Orchestration of Renewable Integrated Generation in Neighbourhoods

Grant Agreement Number: 314742

D3.4 Pre - deployment energy data collected from each validation site

WP3 - Installation and commissioning of ICT infrastructure in data collection mode

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2 Introduction

A significant part of the innovation in ORIGIN emanates from the high resolution demand data gathered in the trial communities. Originally, this deliverable highlighted where this data is stored Following recommendation 2 of the second year review, this deliverable now includes analysis of some of the pre deployment data from each validation site , Further analysis of this data for the three communities is also detailed in D3.5 as this analysis forms the basis for the baseline energy usage report.

At the first year review, 3 recommendations were made including a request that the risks related to gathering and storing of sensitive data related to personal activities be discussed. Sections 7 and 8 of D 3.2 highlights the steps ORIGIN has adopted to secure and protect data and fulfil this recommendation

A single ORIGIN server is employed for all 3 communities and is cloud based. The ORIGIN server mirrors data that is captured from ISA measurement equipment (stored on ISAs dedicated server), weather data and where appropriate forecasting and information models. The ORIGIN server is hosted in Manchester in the UK with cloud hosting provider Serverlove (http://www.serverlove.com/). In the original DoW it was envisaged that the server would be mirrored and archived at HWU, UoS, FISE and ITI but with the recent developments in cloud technology this is no longer required and the appropriate levels of access can be granted to all beneficiaries directly via cloud storage.

Data from active sensors and devices in all 3 communities has been gathered for the past year and access details are given in D3.1 (which is now a PP deliverable). There are over 3800 sensors (approximately 500 in Damanhur, 500 in Tamera and the rest in Findhorn) recording data. The number of sensors is much higher in Findhorn due to the number of residential houses involved in the project. The data for each device can be shown for different time periods and data can be exported for analysis.

3 Initial Analysis of data

3.1 Introduction

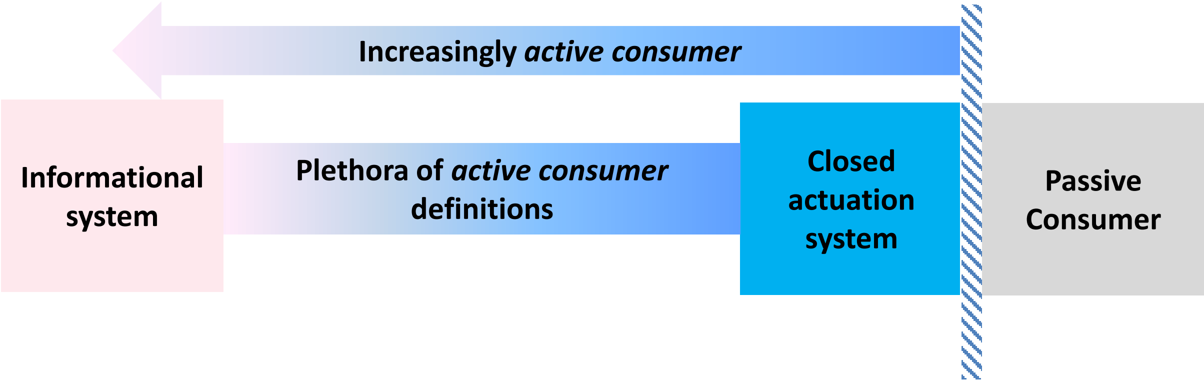
The overarching aim of the ORIGIN system is to increase local utilisation of locally generated renewable generation. The project is achieving this by forecasting the availability of surplus renewable energy and providing this information to participants through a bespoke interface or using it to directly actuate loads.

3.2 Description of differing demand response approaches

In determining the contribution that can be made by mass market consumer involvement in demand response, it is critical to explore the definitions that can be envisaged to describe the term ‘active participant.’ There is a marked contrast between a model which has at its centre the energy aware user and a system in which load response processes are automated (Darby and Mckenna 2012), these effectively representing the boundaries of active participation (Fig. 1).

At one extreme is an entirely actuated system where the targeted load is the recipient of the information exchange. From the perspective of the consumer, this could be viewed as being closest to the current passive paradigm. Ownership of the control and assumptions that cause load manipulation rests with the system controller, and although the occupant may have oversight, no behavioural change is required to initiate a transaction. The benefits of direct actuation are that its impact can be quantified and is firm. In the UK, some experience does exist for directly actuating loads in residential buildings to perform load manipulation. Approximately 1.5 M households use electric storage heaters for space heating which are tele-switched by the network operator to avoid significant peak rise during the night (Boait et al. 2007). Additional loads that can be manipulated without recourse to occupant interaction may also arise in the coming decades depending on the market success of, for instance, electric heat pumps and electric vehicles (Barton et al. 2013).

Figure 1: Schematic description of how energy consumers may change with the onset of active network systems



However, direct actuation may lead to significant socio-technical jeopardy associated with loss of control, maintenance of installed monitoring, sensing and actuation systems and the extent to which actuation could be retrofitted to existing appliances and systems. The adoption of direct actuation systems may only occur gradually as a consequence of appliance and heating system market churn and the establishment of trust between actors. This may place it out of step with the pace of change deemed necessary by the Electricity Supply Industry. At the other extreme, there is essentially a feedback type system, containing no actuation where the occupant is informed of future events, is cognisant of the implications of their response and decides whether to act based on the information received. Consumers may be incentivised to participate through modified tariff structures such as time of use pricing, critical peak pricing and real time pricing (Cappers et al. 2012). Appropriate architecture could be installed in dwellings without the requirement for sensing and actuation equipment and without the requirement for there to be a range of smart appliances. Whilst social acceptability issues may arise particularly where modified tariff structures are imposed, these barriers could be addressed by well-designed education programmes, attention to data privacy concerns and carefully structured tariffs (Darby and McKenna 2012). The growth in distributed energy systems could also create network and grid management with a demonstrable local character which may further contribute to public understanding leading to increased participation rates.

