with summary of specifications. All meters listed below are suitable replacements units for Network Power Quality Meter MC750 and MC760.

Manufacturer and product name:
Satec **PM 135**
Application:
Power Meter
Webpage:
http://www.satec-global.com/PM135
Description:
The PM135 is a multi-functional three-phase power meter with basic revenue metering, power quality and harmonics analysis. It is widely integrated in panel boards and SCADA systems. With the addition of the unique TOU module, the EH model answers the needs of revenue metering applications. It is also suitable for utility substation automation with its support of the industry standard DNP 3.0, Modbus RTU and IEC 60870-5-101/104 protocols, as well as its I/O capabilities (using the Digital Input/Output modules)
Product specification:
• Voltage, current (including neutral current), • Power, energy, power factor, frequency, voltage/current unbalance, • Current range up to 200 %, • Supported frequencies: 25, 50, 60 and 400 Hz, • Direct connection up to 690V L-L (up to 1.15 MV via PT), • Individual voltage and current harmonics (up to the 40th), • Voltage and current THD, TDD & K-Factor, • Time stamped max/min values, • Waveforms 128 samples/cycle (via comm.), • Standard 2-wire RS-485 communication port, • Protocols: Modbus RTU, ASCII, DNP3.0, • Optional IEC 60870-5-101; • With Ethernet Modbus/TCP, DNP3/TCP; Optional IEC 60870- 5-104 and with GPRS module: Modbus/TCP • ExpertPowerTM client for communicating with SATEC ExpertPowerTM

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Internet services (with Ethernet or GPRS modules), • TCP notification client for communicating with a remote Modbus/TCP server on events or periodically on a time basis (with the Ethernet or GPRS module)

Manufacturer and product name:
Schneider-electeric PowerLogic **PM5000**
Application:
Power Network Analyzer
Webpage:
http://www.schneider-electric.com/en/product-range/61281-powerlogic-pm5000-series/
Description:
PowerLogic PM5000 is the good fit for high-end cost management applications, providing the measurement capabilities needed to allocate energy usage, perform tenant metering and sub-billing, pin-point energy savings, optimize equipment efficiency and utilization, and perform a high level assessment of the power quality in an electrical network
Product specification:
• Accuracy class 0.2S (PM5500 models) and 0.5S (PM5100, PM5300 models) for active energy metering, • Compliance to regulations EN50470-1/3 (MID), IEC 61557-12, IEC 62053-21/22, IEC 62053-23, • Dual Ethernet ports (PM5500 models) to daisy chain meters together - less wiring, simpler installation, • Ethernet-to-serial gateway functionality, • On-board web pages (PM5500 models) for viewing real-time and logged information, • Cyber security enhancements to help ensure data integrity, • Data logging (PM5300, PM5500 models) locally in non-volatile memory ensures that information is not lost during a power or communications outage, • Multiple tariffs (PM5300, PM5500 models) give you flexibility in your billing structure, • Individual harmonics in addition to the THD (total harmonic distortion) and TDD (total demand distortion) to help locate the source of disturbances, • Graphical display with intuitive menu-driven navigation means the information is easy to locate and read (optional remote display for PM5563 meters), • Compact design, two clips for mounting, • 4 current inputs (PM5500 models), • Extended voltage range (direct connection up to 690 V L-L), • Real-time clock with battery backup

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Manufacturer and product name:
Hoyt Electrical Instrument Works, Inc **N100** powerful network analyzer
Application:
Power Network Analyzer
Webpage:
http://hoytmeter.com/hoytmeter/product/n100-3-phase-power-network-analyzer/
Description:
Lumel N100 is power network analyser for energy monitoring requirements in modern industrial applications. It offers measurements of power network parameters with multiple communication options and supported protocols.
Product specification:
• Measurement of power network parameters in 3 or 4-wire, balanced or unbalanced systems • harmonics up to 51st, • THD (total harmonic distortion), • Two-colour LED display (red, green), • Four quadrant energy measurement, • Indications taking into consideration programmed ratio values, • Programmable number of pages and selection of displayed quantities, • Backlit units of all measured quantities, • Configurable analog and alarm outputs, • Pulse input to count the consumption of active energy from external counter, • Digital RS-485 interface with MODBUS protocol, • Archiving data in the internal memory file system, memory 8 GB (option), • Ethernet interface 10/100 BASE-T (option), • protocol: MODBUS TCP/IP, HTTP, FTP, • services: www server, ftp server, DHCP client, • Battery support of RTC,

In the following tables, possible components for measurement of parameters (temperatures, calories, flows, etc.) and control of actuators (valves, pumps, etc.) for thermal storage in district environment are presented with summary of specifications. All meters listed below are compatible replacements for Multical 602 meter and can be used in similar applications.

