FI.ICT-2011.1.8 FINESCE
D2.7 – Horsens trial – v1.0
Trial Results

Contractual Date of Delivery to the CEC: 30 September 2015	
Actual Date of Delivery to the CEC: 16.09.2015	
Author(s):	Michael Diekerhof, Andy Drysdale, Munna Hoffmann, Thomas Hune, Christina Jorgensen
Participant(s):	RWTH, INSERO, ISW
Workpackage:	WP2
Estimated person months:	25
Security:	**PU**
Nature:	**R** = Report
Version:	1.0
Total number of pages:	19

Abstract:

The aim of this report is to conclude on the trial setup and demonstrations, presenting trial results conducted in the WP2 trial in Horsens.

This trial has been highly focused on the interaction between real-life users and green energy technologies, and seeing the small-scale effects of a smart energy setup that integrates different technologies through a FIWARE based software platform.

The WP2 Horsens trial has operated within a set of predefined evaluation criteria of which five out of six have been successfully addressed.

Keyword list:

FIWARE, smart energy applications, user interaction, prosumers, external control

Disclaimer:

All information provided in this document reflects the current stage of the WP2 Horsens trial at the time of writing and may be subject to change.

Executive Summary

Work package (WP) 2 aims to integrate and evaluate FIWARE Generic Enablers (GEs) as components of smart energy trials in the smart house/smart building domain. WP2 is structured in two different trial streams: a community of 20 single-family houses in the Horsens area (Denmark) and a commercial office building in Madrid (Spain). This report applies to the WP2 Horsens trial.

The WP2 trial in Horsens consists of a community of single-family households in a small town near Horsens, Denmark. The town is located outside the collective (district heating) heating supply area, and the houses are characterised by originally having individual oil or gas-fired boilers. The trial site houses have both energy producing and energy consuming equipment and components installed.

During the trial design preparation, six evaluation criteria for the trial execution were defined. Five of the six criteria have been successfully addressed during the trial period with positive outcomes. These criteria cover:

- Achievements in relation to access to, and collection of, data – near real-time and through the FINESCE API;
- Achievements related to demonstration of shifting energy consumption
- Achievements related to creating incentives to shift energy consumption away from peak periods

For the technical setup, the trial demonstration shows that it is possible to build a smart energy solution for a private home based on existing components that are not all specifically designed for this purpose.

The energy consumption can be moved in time to where the consumption is “best” according to both individual constraints (such as price) and global constraints (such as overall load of the grid).

In terms of scalability very good progress has been made. Insero has successfully engaged the local DSO and there has been a close dialogue about the possibilities in the grid.

The trial has chosen a set of GEs to experiment with, as potential components of the trials. Based on the results of the experiments carried out, a subset of these GEs has been integrated into the trial architecture, together with the Domain Specific Enablers (DSEs) developed within WP2, and other software and hardware components specific for the trial. Overall, the GEs have not reached a maturity level suitable for critical infrastructure.

A structured user involvement program has been successfully implemented with a particular focus on four specific areas of interest. Overall it is seen that the users are willing to enter the ‘green’ transition and have an interest in adapting to the smart technologies enabling this.

Authors

Partner	Name	Phone / Fax / e-mail
RWTH AACHEN	Michael Diekerhof	Phone: +49 241 80-49735 Fax: +49 241 80-49709 e-mail: MDiekerhof@eonerc.rwth-aachen.de
INSERO	Andy Drysdale	Phone: +45 41 32 98 41 Fax: + e-mail: adr@insero.com
INSERO	Munna Hoffmann	Phone: +45 41 77 24 62 Fax: + e-mail: mhof@insero.com
INSERO SOFTWARE	Thomas Hune	Phone: +45 40 15 80 22 Fax: + e-mail: tsh@insero.com
INSERO	Christina Jorgensen	Phone: +45 41 77 01 54 Fax: + e-mail: chjo@insero.com

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1. Introduction

The aim of this report is to conclude on the experiments conducted in the WP2 trial in Horsens. The trial consists of a community of single-family households in a small town near Horsens, in Denmark. The town is located outside the collective (district heating) heating supply area, and the houses are characterised by originally having individual oil or gas-fired boilers. The trial site houses are equipped with energy producing and consuming units and components. During the trial there has been a high focus on interaction between the users and the new green energy technologies. The installed equipment is integrated through a FIWARE based software platform that is used to test Generic Enablers (GEs).

In the WP2 Trial Design Document (D2.1) six trial evaluation criteria were defined for the Horsens trial. The evaluation criteria are listed in the table below for easy reference.