This tension between the two extremes of demand response represents a core research area for the ORIGIN research team and has informed the way in which the sensors have been deployed. A detailed compendium of the sensors deployed in each of the participating buildings in each of the three communities is provided in deliverable 3.1. A plethora of sensors are required in each building with their exact configuration being a function of the requirements of the candidate ORIGIN algorithm and logic structure being utilised and the orchestration opportunity present in each dwelling as characterised in WP1, the building audit. Demand, generation, thermal comfort, occupancy and weather data is being measured at a temporal precision of 5 minutes.

For instance, the demand prediction algorithm uses a refined persistence model based on a 4 week rolling dataset of historical load information for each individual building that is participating in each ORIGIN community. Buildings where direct actuation of space heating systems is possible can only proceed through the interaction of the orchestration algorithms with sensors installed in the dwelling in question. Whilst buildings which are informational (where the building occupant receives information from the ORIGIN system and actuates loads accordingly) require less ORIGIN infrastructure, demand response is being encouraged by contextualisation of information such that it reflects the energy behaviour of the building occupants.

In addition to allowing information to become contextualised, the capacity to disaggregate consumption by building and/or load is also necessary so that the assumptions made during the audit phase of the project with respect to characterisation of orchestration opportunity can be tested. This will take the form of isolating individual loads and then contrasting their consumption pattern with respect to local renewable generation before and after the deployment of the ORIGIN system in the communities.

Analysis of the datasets for each individual building also allow the group to investigate and characterise opportunities that may be present for demand response and energy efficiency interventions in the buildings that were not identified during the building audit.

Because of the extent of the ORIGIN infrastructure with over 3,800 sensors installed across the three communities it is impossible to provide an example of how each of these are being used by the system. The sections below describe a series of case studies describing how the sensor infrastructure is being used across each community.

4 Case Study 1: Use of renewably generated electricity in each building

In some cases measuring generation output refers to community scale generation (Tamera and Findhorn) whilst in others it refers to building integrated systems. Examples of the latter type of building are the Nucleo's in Damanhur, Italy. The Magilla nucleo in Damanhur for instance has a building integrated system with total capacity of 27kW. The logic that is employed to quantify the proportion of electricity generated by this system that is used in the Magilla nucleo is described in Table 1. Sensors with the tag id's 3521, 3522 and 3523 are voltage clamps that are attached to each phase of the main feed incomer to the nucleo and measure total electricity consumption. The sensors with tag id's 3499, 3500, 3501, 3565, 3566 and 3567 are also voltage clamps and are connected to the solar PV inverters to measure total electricity generation from the 27kW system.

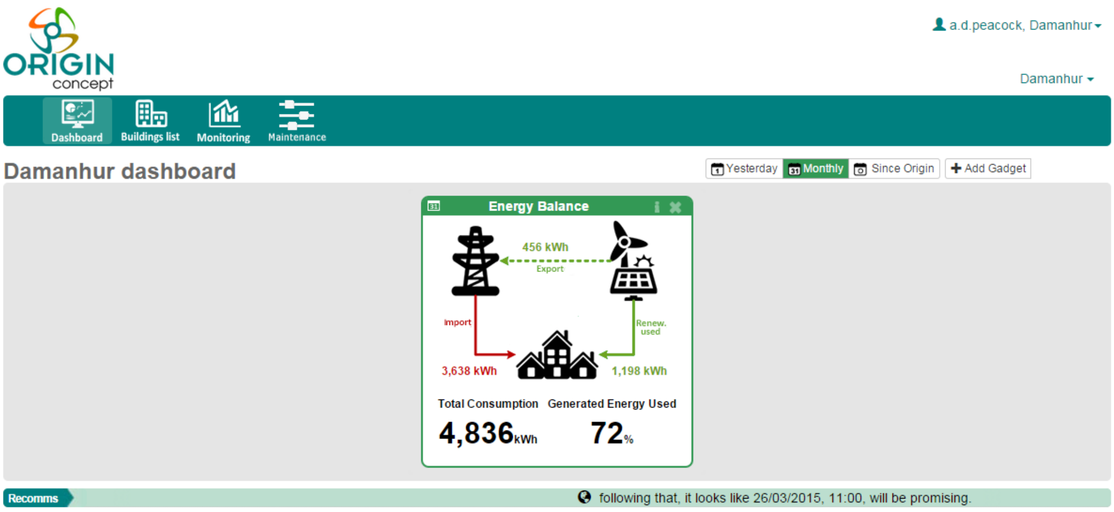
Performance Metric				
Symbol	**Parameter**	**Unit**	**Temporal precision**	**Details**
E_DEM	Electricity demand in Magilla	kW	5 minutes	*(3521+3522+3523)*
E_PV_GEN	Electricity generation from PV	kW	5 minutes	*(3499+3500+3501+3565+3566+3567)*
E_EXP	Electricity exported to the grid	kW	5 minutes	IF E_DEM<E_PV_GEN THEN E_EXP = E_PV_GEN - E_DEM. IF E_DEM>E_PV_GEN THEN E_EXP = 0.
E_IMP	Electricity imported from the grid	kW	5 minutes	IF E_DEM<E_PV_GEN THEN E_IMP=0. IF E_DEM>E_PV_GEN THEN E_IMP = E_DEM - E_PV_GEN
E_PV_USED	PV generation used by Magilla	kW	5 minutes	IF E_DEM<E_PV_GEN THEN E_PV_USED = E_DEM. IF E_DEM>E_PV_GEN THEN E_PV_USED = E_PV_GEN
E_DEM_D	Electricity used in Magilla yesterday	kWh		ΣE_DEM/12 yesterday
E_DEM_M	Electricity used in Magilla so far this month	kWh		ΣE_DEM/12 so far this month
E_DEM_Y	Electricity used in Magilla since origin system launched	kWh		ΣE_DEM/12 so far since origin system launched
E_PV_GEN_D	Electricity generated from PV yesterday	kWh		ΣE_PV_GEN/12 yesterday
E_PV_GEN_M	Electricity generated from PV so far this month	kWh		ΣE_PV_GEN/12 so far this month
E_PV_GEN_Y	Electricity generated from PV since origin system launched	kWh		ΣE_PV_GEN/12 so far since origin system launched
E_PV_USED_D	Electricity from PV generation used locally yesterday	kWh		ΣE_PV_USED/12 yesterday
E_PV_USED_M	Electricity from PV generation used locally so far this month	kWh		ΣE_PV_USED/12 so far this month
E_PV_USED_Y	Electricity from PV generation used locally since origin system launched	kWh		ΣE_PV_USED/12 so far since origin system launched
P_PV_GEN_D	Proportion of Electricity from PV generation used locally yesterday	%		E_PV_USED_D/EW_GEN_D
P_PV_GEN_M	Proportion of Electricity from PV generation used locally so far this month	%		E_PV_USED_M/EW_GEN_M
P_PV_GEN_Y	Proportion of Electricity from PV generation used locally since origin system	%		E_PV_USED_Y/EW_GEN_Y

