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List of Abbreviations

BCU	Birmingham City University
BMS	Building Management System
EPIC	EU Platform for Intelligent Cities
iMinds	Interdisciplinary Institute For Broadband Technology
MQTT	Message Queuing Telemetry Transport
NAV	Navidis

1. Introduction

This new deliverable (described in the DOW-Amendment February 2013) is describing the specification of the re-designed Smart Environment Pilot after partner Hildebrand left the project end of July 2012.

It is the replacement of § 3.3 of Deliverable D4.2 (delivered February 2012) and it described the new specification of the Domestic Energy Pilot and the project new engagement what concerns "Public Building Energy monitoring" as described in the new DOW).

The aim of the Smart Environment Pilot (SEP) is to provide citizens with increased awareness of energy usage, and particularly electricity consumption, with the longer-term aim of changing usage patterns and hence reducing consumption and CO2 emissions, although behavioural change of citizens is out of scope of the EPIC project. The Smart-Environment pilot has two different but complementary components. The domestic energy dashboard provides a personal dashboard of electricity consumed in the homes of participants, and allows a comparison with the average of similar properties. The public buildings dashboard makes visible data on electricity and, where data is available; gas consumed in the operation of public buildings owned the city administration and other organisations.

The SEP also makes significant use of Internet of Things (IoT) standards including MQTT to handle the transport, storage and querying of heterogeneous data obtained from large scale sensor networks accessible via the Internet. SEP has also required the design and implementation of a relational database structure capable of aggregating data from a diverse range of sensor types with different transport protocols and of leveraging existing electronic exchange of data between Building Management Systems (BMS), including fiscal smart-meter and sub-meter data. This has been termed the Generic Monitoring Framework (GMF) and is used to hold domestic and public building data, which is accessed by web-services to feed the energy dashboards, which are delivered as portlets.

2. Description of the of Revised EPIC Smart Environment Pilot

Energy Dashboards and Web-Services

The EPIC methodology creates user interfaces in the form of standard JSR168 portlets, which are served to the user's device by the portal server and creates re-usable web-services, which feed data to the portlets. The energy dashboards employ the same architecture, with individual interfaces for domestic and public buildings fed by the appropriate web-services, which, through SQL queries, retrieve and aggregate energy data stored in the GMF database. This approach ensures that energy data delivered via web-services could be consumed by other EPIC Pilots, for example to provide a live energy-data feed onto a house or a public building that appears in the city model in the Smart Environment pilot. This approach, termed the "integrated scenario" within the EPIC project ensures that the reusability of web-services can be demonstrated in the context of smart-city services

Generic Monitoring Framework

The GMF is in essence a large relational database, with a set of data-input services and data-output services, with the ability to store energy usage data derived from a wide range of buildings and sensor types and to store associated with this the meta-data that describes the energy data. For example, the domestic energy sensors return every six seconds a reading in Kw of the total power flowing in to the household through the electricity meter. By contrast, the public-building smart-meters typically measure either electricity energy consumed or gas or water flows in the preceding 30-minute time slot. All of this raw data plus associated meta-data needs to be held in the GMF and needs to be pre-processed and stored in different ways.

Role of Web-Services

Web-services are reusable software components that handle flow of data between the back-end database, in this case the GMF, and the data consumer, in this case the portlet(s) that form the energy dashboards. The output-data services are the sets of web-services necessary to extract and process data from different building sensors, to present this information to the portlets that form the energy dashboards. The flexibility of this approach has been underlined by the need to monitor electricity consumed by schools in Tirgu-Mures, which do not have smart-meters.

3. Domestic energy solution

The measurement of domestic electricity consumption required that the participating households installed a home energy monitor, which typically measures the total energy consumed by the property. Energy monitors normally comprise an inductive clamp sensor connected to a battery-powered wireless transmitter. The sensor is clamped a single-conductor feed into the electricity meter or consumer unit, and does not require a direct electrical connection so can be easily installed by the householder. The transmitter normally transmits via 433 MHz radio to a small LCD display in the house, the instantaneous power consumption measured by the clamp meter. In normal use, such monitors provide only stand-alone an in-home view of instantaneous power consumption and the monitor unit calculates energy consumed, typically providing hourly, daily and monthly figures.

For the EPIC project we have used the EnviR monitor manufactured by Current Cost Ltd, which is a widely used monitor, often issued free of charge to customers in the UK by utility companies including eON and nPower. Figures 1-4 show the clamp meter, transmitter and a typical installation and the EnviR display until. The wireless transmitter has a range of 30-50 metres depending on location and property construction method.

The EnviR display until shown in Fig. 4 displays the instantaneous power usage, updated every 6 seconds and also the cumulative energy usage, with estimates of energy cost based on customer-provided tariff information.