Table 1 Trial evaluation criteria

	Evaluation Criteria
1	It shall be evaluated to what extend the data and controls in the houses are available to the FI platform. The aim is that all data shall be available for all houses in near real-time.
2	It shall be evaluated to what extent the FINESCE API grants access to the data and controls in all the houses in the trial. The aim is that all data defined in the API is available through the API (Please note that some data may not be defined in the API).
3	The possibility for the users (manual, automatic or a combination) to shift electricity consumption to periods in time with high levels of renewable energy production (either own or available on the grid) shall be evaluated.
4	It shall be evaluated to what extent it is possible to shift electricity consumption from peak periods to enable a higher level of grid utilization.
5	It shall be evaluated whether the prosumers are willing to participate in demand controlling either by semi-manual interaction or by allowing automatic shifting of the electricity consumption.
6	The scalability of the designed algorithms for demand controlling shall be evaluated in a number of larger setups. The evaluation shall be performed by simulation.

The experiments conducted during the project have resulted in several findings. This report is structured in three main sections. One section with findings related to Generic Enablers, one with results on user involvement and finally a section on findings related to energy consumption. The criteria are evaluated based on the findings related to user involvement and energy consumption.

2. Trial Results on use of Generic Enablers and FIWARE

The aim of using FIWARE GEs in a setting for managing energy consumption in single-family houses was (1) to provide a robust and scalable infrastructure for handling data in a secure way and (2) to provide a standardized way of interfacing to equipment in the houses.

The possibility of having a test-bed such as FI-LAB, where generic components can be easily deployed and new instances can be set up, is very attractive when designing a new system such as the SW platform deployed in the Horsens trial. FI-LAB has the potential to become a very powerful tool, but stability issues and incidents where resources have been allocated to other purposes have a negative impact. For such an environment already in the phase of demonstration and even more so when deploying commercial solutions, a key requirement is stability. This requirement has not yet been fully achieved in the FIWARE setup.

The most positive experience with using GEs has been with the Publish/Subscribe Context Broker and Backend Configuration Management. We have experienced good support from the developers, frequent updates with advance notice and it is available as Open Source on github. In general, the GE has improved during the entire period. The documentation has been good for our needs and performance. It has a FI-LAB image, which makes the installation process very easy. However, the images have not been entirely stable. In our view this stems from issues related to FI-LAB rather than the GEs but we do not have the insight to analyse this entirely.

Another GE that has provided good functionality is the Identity Management (GCP). It provides many features and is targeted at a setup requiring many more different security features than is the case of the Horsens trial. Support and documentation from the developer has been good. The fact that it is a software as a service, and therefore very closed, is our primary issue. It is generally very stable, but there has been an incident where the service was moved to another hostname without notification.

Integration of many different types of equipment is essential to the Horsens trial. Therefore, a set of GEs from IoT Service Enablement has been integrated to test a setup where data is handled from the sensors to the infrastructure entirely by GEs. Our experience with the GEs was mixed and at times frustrating. Individually the GEs worked satisfactorily, but integration between the GEs resulted in many issues. Because of incompatibility, we ended up creating links that could translate the NGSI messages between the different GEs. We have the impression that the IoT section has been subject to many changes, including replacement of the Gateway Device Management (OpenMTC) and the Backend Things Management being spilt up into separate GEs. Integration between EspR4FastData and ZPA is key in this setup. We have been in close dialogue with the responsible GE developers in the process. A new version of EspR4FastData was provided, but the integration issue with ZPA could not be solved. Hence a workaround has been introduced for the test setup used for long term testing. Based on experiences during the trial, we would not yet recommend using it for critical components.

In conclusion, there are many good ideas, but the overall maturity has not yet reached a level suitable for a critical infrastructure. It is possible to deploy a set of scalable infrastructure components but much work is needed to combine these into complete solutions. In particular, confidence in GE architecture as a whole is reduced when GEs that share a common interface cannot work together.

3. Trial results and learnings from user involvement

User involvement and technology co-creation with market players is a strategic focus area for Insero, and thus a driving motive for establishing the trial site in Horsens – a living laboratory for testing smart energy solutions through a dedicated user involvement programme.

Taking into consideration the characteristics of the users and technologies to be tested in the Horsens trial site, four focus areas were decided on. These four areas have been the guiding line for the design of user involvement activities:

- Technology and social behaviour
- Energy visualisation
- External control of energy resources
- Prosumers in the smart grid

Across these four focus areas, desirability, usability, flexibility and acceptance emerge as crucial topics.