	launched			

Table 1: Logic for determining the energy balance of the Magilla Nucleo in Damanhur

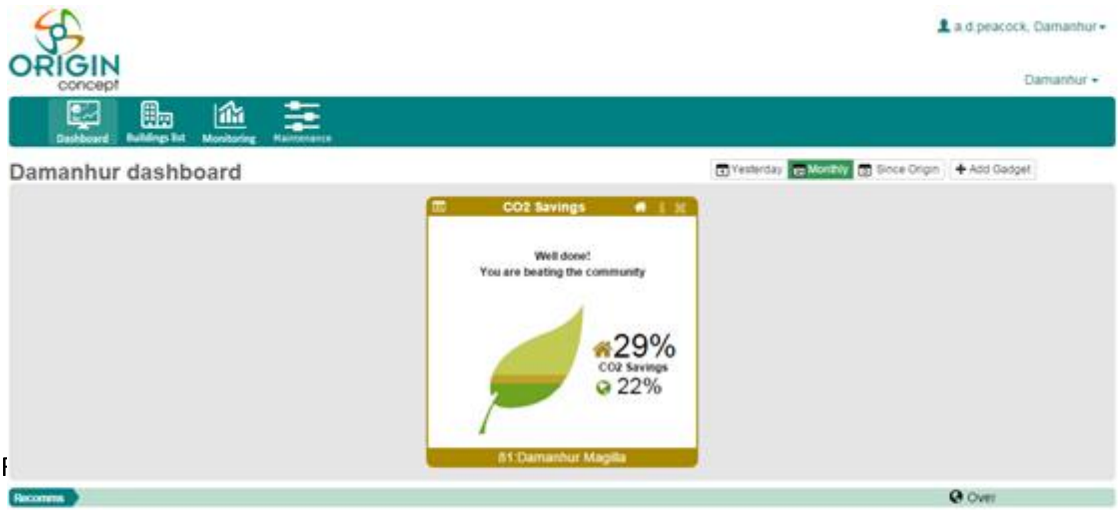
The user interface accesses the data generated by the logic described in Table 1 in the gadgets displayed in Figure 2 indicating data for the period from 1st March to 23rd March 2015. This characterises how much renewable electricity was used by the Magilla Nucleo, how much renewable electricity was exported to the Italian grid and how much electricity was imported from the Italian grid to the nucleo. In this manner the core ORIGIN metric of proportion of renewable electricity generation that was used by the nucleo is calculated and displayed.

Figure 2: Energy balance gadget of the ORIGIN User Interface – applied to the Magilla Nucleo



The CO_2 emissions attributable to electricity consumption in the Magilla nucleo is computed and the savings made as a consequence of utilising electricity generated by the building integrated solar-PV array are calculated and expressed as a % in the gadget using the logic shown in Table 2. This is used in the gadget shown in Figure 3 that also shows the savings made by the Damanhur Community as a whole so that the Magilla occupants can benchmark their performance. In Magilla for instance, the community have managed saved 29% of the CO_2 emissions attributable to their electricity consumption through the use of the electricity generated by the building integrated PV array. This compares to 22% for the Damanhur community as a whole.