The EnviR unit also has a serial data output, which allows connection to other devices including a network interface module to allow energy data to be transferred to the Internet if an appropriate network and recipient is available.



Fig. 1: Meter with current clamp in place



Fig. 2: Close-Up of current clamp installed around a single conductor



Fig 3: Meter, clamp and wireless transmitter

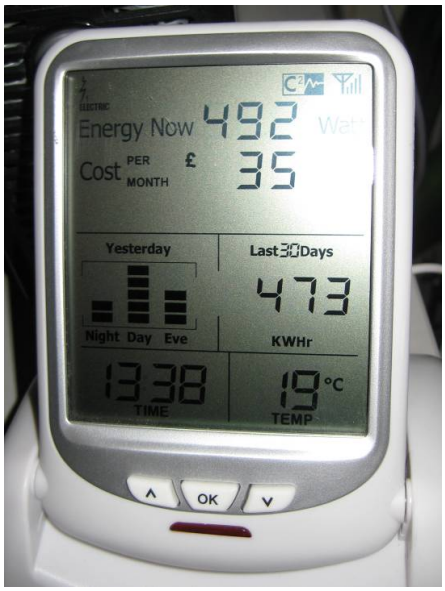


Fig 4: Data display on Current Cost EnviR

Network Interface and Data Transport

Within the EPIC project it was necessary to create a mechanism by which data from the EnviR could be transferred to the GMF repository, so that it could be queried, aggregated and returned to the Energy Dashboard by a custom-developed web-service. A key requirement, aligned with the open-standards focus of the EPIC project, was that any data transport protocol should use open-standards and well-accepted Internet of Things (IoT) protocols, to provide a path to future extensibility.

Research by project partners identified Message Queuing Telemetry Transport (MQTT), a publish-subscribe (Pub Sub) messaging transport protocol invented by Andy Stanford Clark (IBM) and Arlen Nipper (Arcom) in 1999. MQTT is a very lightweight and small footprint open standard for machine-to-machine (M2) connectivity and is useful for connections with remote locations where a small code footprint is required and/or network bandwidth is at a premium, having developed from earlier SCADA system protocols.

MQTT is widely supported by commercial and open-source products including IBM's WebSphereMQ Telemetry, Apache MQ and Apache Apollo, Mosquitto and others. MQTT is also used as the underpinnings of many large-scale IoT systems include COSM (previously Pachube) and is widely supported by client APIs.

It was therefore agreed that IBM would configure a WebSphere MQ server of the EPIC platform and that IBM and BCU would jointly create a network interface unit, to connect the EnviR monitor to the Internet and allow data to be published to the WebSphere MQ server as an MQTT message. This would happen once every six seconds, as the EnviR sends automatically to the serial port the data updates received from the wireless current clamp.

To avoid the need to build custom hardware, an open-source wireless router was used, to which custom-code could be added. The TP-Link TL-MR3020 is a small portable wireless router that can connect via Ethernet or Wi-Fi to a host network and supports USB 3G or 4G modems. The MR3020 employs the Open-WRT firmware image, which allows user generated code to be created and loaded into the router firmware, thereby extending the functionality of the device.

MR3020 Firmware Extensions

The requirements to interface the EnviR to the MR3020 and to transmit EnviR data using MQTT were:

a) to accept serial data from the EnviR via the USB port on the MR3020 and serial-USB cable provided with the EnviR

b) to create and manage a connection to the remote WebSphereMQ server, accessed via the home-user's broadband to which the MR3020 would be connected via the Ethernet port

c) to package the energy data updates received every 6 seconds from the EnviR as MQTT messages and transmit these to the WebSphereMQ server

Custom C language code was written to handle the serial port traffic and this was combined with the open-source code for Mosquitto, a small open-source MQTT server to provide the MQTT messaging support and flashed into the router firmware.

Figure 5 shows the TP-Link router with connection to the EnviR and network switch in a domestic installation.

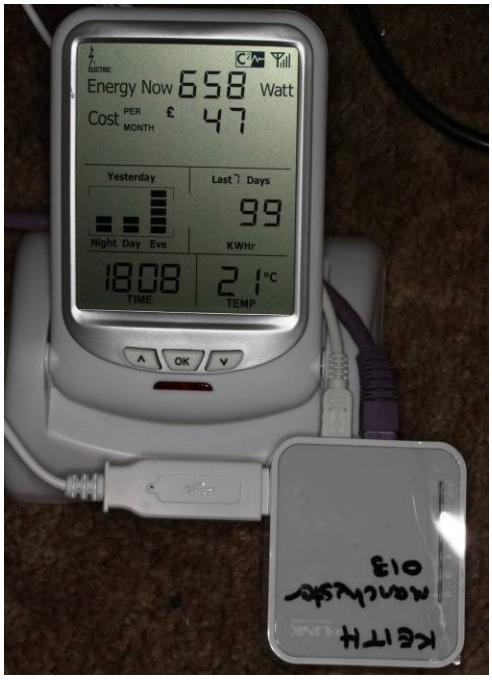


Fig 5: EnviR connected to TP-Link. CAT5 cable is linked to network switch and onward to broadband router