During planning of the user involvement programme, it was decided to include all adults living in the test houses making up the trial site. The user programme holds both mandatory activities and optional activities for active involvement.

The user involvement programme has included two primary tasks.

- Firstly, to carry out a user study to identify changes within the test group on variables that are either directly or indirectly related to the four research areas: Technology and social behaviours, Energy visualization, External control of energy resources, and Prosumers in the smart grid.

The user study has been carried out as a process evaluation study to investigate how the trial site families react and experience the transition in their house supply units. A number of methods have been used to cover the transition process before and during the project period.

- Secondly, to involve trial site families in the development of solutions related to energy visualisation, consumption and production feedback, and shared control features.

The user study, co-creation workshops and real-life tests of external control with energy units constitute interrelated activities – all feeding into a pool of knowledge about users and their experiences on living with the implemented technologies.

The close interaction with users has generated empiric learnings and insights into the present market demands of private end users. Within the project, we have implemented the learnings on product level in two visualisation platforms – eButler and the iSEA platform. The eButler visualisation platform was part of the equipment “package” from the project launch, and the iSEA platform is a visualisation platform introduced with the partner SEnerCon joining the project in May 2014, as a result of the FINESCE Open Call.

Furthermore, the continuous dialogue with the test families and the local community has been used directly in the communication, planning and coordination of sub activities. This resulted in an agile process and reflects that the trial site participants’ demands for information and additional support have been hard to predict, which have called for an agile work effort in regards to building up a responsive and constructive relationship to the test families in the village.

In the following sections, we briefly present the learnings related to each of the four aforementioned focus areas.

3.1 Technology and social behaviours

- The process of deciding and installing the test equipment increases user awareness on heating consumption and mobility need and opens up for internal family discussions about energy topics.
- Involving the individual and the family in a green transition by accepting the premises of the test (the replacement of energy supply units in the household and the subjection to external control) are motivated by five areas of sense-making: economics, comfort, functionality, environment and technological enthusiasm.
- The house owners are by default micro managers of the household economy and they are prone to engage in hands-on optimisation of their new energy equipment to boost the potential rewards of their investments: There is a strong interest among the owners for optimising the performance of the individual units and/or the system as a whole.
- There is a high level of willingness and good intentions among the users to change towards more flexible consumption patterns. The user's efforts towards a more flexible behaviour are primarily practices, for which users expect certain rewards.
- Users experience market conditions, regulations and infrastructures, which do not yet reward private consumer flexibility.
- Users want to "cooperate" with their new equipment and they ask for guidelines to "act right".
- A behavioural "rebound effect" appears in some families when a family member enjoys more luxury than he or she has allowed themselves before the purchase of the new energy system. These cases can be explained as a reaction to previous "lack of comfort" more than to "overspending".

As new owners of smart energy technologies, the users are asking for, and are in need of, advice and guidelines. Should they maintain their old routines or adapt to new ones? Examples are ventilation requirements, how to use a woodstove, how to adjust the radiator settings or what to do when leaving the house for a weekend trip or a longer holiday. A lack of clear and unambiguous guidelines can result in old habits or "best intentions" causing counterproductive results, which was the case when one family shut down their heating system when leaving the house, which had negative consequences on comfort, expense and operational annoyances for the family.

3.2 Energy visualisation

- The services offered by the "one-entrance" energy visualisation platform (eButler) have been investigated and subsequently improved based on users' feedback, by pilot testing, interviews and workshops. Interaction with the market (the users and their reactions to the platform data) have been used to optimise the front-end information on energy production and consumption, including graphs and analyses offered to the end users.
- Energy usage is invisible in the everyday life of a family. The exposure of the energy conditions in an energy visualisation service helps relate everyday practices to consumption. The various types of information, provided via this service opens up for the users' perception of energy as something one can actually influence as a consumer, rather than a one way exchange from the utility.
- The "one-entrance" service stimulates the users' curiosity towards their own energy resources, and there are examples of users using the eButler platform for further investigation, if they see indications of deviating energy flows.
- The users evaluate the energy visualisation service (eButler) as valuable because it offers a monitoring and documentation tool. Users would like the service to further offer services in form of local weather forecasts (to be able to take advantage of sunny hours) and forecasts of wind and local grid peaks. Users also ask for implementing services such as daily planning advice and alarms, notification of real time "level of self-

supply" and daily evaluation of grid exchange that could inform them of bought and sold electricity.

- In the launch of eButler to the test families, a number of challenges have been identified. First, there are instances of a "no-use situation", indicating that some users put less value in the energy visualisation. Among the most significant challenges are situations, where users find the information confusing, have difficulties reading and comprehending data, experience data overload, and distrust of the data validity.