Figure 3: CO_2 savings arising from the use of renewably generated electricity installed in the Magilla Nucleo

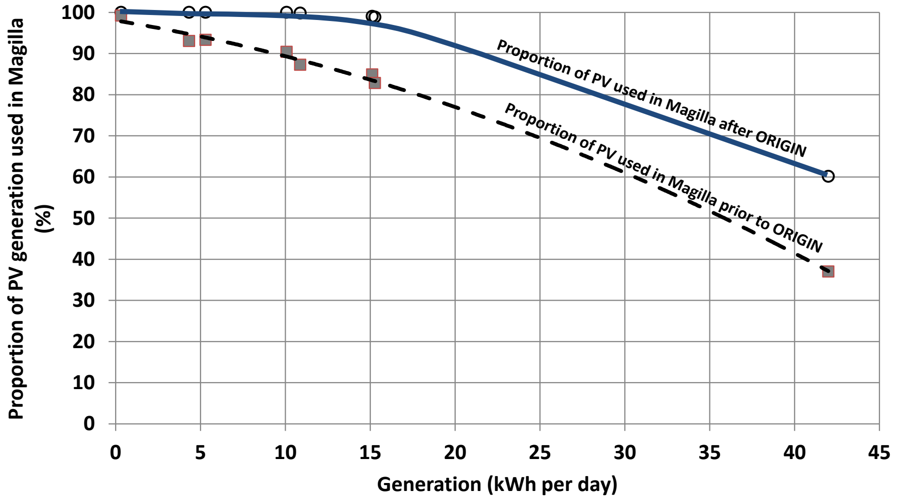


Performance Metric				
Symbol	**Parameter**	**unit**	**Temporal precision**	**Details**
M	Month			January to December
D_T	Day type			Weekend or weekday
H	Period of the day			(1-48) (half hourly periods)
EF_GRID	Emission factor of Italian electrciity	$kgCO_2/kWh$	30 min	Lookup for this M, DT and H in Italian-EF
EF_PV	Emission factor for PV generation	$kgCO_2/kWh$	constant	0.051
EF_Magilla	Emission factor for Magilla electricity	$kgCO_2/kWh$	30 min	((E_IMP*EF_GRID)+(E_PV_USED*EF_PV))/E_DEM
EM_D	Daily Emissions; Emissions yesterday	$kgCO_2$		Σ(E_DEM*EF_Magilla) yesterday
EM_M	Monthly Emissions; Emissions so far this month	$kgCO_2$		Σ(E_DEM*EF_Magilla) so far this month
EM_Y	Annual Emissions; Emissions since origin system launched	$kgCO_2$		Σ(E_DEM*EF_Magilla) since origin system launched
EM_Magilla_It_D	Emissions yesterday if Magilla had sourced all its electricity from the Italian grid	$kgCO_2$		Σ(E_DEM*EF_GRID) yesterday
EM_Magilla_It_M	Emissions month to date if Magilla had sourced all its electricity from the Italian grid	$kgCO_2$		Σ(E_DEM*EF_GRID) so far this month
EM_Magilla_It_Y	Emissions since origin system launched if Magilla had sourced all its electrciity from the Italian grid	$kgCO_2$		Σ(E_DEM*EF_GRID) since origin system launched
SAVINGS_D	emission savings yesterday compared to the situation whereby Magilla sources all its electricity from the Italian grid	%		(EM_MAGILLA_It_D - EM_D)/EM_MAGILLA_It_D *100
SAVINGS_M	emission savings month to date compared to the situation whereby Magilla sources all its electricity from the Italian grid	%		(EM_MAGILLA_It_M - EM_M)/EM_MAGILLA_It_M *100
SAVINGS_Y	emission savings since origin began compared to the situation whereby Magilla sources all its electricity from the Italian grid	%		(EM_MAGILLA_It_Y - EM_Y)/EM_MAGILLA_It_Y *100

Table 2: logic used to define the CO_2 emission savings arising from the use of locally generated RE

These initial methods of benchmarking performance will be augmented in time with assessments of how the energy behaviour of both the building occupants and the community as a whole has changed with respect to utilisation of locally generated renewable generation. These assessment methods are currently being developed and refined as the post launch datasets increase in size. An initial method of benchmarking performance in Magilla has been developed by comparing energy consumption behaviour before and after the launch of the ORIGIN system. This used the relationship described in deliverable 3.5 to describe pre-launch behaviour. The method was applied to the relationship between the proportion of electricity that is used within the Magilla nucleo and the total amount that is generated for the 4 week period to December 22nd (Fig 4). It indicates that the Magilla residents were modifying their energy consumption behaviour to utilise 26% more electricity from the building integrated PV array. Other monitored data together with interviews with participants is being used to evaluate the extent to which this change in energy behaviour is directly related to the deployment and use of the ORIGIN system in the Magilla nucleo.