So within EPIC, the Smart Environment team created a data-bridge to the internet for the stand-alone units, allowing energy data to be transmitted using Internet-of-Things data protocols to an EPIC data repository. The domestic energy monitoring will leverage the MQTT protocol (www.mqtt.org), an open-standard designed for internet-scale telemetry (sensor) networks. The Smart Environment pilot uses commercially available energy

monitors for in-home energy measurement and access data feeds from fiscal smart-meters and BMS sub-meters for public buildings. Data feeds will be aggregated into a Generic Monitoring Framework (GMF) database and exposed to the energy dashboards which will be implemented as portlets consuming web-services that extract and process energy data from the GMF.

Domestic Energy Data

The Domestic Energy pilot provides a personalised dashboard, through which users can view the electrical power profile and energy consumed by their household over different time-periods. AS per the other EPIC Pilots, the domestic energy dashboard is implemented using portlets, fed by web-services which query and aggregate the back-end energy GMF database to calculate the average energy profiles and energy consumed during 1 hr / 24 hr / 7 day and 30 day periods. An estimate of energy cost is also be calculated by user-input of energy pricing per unit, but this will be an estimate only. It must be emphasised that domestic energy monitoring is about patterns of consumption and not billing, which is of course the responsibility of the energy provider.

The dashboard shows both the power profile and energy use for an individual household and provides for comparison purposes, the average of similar properties in terms of property type and primary heating source. This will provide a baseline against which a household can compare their individual consumption.

A wireframe for the personal dashboard design is shown in Figure 6 and screen-grabs of the live dashboard delivered by the EPIC platform are shown in Figures 7 and 8.