The trial equipment package includes an energy visualization service – eButler that provides "a one-entrance information platform" to the energy equipment in the house. The eButler includes functions that enable the users to manually set their indoor temperature comfort level and demands for driving distances with regard to charging their electric vehicle (EV). In eButler the families have settings for preferred indoor temperature and a minimum and maximum temperature. When charging their EV, the families have been asked to differentiate their driving needs based on weekdays and weekends and to register the time when they need the car to be fully charged. In accordance with evaluation criterion 3 (the possibility for the users to shift electricity consumption to periods in time with high levels of renewable energy production), the eButler thus enables both "shared control" and an overview of energy flows, enabling them to define their individual comfort and functionality demands for indoor temperature and EV usage. We find that this paves the way for central effects. Firstly, acceptance of external control (users state that they are positive towards the external control as long as the control system will comply with their individual comfort settings). Secondly, the available information and graphs push reflections on how users gain an advantage from their own energy production by adjusting everyday practices.

However, some unforeseen challenges have been identified. The idea of including this service in the equipment package was to provide the users with an overview of the different energy equipment, to encourage better understanding of the energy flows in the house, and to strengthen the users' understanding of the relation between their behaviour and its consequences. User feedback shows that the amounts and different types of information on the eButler platform challenge the overview that was the original intention of the eButler service. In addition to the eButler platform the families are exposed to additional data information streams, including the solar cell inverter, the main electricity meter and sensors on the heat pumps, to mention a few. Furthermore, a number of participants are using smart phone applications offered by the energy supplier and Nissan (the EV manufacturer). All of these contribute to various data feeds and information loads that the users need to understand and process and, not surprisingly, some users express confusion towards the overload of information they meet in the various user interfaces available.

3.2.1 Evaluation of user workshops with Open Call partner SEnerCon

Two user workshops with Open Call partner SEnerCon have been carried out. The intention of SEnerCons iESA platform is to engage and motivate end users as actors of the smart grid with help of the iESA. The platform provides extended monitoring with the heat monitor and energy saving advice from experts within a blogging module.

To innovate the platform targeting private users with smart meters, SEnerCon has been interested in collecting user experiences, decisions and behaviours that lead to a change in consumption, to design a solution that empowers people to act more deliberately and make decisions taking the environment into account. This has resulted in two workshops where SEnerCon had a chance to interact with the trial site participants. The workshops have enabled a direct exchange of experiences and ideas between the trial site users and the Open Call partner.

The first workshop was held on 2 December 2014. The focus was to introduce the overall ideas of the platform. SEnerCon's leading developer, Elmer Stöwer, was there to present himself and to get to know the target group (private house owners with smart grid energy equipment). The participants were very open towards the new product and they shared both good and bad experiences as "first season owners" of heat pumps, solar cells and EV drivers. They also shared experiences with the eButler platform, and it became very clear that it was a group with a high level of interest for energy visualisation. The workshop was held as an open event, meaning that those with no or little interest did not attend. Even though the participants can be characterised as a group of very enthusiastic users, it was clear that their motivation arose from different areas of interest. Participants included both genders and different age groups.

The second workshop was held on 22 April 2015 with a more dedicated and deeper presentation of the features in iESA. To encourage the participants to try out the iESA platform, the participants were provided with passwords just after the presentation and were invited to participate in a competition. Finally, the workshop ended in an entertaining way with a quiz with questions about the participants' energy equipment.
Nine families were invited to this workshop, and seven families attended. The participants were more representative to the total of test participants in the trial site, compared to those who attended the workshop in December.

3.3 New prosumers in the grid

- The users exhibit a positive attitude towards being seasonally self-sufficient, as they stress it is displeasing to be dependent on varying oil prices.
- Consumption practices among the trial site families easily adjust to clearly rewarding behaviours, such as charging the car when the sun is shining or timing the washing machine to run outside peak hours.
- Factors such as price regulations, utility licenses, and grid charges obscure the benefits of producing and using own energy.
- Users got lost in a jungle of national price regulations related to solar cell production in private households, and many are still confused and uncertain of what price group they belong to and what they have signed up to in this regard.
- Grid licenses, flat prices during day and night, and different prices for bought and sold electricity minimise the final economic effects of performing a "demand-response" behaviour.
- The private solar cell owners in a smart grid ready home pave the way for the emergence of a new "prosumer" role, that claim fairness towards one's own role in the market.