Figure 4: Utilisation of electricity generated by the building integrated solar-PV array by the Magilla nucleo before and after the deployment of the ORIGIN system

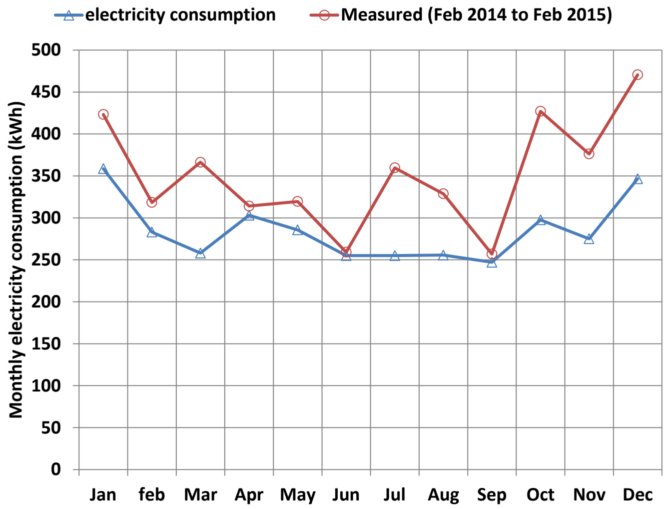


5 Case Study 2: Benchmarking a single building against national standards

In addition to providing information regarding the consumption of energy that is used by the dwelling that was generated by renewable resources, the user interface will also be able to provide more generic feedback to residents and building users about their energy consumption. A simple example of this is by benchmarking annual electricity consumption of a dwelling against national data.

In the UK, the national calculation methodology (SAP) estimates the monthly electricity consumption of a dwelling attributable to the appliance and lighting use based on its floor area and occupancy level [ref]. In addition the monthly cooking consumption was calculated using formulae described in the TARBASE research project [ref]. This calculation procedure was applied to a detached dwelling in Findhorn whose primary method of provision for space heating and domestic hot water is non-electric and compared to its monitored consumption data for the year to February 2015 (Figure 5). The data indicates that the dwelling consumed 23% more electricity than the NCM estimated with the majority of this increase occurring in the winter months, perhaps suggesting that electricity was used as a secondary form of heating in the dwelling. This type of data is being used by the research group to provide a more comprehensive understanding of energy consumption behaviour in each of the communities.

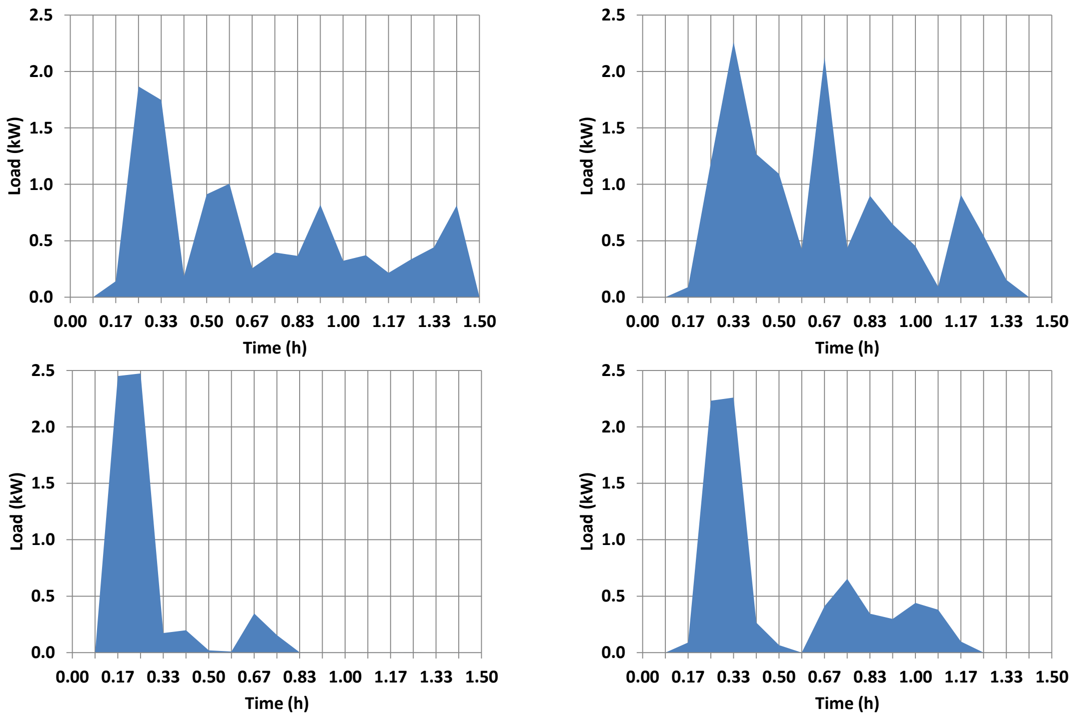
Figure 5: Modelled and measured monthly electricity consumption of a dwelling in Findhorn