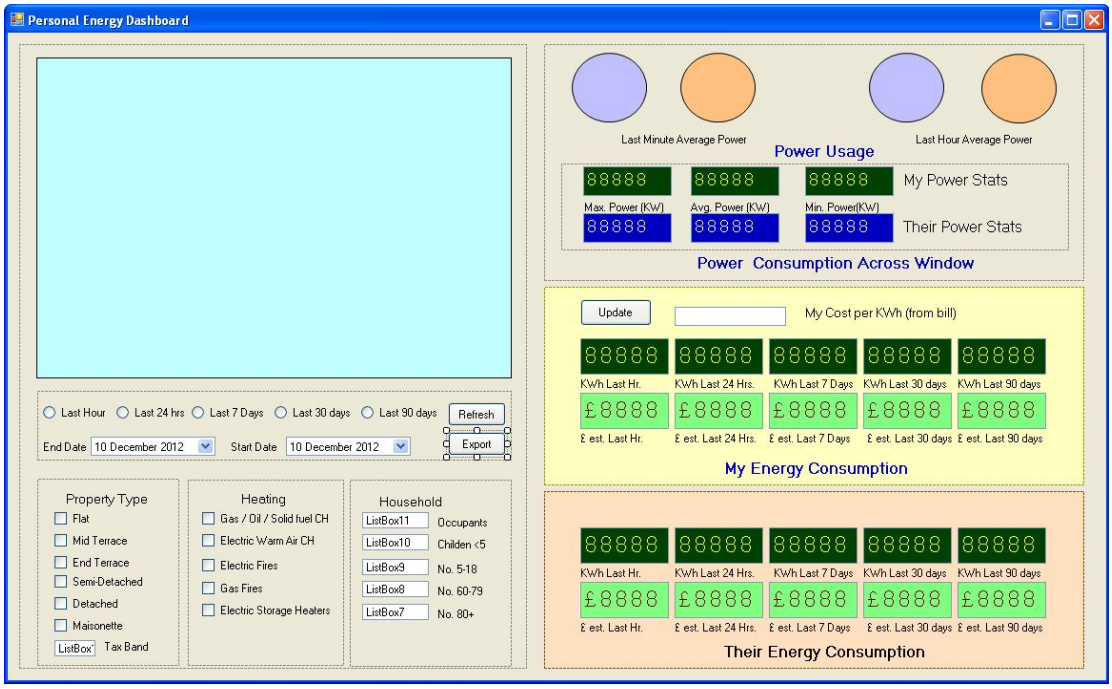


Figure 6: Dashboard Initial Wireframe

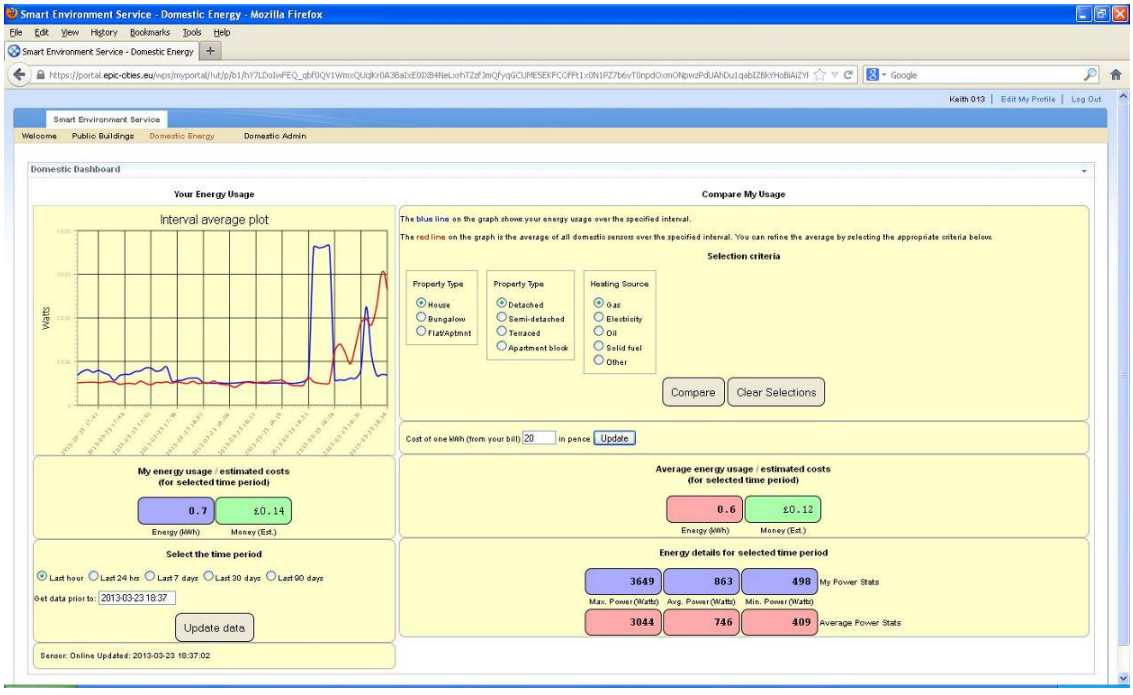


Figure 7: Personal Energy Dashboard Screen Grab: 1 Hour View

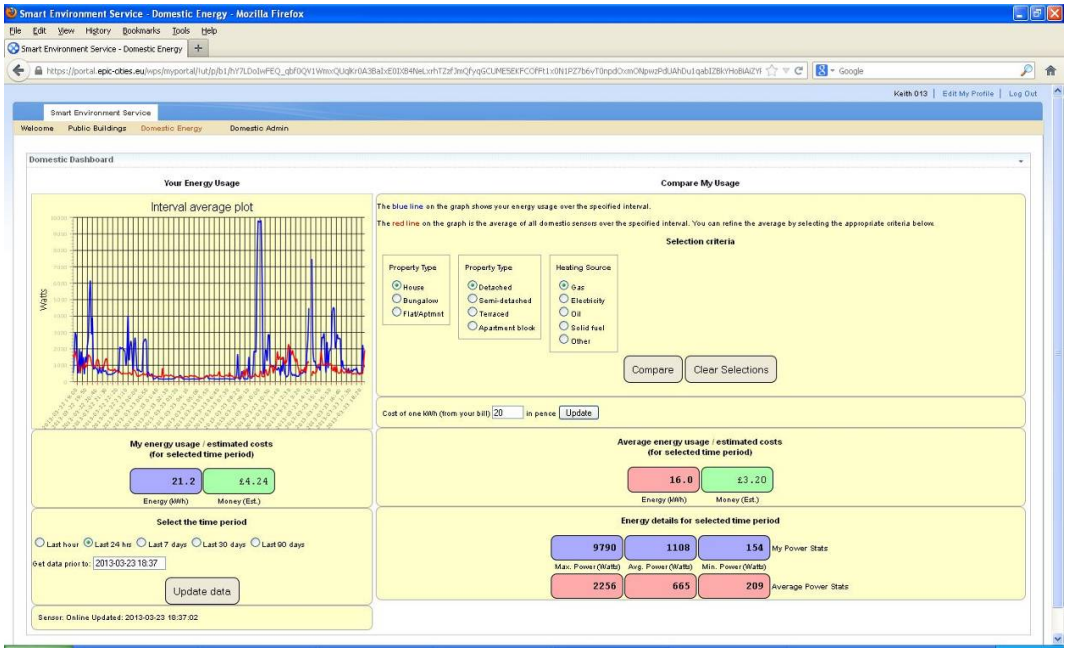


Figure 8: Personal Energy Dashboard Screen Grab: 24 Hour View

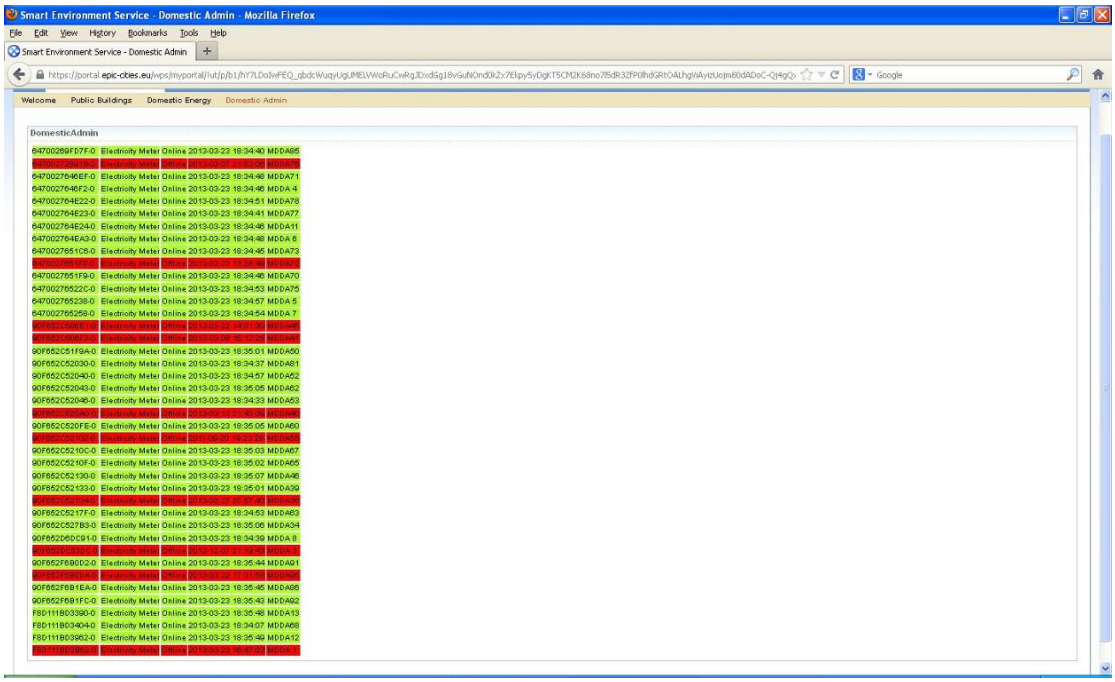


Figure 9: Status View of Domestic Energy Feeds

Figure 7 shows the hourly view, comprising the 10-minute averages calculated from the 6 second readings published by the EnviR and subscribed to by the GMF. The blue trace is the energy consumed by property 013 and the red trace is the averaged consumption from the other monitored properties which are detached houses and which have gas as the primary heating source. The 5-minute 3.5 KW spike shows the increase in energy consumption caused by boiling a kettle.

Figure 8 shows the 24-hour view, calculated from the averages over a 10-minute period. The 10KW spike is the additional load of an 8 KW shower and the other large spikes are associated with kettles and / or the dishwasher and electric oven.

For those involved in managing the test users (in this case MCC), an Administration portlet was created so that the status of each domestic energy feed could be reviewed, and is shown in Figure 9. Data should be received every six seconds from each monitored unit, assuming the user's broadband connection was functioning. If a unit has been off-line for more than 1 hour the unit is shown as red in the Administration portlet until connection is re-established.

4. Public building data

Many public buildings have smart-meters installed by the utility companies, which transmit data on consumption of electricity, gas and water to their utility provider, normally every 30 minutes. Furthermore, most public buildings have some form of electronic Building Management System (BMS) which is essence a building automation network, including sensors, actuators and sub-metering. City energy management teams are general able to see and control what is happening in monitored buildings, through a graphical user interface to the BMS, commonly termed a "head-end".

Unlike the domestic energy pilot, which required participating users to install energy monitoring equipment in their homes, public buildings are in general comprehensively instrumented, through sensors and actuators on the BMS network and fiscal smart-meters. The aim of the Public Buildings pilot was therefore to maximise the use of data already available within public buildings BMS, rather than to add extra sensors to existing systems.