Living in a smart grid home with its own energy production, and an intelligent control system to optimise your private energy equipment, constitutes a new "prosumer" role. These new prosumers in the grid are subjected to market conditions, infrastructures and regulatory landscapes that do not yet reward private consumer flexibility, nor do they reward end-users' active engagement in balancing grid loads.

3.4 External control

- The users' positive attitude towards having their home energy appliances externally controlled is connected to the sense of achieving "something".
- The users express a positive attitude towards external control enabling the same level of comfort as before, but now supplied by renewable energy. The logic behind this attitude is "same comfort, but green".
- With regard to the EVs there is a slightly negative attitude towards the aspect of losing full freedom of spontaneous driving.
- The users demand transparency in "what" they will gain if they should have "external control as a service" in the future. They also demand transparency towards "who will gain" - the control service provider, the utility, the DSO?
- Users demand compliance with their individual comfort settings, and shared control in form of individual setting options and overrule functions
- The users ask for easy accessible means to interact with external control services

- Some users expect the external control system to contain the ability to track and prevent unfavourable running operations of the heat pump and errors on the solar inverter

To get deeper insights into the users' attitude and acceptance towards external control, families in the trial site have been asked about their previous priorities in relation to energy decisions; their previous heating systems and decisions about energy supply models. Users' feedback on these topics show that they are motivated towards investments and decisions that pave the way for optimising household economy and comfort improvements.

As mentioned earlier the prosumers are willing to participate in external demand controlling in semi-manual interaction. As all users have been provided with a simple private homepage offering an "overrule button", it has not been further investigated how the users will react to external control without this option.

There is a positive and strong interest in improving comfort levels (or to have "the same for less"). Hence adjusting towards some kind of an achievement is essential, as long as the achievement lies within the area of personal finances, comfort and functionality or green ethics.

Due to the flat price structure of energy in Denmark, there are no financial benefits for the users in allowing the EV charging to be controlled externally, whereas optimising the operations of the heat pumps by external control offers the potential of financial benefits to the owners.

The attitude in general is that external control of the heat pumps is welcomed as a means of reducing the risk of unnecessary operational costs. For some users in the trial site, their attitude towards external control of the EV-charger is associated with the feeling of losing something without getting anything in return. This also relates to the dilemma between the benefits of energy optimisation versus the sense of freedom ensured by charging to full battery capacity as soon as possible.

With regard to the perceived value of external control, the users express a positive attitude towards a number of non-economic benefits such as maintaining a preferred level of comfort without having to act actively. This is in line with the fact that automated indoor temperature control is an appealing alternative to previous difficulties in heating the house by straw or pellet burners, which was the reality for a number of the trial site users before attending the project.

Investigations on how the families in the trial site prefer the procedures of external control point to three essential requirements:

- Transparency with regard to who gains something out of it, and what the real benefit is
- Certainty that individual comfort settings will be respected
- Retain the possibility to manually overrule the external control

3.5 Recommendations for further design of smart grid services based on human insights from the trial site

For the users, unsolved challenges remain related to the management and optimisation of the new technologies. We see that nearly all participants actively engage in "hands-on" optimising guided by common sense.

With their new equipment, and in particular the production of their own energy, we see that the families adjust towards "more rewarding" consumption practices. Danish legislation stipulates two payment models for selling surplus electricity production, and both models are represented among the test families. The two payment models demonstrate different perceptions of ownership towards own energy production. One payment model, where selling surplus electricity to the grid is sufficiently rewarding – and one, where users keep surplus electricity within their "own" micro-grid in return for a financial reward.

Finally, the sense of achieving something is essential for the users' attitude towards external control.

The users emphasise the importance of issues like transparency, level of energy supply security and shared control when asked about a future partnership with an external control service supplier.

Insights from end-user co-operation have generated three recommendations that can be emphasised as having universal relevance for any end user engaging in a “green” energy transition, interested in converting their private energy resources into intelligent alternatives.

1. Well-designed support and instructions should accompany the delivery of intelligent, green technology – both hardware and software – to encourage and empower end-users in the transition and to prevent old habits from counteracting the full potential of their investments.
2. Users ask for easy means to interact with external control services, and system interfaces must invite the users to easy-accessible, shared control features with clear feedback on “who” has control, and for how long.
3. In the case of offering control as a service, the services must be open to accommodate clear local motivators. This means that intelligent control services must be flexible and adaptive in order to meet the present price and payment conditions, as in the case of profiting from free solar energy.