6 Case Study 3: Clothes washing

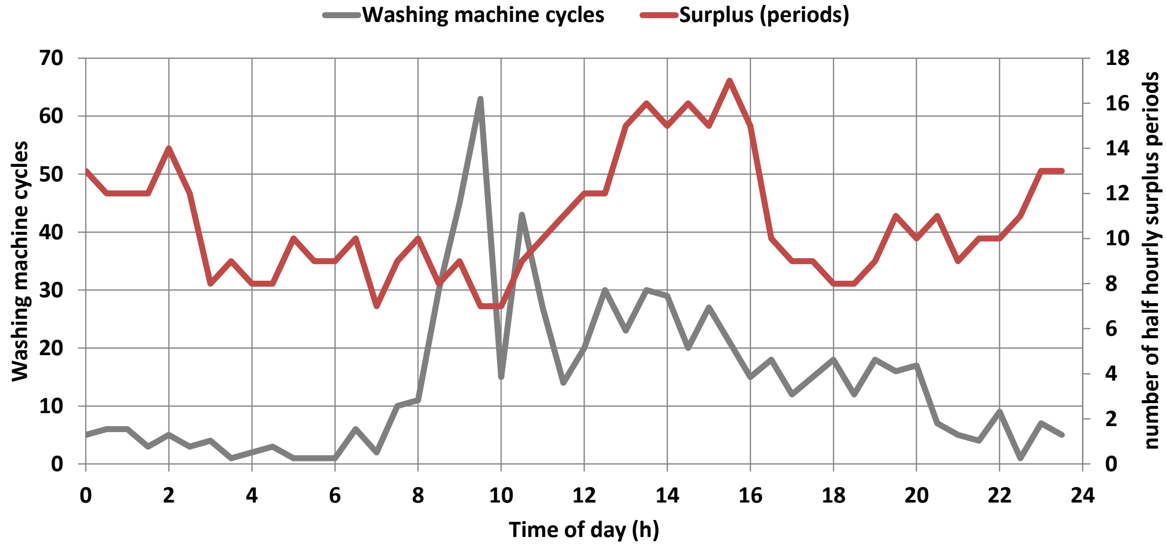
The number of electricity consuming activities that can be comfortably shifted in time is limited in the residential sector. One key load that is regularly championed as being dispatchable is clothes washing. Cycles vary in length and magnitude with hot water heating using circa 2kW elements dominating the early stages of the cycles. Gottwalt et al. (2011) reported that the average cycle time of washing machines was 105minutes, a period reflected in the selection of washing machine cycles taken from Findhorn dwellings shown in Figure 6.

Figure 6: Selection of washing cycles used in Findhorn dwellings



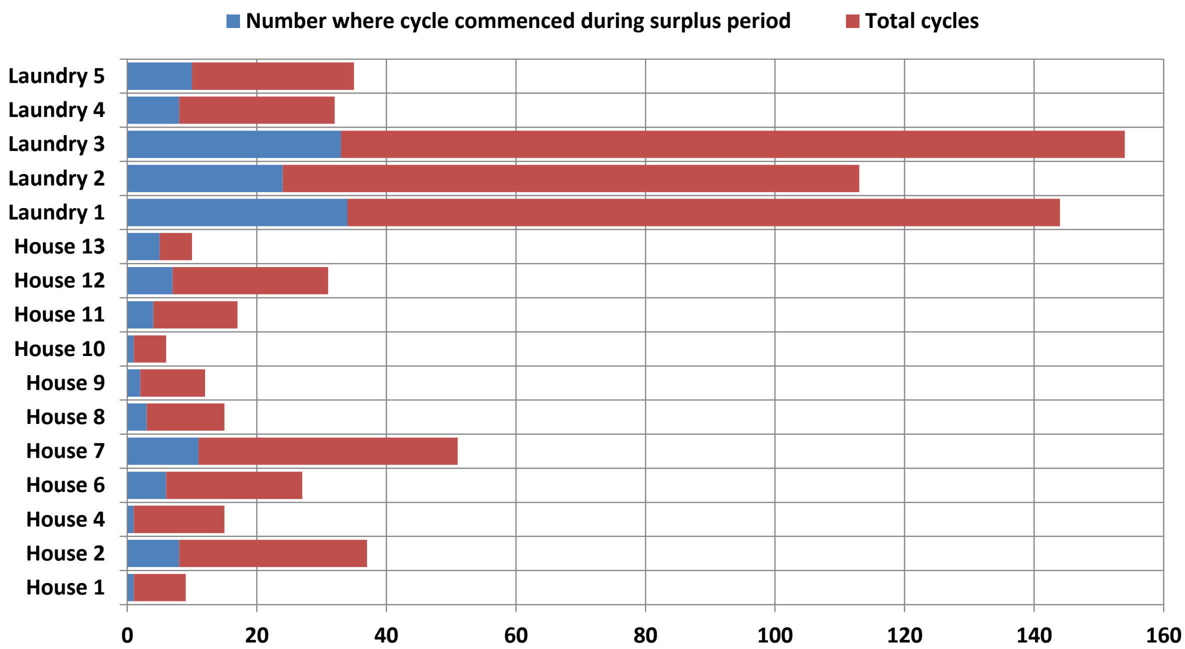
The electricity consumption of 20 washing machines is being monitored in Findhorn. Of these 13 are in individual dwellings and 7 are in communal laundry facilities. Monitoring of the two washing machines included in the East Whins laundry came on-line in March 2015 and is not included in this assessment. The total number of cycles from the remaining washing machines during the two month period to the 30th November 2014 was found to be 708. The timing of these cycles was analysed to establish the extent to which they were coincident with periods of surplus wind energy from the Findhorn wind park. These periods of coincidence could be deemed to be fortuitous as the users of the machines would not have received any notification that surplus renewable generation was available. If it is assumed that the a surplus period occurs when generation from the wind park exceeds community demand by 55kW, then the number of coincident cycles was found to be 18%. Washing machine cycles typically started in the in the morning which was out of step with frequency of periods of surplus which peaked in the mid-afternoon (Fig 7). Clearly an orchestration opportunity exists to try and shift behaviour from the morning to the afternoon, particularly in the winter in Northern Scotland when the opportunity for drying on external washing lines will be limited.