Data accessible via the BMS or from smart-meter feeds to utility companies was directed into the GMF and stored with the required meta-data. The GMF combined domestic and public buildings data, derived from different sensor types and at very different sampling rates, which tested how *generic* the GMF actually was.

The Public Buildings dashboards allow visualisation and comparison of electrical energy consumption and, where data is available, of gas consumption, between different public buildings and across different time periods. The energy usage has also be converted in CO2 figures using well-accepted methodologies and the addition of degree-day data is planned, to allow meaningful compassion of energy consumption across different time periods.

Public Buildings Data Transfer

The data feeds from fiscal smart-meters are not accessible by the general public, but instead communicate directly with the utility provider and normally into the BMS network. It is common that a single BMS head-end will provide access to a number of monitored buildings through their individual BMS. Many organisations delivery daily energy data reports to organisations that specialise in the analysis of energy data, either for the purposes of carbon-footprint calculations or to ensure that the most advantageous energy tariffs are being applied and that utility companies are calculation bulls correctly.

The simplest approach for EPIC public buildings was therefore to be included in the daily data updates from the BMS in the monitored buildings. In the case of the Manchester buildings the data was obtained indirectly, by creating a custom report which ran daily on the remote data store into which the city archived daily energy data, which generated a

daily email with an MS-excel attachment containing the energy data. The GMF server therefore received and processed automatically the incoming daily data uploads, adding the public-building data in to the GMF. This meant that data was available with a 24 hour lag, but meant EPIC was able to upload several years of historic data from the remote systems into the GMF to allow analysis of with energy usage before the EPIC project started.

Agreement was reached to go gain access to energy data from four buildings in Manchester: the Town Hall; an office block; an enterprise academy and a health academy, where staff were interested also in using the dashboard within the part of the curriculum being studies by the 14-19 year old students.

Public Buildings Dashboards

Initial user requirements capture confirmed that comparison between buildings in the same time period, or comparison of the same building at diffident time periods was a key requirement of the public buildings dashboard, and was a function missing from the commercial head-end systems used by the city council. The dashboard was therefore designed containing two identical sets of portlets which allowed data to be displayed and compared from any of the monitored buildings and for any time period. The default interface also provided a graph of hourly electricity consumption for the preceding 7 days and a graph of daily energy totals for the preceding 12 week period. This complexity necessitated that the dashboard was quite large, requiring scrolling down the screen to see all of the displayed information.

To use the dashboard, the user first selects the monitored building and the metered quantity, either electricity or gas (available only for building A). The default views start from the current time and the user is able to control the period for which data is displayed. The data selected can also be downloaded as a simply .csv file for subsequent analysis outside of the EPIC system.

Screen-grabs of different areas of the Public Buildings dashboard are show below in Figure 10 to 16 below:

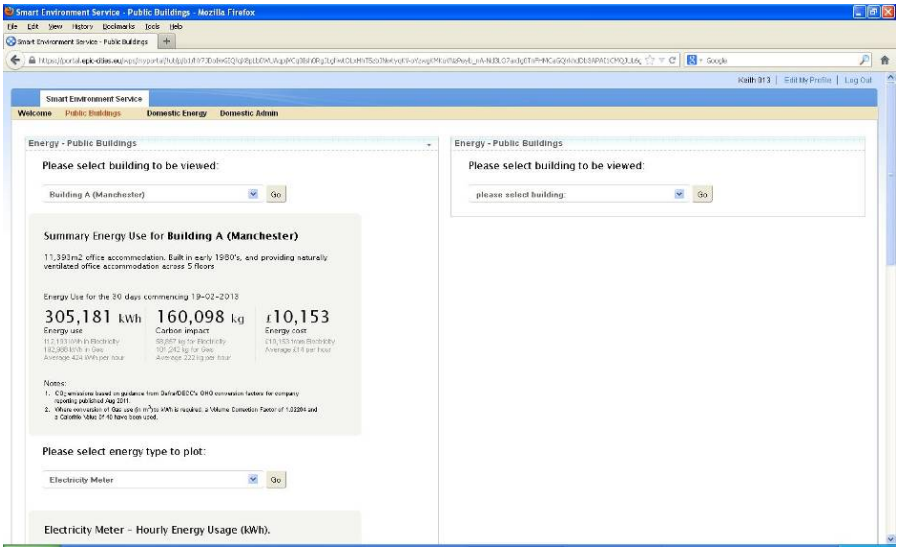


Fig. 10: Summary Data for Building A

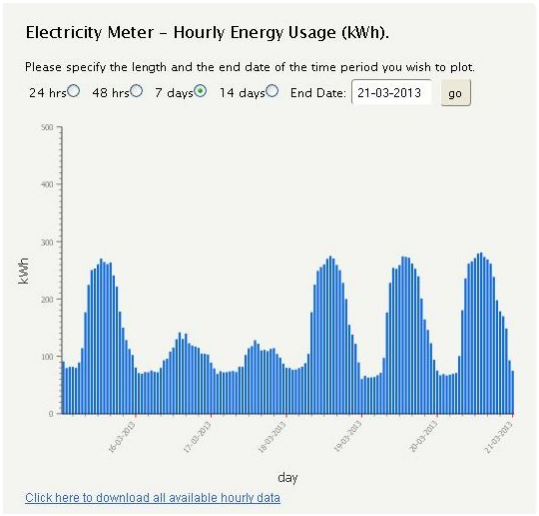


Fig. 11: Hourly Electricity Use for Building A

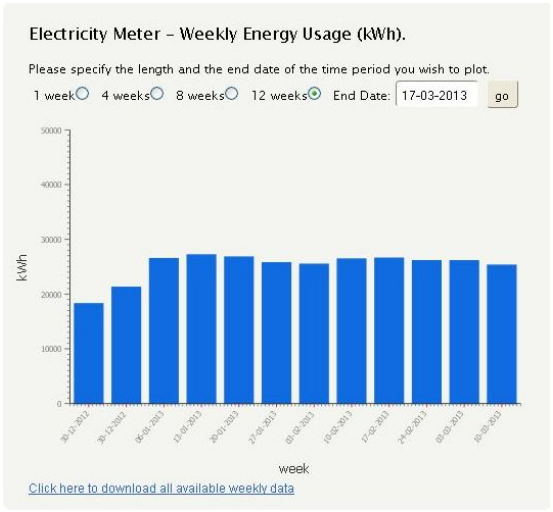


Fig. 12: Weekly Electricity Use for Building A

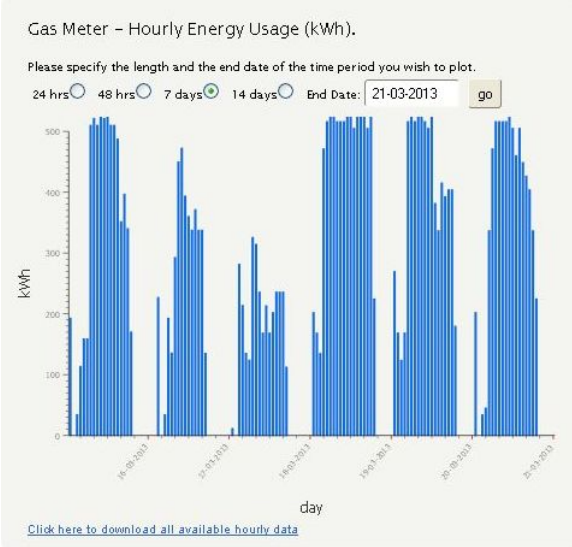


Fig. 13: Hourly Gas Use for Building A

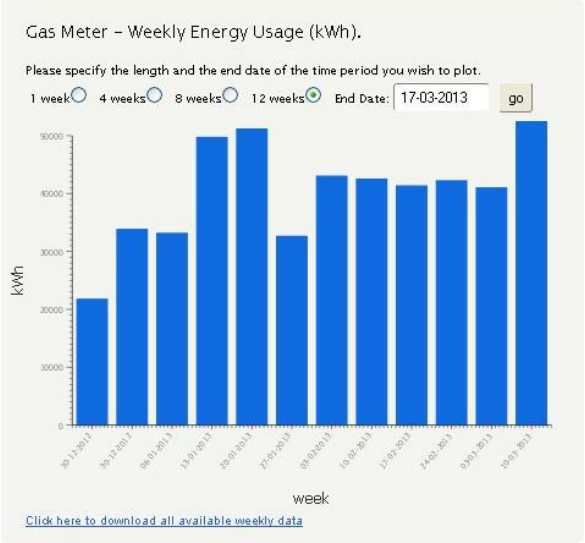


Fig. 14: Weekly Gas Use for Building A

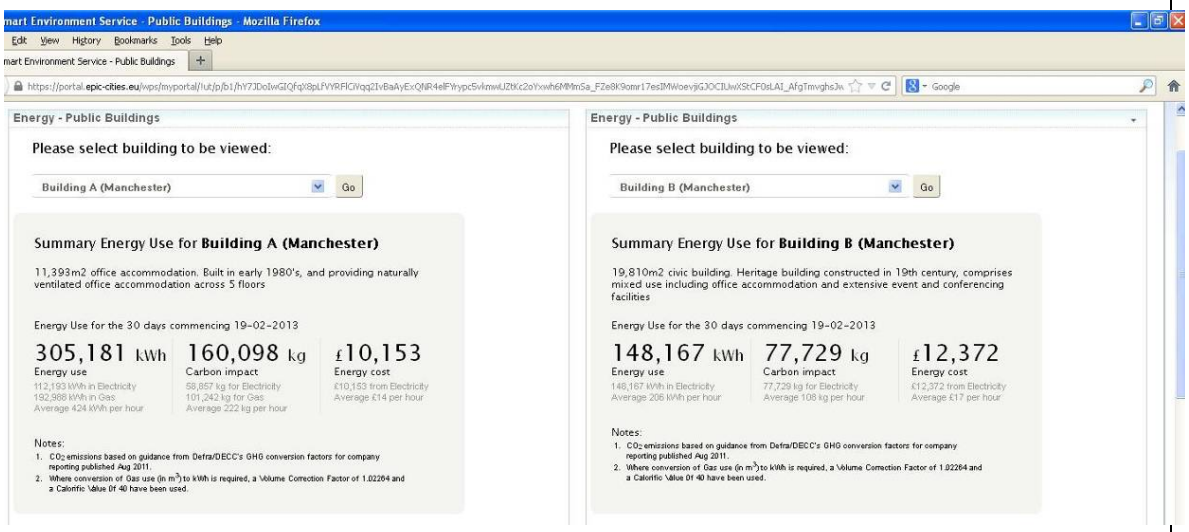


Figure 15: Comparison of Weekly Electricity Use for Building A and Building B



Figure 16: Comparison of Weekly Energy Use for Building C and Building D

5. Tirgu-Mures Users

Domestic energy monitoring for users in Tirgu-Mures uses exactly the same monitoring hardware, TP-Link and web-services as for users in Manchester and Birmingham, so the required hardware was provided to T-M by Birmingham City University.

Public Buildings proved more difficult, because T-M was keen to monitor two schools, but these were neither fitted with smart-meters nor connected to a BMS. Therefore the BCU technical team created a hybrid solution, using the EnviR monitor with three separate inductive clamps to monitor a 3-phase electrical supply, as is normal in larger commercial premises, and calculated in the TP-Link firmware the instantaneous 3-phase power usage in KW, which was sent to the GMF in the same way as for the domestic installations, using the MQTT message broker, but identified with different meta-data to avoid confusion with domestic energy data.

However, the T-M school energy data could not be visualised using the domestic energy dashboard because this would have caused confusion and would not have allowed comparison between different T-M schools. But neither could the 6-second instantaneous power data be used directly by the Public Buildings dashboard, as this consumed the half-hourly consumed-energy (KWh) data from the smart-meters.

Therefore yet again the flexibility of the web-service and portlets solution was demonstrated by the hybrid solution for T-M schools. A new web-service was created which calculated from the 6-second 3-phase power data received from the T-M schools, a set of "pseudo 30 minute energy" readings, which were equivalent to those, received