4. Trial results and learnings on energy consumption and control

4.1 Integration of equipment

A prerequisite for experiments is that the software platform in the trial site collects data from all the installed equipment and makes it available for both the users and the optimization algorithms. It is also a prerequisite, that the controls for the EV charging boxes and the heat pumps are made available in the software platform. A description on how this is achieved is included in the Trial Description and Test Bed Manual deliverable D2.2. The aim of achieving near real-time data is obtained to the greatest possible extent by the gateway connecting to the equipment. When data is received, it is made available in the software platform as “live data”. Hence, evaluation criterion 1 (… all data shall be available for all houses in near real-time.) has been met.

The data is also made available in the FINESCE API as described in the FINESCE API and Handbook deliverable D2.6. SEnerCon - one of the SMEs joining the project as a new partner through the Open Call uses an early version of the FINESCE API to get data for the user interface now being tested at the trial site. The evaluation criterion 2 (… all data defined in the API is available through the API) has also been addressed.

The trial has shown that it is possible to build a smart energy solution for a private home based on existing components that are not all designed for this purpose. However, the setup is not scalable with respect to cost of the equipment and maintenance. A truly scalable setup should be built from equipment prepared for integration in a smart home setup with appropriate communication features implemented.

4.2 EV smart charging results

The Horsens trial includes a demonstration of controlled charging of 19 EVs.

Online measurements of the Live Lab users’ power consumption for EV-charging and the EV’s batteries state-of-charge are used as input parameters for an optimized charging schedule. In addition, external and public data containing information on CO_2-emission and electricity spot prices are included.

An optimization algorithm produces a revised charging schedule every 15 minutes.

The control settings are designed to evaluate criteria 3 and 4 related to shifting consumption to periods with renewable power generation peaks and to offload peak load periods respectively. The primary focus of the control settings is reducing the load on the local 400 V power grid during peak load hours from 5 pm to 8 pm, and the users’ CO_2 footprint.

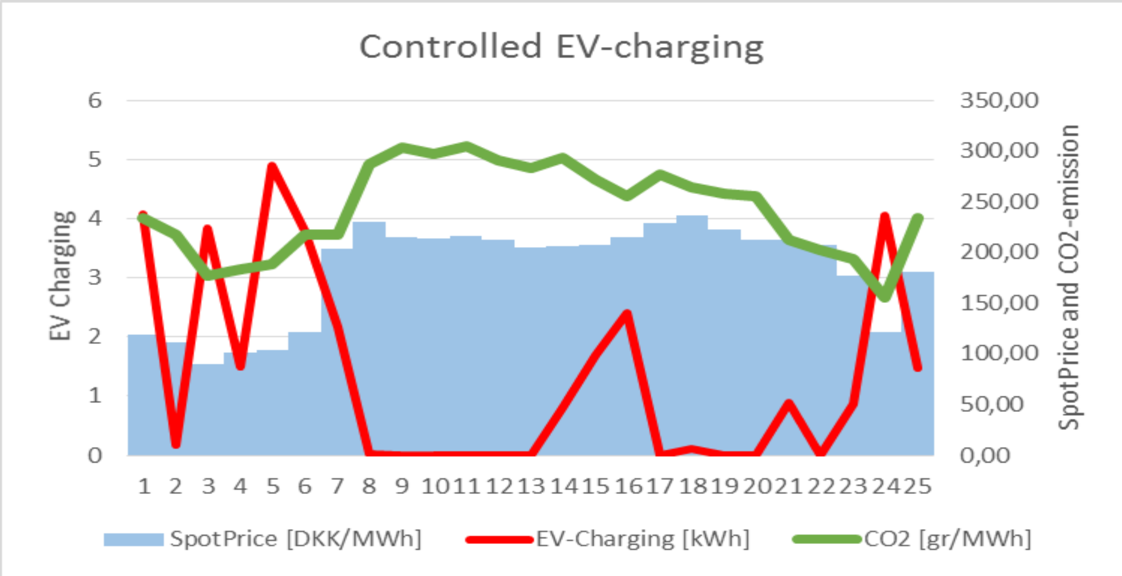
Additionally, the optimization algorithm honours each user’s personal comfort settings with respect to minimum charging levels and EV-usage.

In order to allow the users additional flexibility, a web-based “Charge Now” button allows the user to easily by-pass the controlled charging schedule also allowing for immediate charging of their EV, if the user had special needs for transportation.

Initial tests commenced in September 2014. During the period October-November 2014, the control software was stabilized – and during the period from 1 December 2014 through 31 January 2015 charging schedules of eight EVs were controlled on a daily basis without interruption. An additional pool of 11 EVs did not participate in the test, but was used as an unbiased reference group. This group were not included in the test, due to user specific constraints and wishes – e.g. engaging in night shift work, which made it harder to control their use case compared to the other participants.