Figure 7: Utilisation of electricity generated by the building integrated solar-PV array by the Magilla nucleo before and after the deployment of the ORIGIN system



If we consider each individual washing machine then the proportion of cycles that commence during a period of surplus was found to vary from 7% for House 4 and 50% for House 13 where 5 out of 10 cycles were coincident with a surplus period (Fig 7). These baseline assessments will be used to inform the research group of the extent to which the use of washing machine cycles becomes coincident with surplus at both a total and household level as a consequence of the ORIGIN system being deployed.

Figure 8: Proportion of washing machine cycles that commenced during periods of renewable generation surplus in Findhorn during Oct-Nov 2014



7 Case Study 4: Actuating electric boilers in residential dwellings

The loads that will be directly actuated by the ORIGIN system will predominantly be:

a) thermal, where electric heating is used for heating hot water either for domestic use or for space heating
b) Electric vehicles
c) Water pumping, both potable and irrigation

In Findhorn, three types of dwelling namely East Whins, Centinnis and Soillse are being actuated (Figure 9).

Figure 9: Description of the dwellings in Findhorn whose thermal loads are being actuated

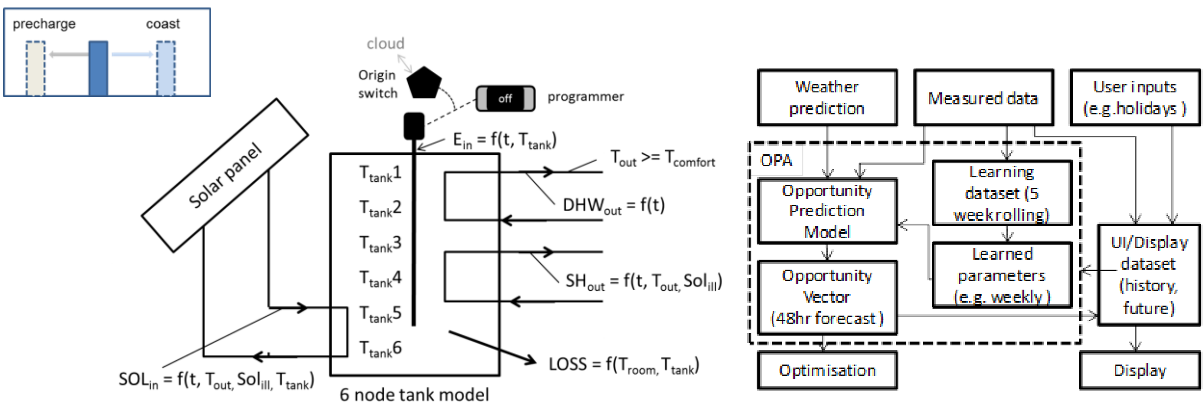
East Whins
- 25 dwellings
- Passivhaus ~
- MVHR
- Solar Thermal
- 200 litre store
- Heat Pump, PV

Centinnis
- 14 dwellings
- 2007 regs
- Solar Thermal
- 500 litre store
- Electric off peak (space and water)

Soillse
- 6 dwellings
- 2010 regs
- Solar Thermal
- 200 litre store
- Biomass district heat (space and water)

Considering the Centinnis dwellings a critical issue associated with actuating thermal loads will be the capacity for the forecasting and orchestration architecture to be able to take account of different energy inputs (e.g. from Solar heating systems and electric boilers) and energy behaviours that will in part determine the constraints associated with shifting thermal demand. For instance, this will only be carried out whilst ensuring that the thermal comfort requirements of each individual dwelling are maintained.

Figure 10: Schematic description of the methodology used to define opportunity vectors for the Centinnis dwellings

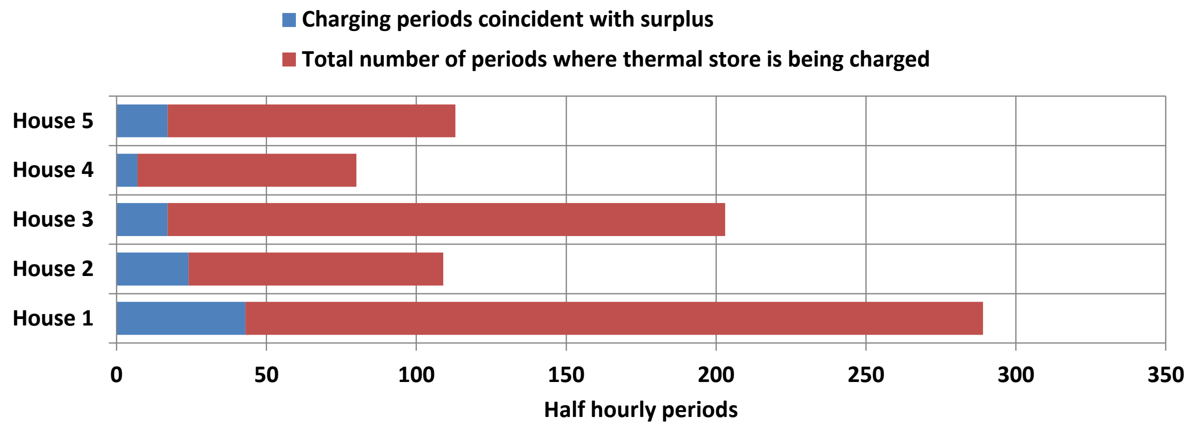


To create a library of forecasted load shift or coast opportunities different models and algorithms have been developed each of which rely on different aspects of the installed monitoring systems. System and user behaviours with respect to space heating and domestic hot water usage is learnt on a weekly basis and allows input to the 500 litre thermal store from the electric boiler and the solar water heating system and draw profiles to be created that allow the outflow of hot water from the store to be forecasted. The losses associated with these movements and from the store to the dwelling itself are also computed.