Manufacturer and product name:
Micronics CF55 Heating &Cooling calculator
Application:
Cooling and heating applications
Webpage:
http://micronicsflowmeters.com/energy-calculators/cf51cf55-heating-cooling-calculator-2/
Description:

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CF55 is a meter for heating, cooling and combined applications. The meter works with any flow meter with a pulse output and supports 2 or 4 wire temperature sensors. Internal batteries should provide up to 12 years of autonomous operation of powerful data logging. Up to 250 units can be connected to a single M-bus network-using repeater.
Product specification:
Measurement of: • Power (W), • Flow (m3/h), • Supply Temperature (°C), • Return Temperature (°C), • Temperature Range –0…180°C, • Temperature Differential –1(3)…160°C, • Display LCD 7-digits, • Backup memory EEPROM, • Power supply (optional) 6 to 12 year Lithium battery – 230 V main power supply, • Sensors –Pt100 or PT500, 2 or 4 wire (CF51 2 wire only), • Power Supply –12 year Lithium Battery, 230Vac or powered by M-bus network • Protection Class –IP64, • Output –Choice of output option boards including E/V pulse and M-bus, • Optional –Connect up to 2 external water meters with some options boards.

Manufacturer and product name:
Landis +Gyr Ultraheat T550
Application:
District heat and cold measurements
Webpage:
http://www.landisgyr.eu/product/landisgyr-ultraheatcoldae2wr5/
Description:
Landis +Gyr Ultraheat T550 is high-precision heat meter for heating and cooling applications at district level. Flow rate measurements occur with ultrasonic method. It can support several communication methods: M-bus, GSM, and ZigBee. Modular design assures that it can be tailored to particular needs and applications.
Product specification:
• Ultrasound principle ensures extremely accurate and stable measuring results, • No moving parts, so no mechanical wear, • Logbook included as standard, • Approved measuring range 1:100, • No straight lengths of pipe required,

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• All-metal volume measuring components, • Batteries have a service life of up to 16 years, • Power supply units available from 24 V AC/DC to 230 V, • Optical interface acc. to EN 62056-21:2002, • Two slots for communication modules, • Allows data from 60 preceding months to be read, • Wealth of tariff functions allow the unit to be customized to individual requirements, • Accurate, rugged, non-wearing, • Automatic self-diagnosis and fault detection, • Optional extra: programmable data logger for system monitoring

Manufacturer and product name:
Danfoss Sonometer 1100
Application:
heating/cooling application in local and district energy systems
Webpage:
http://products.danfoss.com/productdetail/documents/heatingsolutions/energy-meters/sonometer1100/087g1040/
Description:
Danfoss Sonometer 1100 is an ultrasonic static compact energy meter especially designed for heating, cooling or combined heating/cooling application in local and district energy systems. The calculator contains all the necessary circuits for recording the flow rate and temperature and for calculating, logging and displaying the data.
Product specification:
• Ultrasonic energy meter with dynamic range of qi /qp 1 : 250 in class 2 (qp 1.5 / 2.5 / 6 / 10 / 15 / 25 / 40 / 60 m³/h), • Complete dynamic range: ≥ 1 : 1500, • Lithium battery, 230 V AC or 24 V AC mains unit, • Battery lifetime 11 years (16 years optional), • Unique free- beam principle, • Housings with thread and flange (PN 16 / 25), • Can be configured for heating, cooling or combined heating/cooling application, • Temperature range: 5 - 130 / 150 °C, • Overload temperature up to 150 °C (qp= 0.6 - 2.5 m3 /h), • Swirl-free flow around reflector • Lower pressure loss, • Robust stainless steel reflector, • Insensitive to dirt,

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• Available in nominal sizes qp 0.6 / 1.5 / 2.5 / 3.5 / 6 / 10 / 15 / 25 / 40 / 60m³/h, • Approved according to MID in class 2 and 3, and PTB K 7.2 for cooling, • No calming sections necessary in the inlet and/or outlet (standard installation), • Power save mode • NOWA test capability • Remote reading via M-Bus, L-Bus, RS 232, RS 485, Radio or optical interface, • Integrated Radio 868 MHz, Open Metering Standard (OMS), • Individual remote reading (Automatic Meter Reading) with add on modules Plug&Play, • 2 communication ports (e.g. M-Bus + pulse input), • Improved radio performance, • Individual tariff functions, • History memory for 24 months, • Extensive diagnostic displays, • Dedicated district energy application telegram, • Suitable for Danfoss ECL Comfort controller and ECL 310 internet portal connection

Manufacturer and product name:
Siemens WFM5
Application:
Cooling and heating
Webpage:
https://hit.sbt.siemens.com/RWD/app.aspx?RC=HQEU&lang=en&MODULE=Catalog&ACTION=ShowProduct&KEY=S55561-F177
Description:
Siemens WFM5 is impeller type meters to acquire heat or cooling energy consumption in autonomous heating, cooling or solar plants. The meter consists of a flow measuring section, 2 ready connected temperature sensors and an integrated processor which – based on flow rate and temperature differential – calculates the energy consumption.
Product specification:
• Nominal flow rate 0.6 m3/h, 1.5 m3/h or 2.5 m3/h, • Optional communicating add-on modules, • No settling paths required (neither upstream nor downstream), • Mounting position horizontal or vertical, • Setting of device-specific parameters on the meter itself in the field via buttons or operating and parameterization software ACT50,

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- Optical interface,
- Self-diagnostics,
- Current temperature (return),
- Current temperature (flow),
- Current temperature (difference),
- Current energy flow,
- Current flow rate,
- Total flow rate,
- Pulse value.

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