During the period of steady operations, the five most used EVs in the controlled group drove a total distance of 7.219 km on 2.315 kWh electrical power, corresponding to 0,321 kWh/km. The five most used EVs in the reference group drove a total distance of 7.671 km on a total charge of 2.666 kWh.

The figure below shows an example covering 24 hours in mid-January 2015. It clearly shows that charging the pool of EVs is suppressed during peak load hours (5 pm to 8 pm), and that charging is moved to low CO_2 emission during night hours. It should be noted that in the Danish energy system there is typically a correlation between low CO_2 emission and low spot prices due to the high penetration of wind in Denmark. We use less power during the night; however, we produce wind power during both day and night – thereby lower CO_2 emission during the night.



Comparing the controlled group with the reference group for the whole two months period revealed three encouraging findings:

1. The load from charging on the 400 V power grid in the peak hours from 5 pm to 8 pm was reduced by 62 %
2. The overall CO_2 emission from EV-charging was reduced by 17 %
3. The cost of electricity (based on spot prices) was reduced by 29 %.

During the test period it has been demonstrated that:

- it is possible to reduce the peak load on the 400 V power grid by controlling the charging of EVs without reducing the users comfort
- in addition, controlled charging can reduce CO_2 footprint and electricity cost for individual users.

Therefore, we consider evaluation criteria 3 and 4 to have been addressed by these experiments. With current technologies, a scalable EV charging system can be deployed. It can use changes in electricity prices or tariffs, or provide a “green profile” for users – however, in a Danish setup the business case for such solutions does not exist yet. At the same time, such solutions can provide support for levelling the grid load, or can be deployed solely for that purpose.

4.3 Heat Pump control results

Eight houses in the Horsens trial were selected for participating in a demonstration of controlled operation of heat pumps. These eight houses had the same type of heat pump, and hence the same interface and heat production profile. Initial testing of the heat pump operation control showed issues in the configuration performed during the installation of the heat pumps. The configuration is now performed and technical control of the heat pumps is possible from the software platform. The optimization of heat pump operation has not been performed because the season for using heating in Denmark has passed.

4.4 Conclusion of energy consumption and control

It has been demonstrated that a system based on existing standard components and internet communication can be used to shift energy consumption. The energy consumption can be moved in time to where the consumption is "best" according to both individual constraints (such as price) and global constraints (such as overall load of the grid). The demonstration has been performed on EV charging but methods and technology can be extended to consider a combination of EV charging and heat pump usage. Simulation results (See section 5.3) shows the relevance of this in real life cases.

5. Trial results on simulation

As for the fact that field trials are always limited in size, the main purpose of the simulation was analysing the scalability. In order to investigate the main impact of electric vehicle charging, heat pump consumption and photovoltaic generation on the electricity low voltage and medium voltage grid, a power flow analysis was performed using the professional software tool NEPLAN. The Stenderup trial site's LV/MV grid is a typical rural grid with a radial distribution system. The main objective was to analyse how the system would behave if further buildings with similar equipment and user behaviour were added to the field trial. Voltage profiles at the nodes, transformer and line loadings are parameters that were used to analyse the system behaviour.

5.1 Introduction to Work Flow and Software Environment

The LV-/MV grid was implemented using the grid data information in QGIS provided by the local DSO. Via a C++ Interface the load flow analysis could be performed automatically for given consumption and generation data. PV generation was treated as a negative load. All load and generation profiles were taken from the FINESCE WP2 API. All loads were treated as PQ loads with a cos phi of 0.95. The results are analysed and plotted within a developed Matlab Environment. Time resolution of the one day power flow analysis was five minutes. In terms of scalability analysis a few assumptions had to be made. The measured load and generation profiles of a field trial building taken from the API were duplicated and also used for the same buildings within the same street. Furthermore, since it was supposed to be a worst case analysis, a coincidence factor g equal to 1 was considered. This means basically that for example in one radial feeder of the grid in every house all heat pumps would be turned on, at the exact same time step. However, this is rather unrealistic but it stresses the grid the most. In a future scenario, with more participating buildings, where the control algorithm is not adopting this fact, a g of one would cause high problems.

5.2 Scenarios

The first scenario and analysis was on the PV impact within a very sunny day consisting of high global radiation. Looking into the global radiation measurements, the 4th of July 2014 was considered to be a very representative day. Also the mean average day temperature was higher than 15°C so it is within the summer period according to VDI 4655. The power flow calculation was done for the whole LV/MV grid of Stenderup. The installed PV capacity within the system was around 2-4 kWp.