The orchestration algorithm then establishes for each time step the current state of the thermal tank and a usage forecast. Each load identified in the forecast is then evaluated to create a series of load shift potential vectors that quantify the load magnitude, its forecasted time, its coast or shift potential and the associated energy cost factor. The optimisation algorithm then selects the best option for this dwelling, cognisant of both the disparity between community supply and demand and the orchestration opportunities available to it from other loads in other dwellings.

Five of the 14 Centinnis dwellings are currently participating in the ORIGIN project providing a maximum load shift potential of circa 25kW. The current coincidence of usage of the electric boiler to charge the store with surplus periods is currently low with an average over the 5 dwellings of 14% (Figure 11). The Centinnis are the only dwellings in the Findhorn Community that have dual electricity tariffs with the electric boilers being connected to day and night time meters attracting substantially different tariffs. The boilers almost exclusively are timed to come on between 23h00 and 07h00 when the tariff is low. The ORIGIN actuation system will shift this operation to periods of surplus and it is expected that the timing of their operation will therefore graduate towards mid-afternoon in line with the peak periods of surplus. A critical output from the ORIGIN project will be an assessment of the impact of this on overall energy consumption. To some extent energy use is already disassociated with service requirement as a consequence of the tariff arrangements. The imposition of a tariff that is linked to the availability of surplus wind generation will overcome any financial penalty that would have otherwise been accrued by the householder.

Figure 11: Coincidence of the timing of charging the thermal store using the electric boiler and periods of surplus wind generation



Case Study 5: Electric Vehicle charging

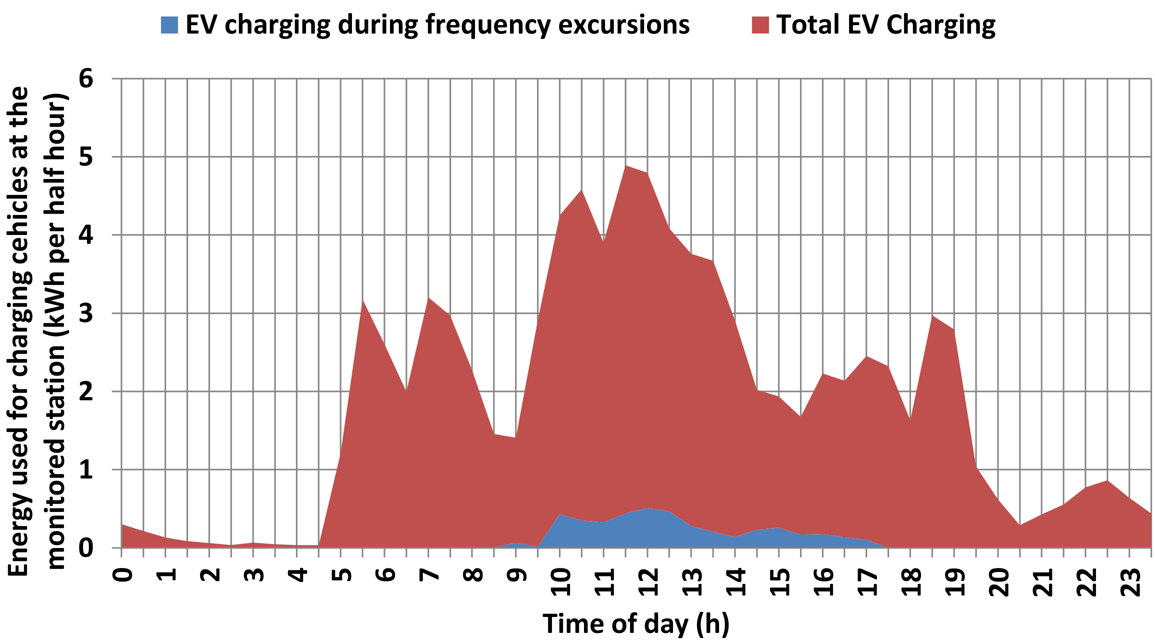
As described in deliverable 3.5 a principal issue in Tamera is the control of their micro-grid within acceptable frequency limits. As supply outstrips demand the frequency of the grid rises above the control set points and in the absence of any demand response or storage output from the PV system is constrained.

A key load that can be used to ameliorate this problem is electric vehicle charging. Tamera has seven electric vehicles and two charging stations, one of which is monitored using an ISA Cloogy smart plug and therefore capable of being actuated. The ORIGIN system forecasts the incidence of grid constraint information that can be used by the community to re-schedule charging times of the vehicles to coincide with these frequency excursions. Whilst it is unlikely that constraint can be entirely eliminated through this single dispatch option it will make a significant contribution and minimise its impact on Solar-PV output.

Analysis of the timing of vehicle charging would suggest that it is a procedure wholly dominated by its internal requirements of trip length, trip frequency and battery status. The total amount of energy used for charging vehicles from the monitored charging station during the two month period to November 30th 2014 was 88.9kWh, of which only 4.3kWh occurred during frequency excursions (Figure 12).

The TAMERA community plan to extend the monitoring and actuation equipment to the second EV charger which will increase the scope and capacity for demand response.

Figure 11: Coincidence of electrical vehicle charging and frequency excursions in the Tamera micro-grid



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