from the Manchester smart-meters. Because the T-M web-service presented data in the same way as the Manchester public buildings web-service, the T-M schools data could then be readily visualised using the same Public Buildings portlet as used by the Manchester buildings.

To reiterate, the ability to separate the data as web-services from the user interface implemented as portlets consuming the web-services meant that the same dashboard could be used for Manchester or the T-M Schools data simply by invoking the relevant web-service.

6. Summary

Domestic energy utilised existing commercially available energy monitoring equipment, the CurrentCost EnviR and an open-source firmware broadband router re-flashed with custom firmware to support the transfer of EnviR data using the MQTT publish-subscribe architecture, a well-accepted and open-source standard for IoT.

The WebSphereMQ Telemetry add-on provided the MQTT message-broker installed on the EPIC platform

The generic monitoring framework (GMF) provided the off-platform data back-end for storage of all energy data from domestic premises and public buildings alike

A subscriber running on the GMF server *subscribed* to the energy messages which were published every 6 seconds by each EnviR / TP-Link and stored the data into the GMF database

Daily data exports were received by the GMF as emails with an MSExcel attachment from the data-backend on the Manchester buildings BMS. Data was extracted automatically and stored in the GMF.

A personal energy dashboard displayed the power data from the monitored property and calculated the energy consumed, and also provided a comparison with the average of similar properties.

The public buildings dashboard allowed a comparison of the energy used in different periods and in different buildings, also providing a data download facility

The public buildings solution for Tirgu Mures schools was a hybrid; using the EnviR kit with 3 current clamps to store the 6-second data in the GMF, and a new web-service to extract the data and calculate the energy consumed in each 30-minute slot, so this could be consumed by the same public buildings dashboard used for the Manchester data.