The second scenario was to analyse the impact of the heat pump consumption on the system within a cold winter day. In terms of the winter period, the main average temperature was taken into account again. On the 5th of December 2014 it was below 5°C, so this day was chosen for the analysis.

5.3 Results

The results for the PV-generation scenario show that in particular around noon, where the PV generation is at highest, the transformer loading in some parts of the area is overloaded by up to 120 %. The voltage profiles at the nodes are increasing significantly during high PV generation but are never exceeding the limits of 1.1 pu. Figure 1 shows an example of the transformer loading of a transformer in the Stenderup grid.

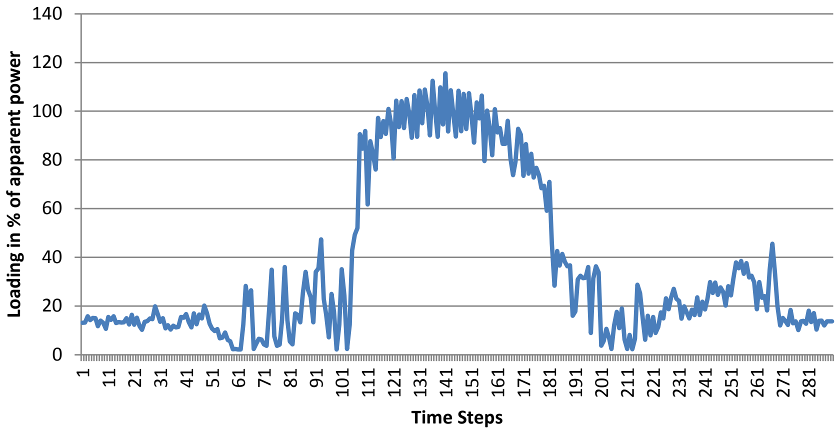


Figure 1: Example of the impact of the PV generation on 4th of July 2014 on the transformer loading

Figure 2 shows an example of a voltage profile of one radial within the PV scenario. It is visible that the further the node is from the transformer, e.g. node 20, the worse the voltage profile gets. However, the 1.1 pu (0.44kV) and 0.9 pu (0.36 kV) voltage limits are never violated.

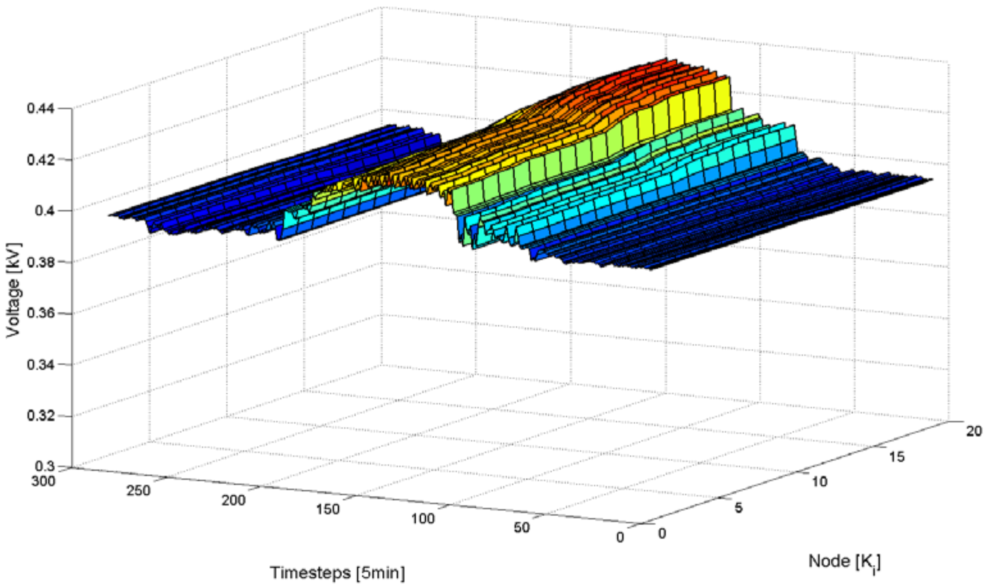


Figure 2: 3D plot of a voltage profile example of one radial depending on time and node for the summer scenario on the 4th of July 2014

The results differ significantly within the winter scenario analysing mainly the impact of the heat pumps compressor consumption on system level. The scenario is supposed to analyse if a further heat pump installation within other buildings and an extended EV charging within Stenderup will lead to problems. Figure 3 shows an example of a transformer with high overload due to electrical power of the heat pumps compressor and the EV charging. In particular, the peaks at the beginning are indicating that.

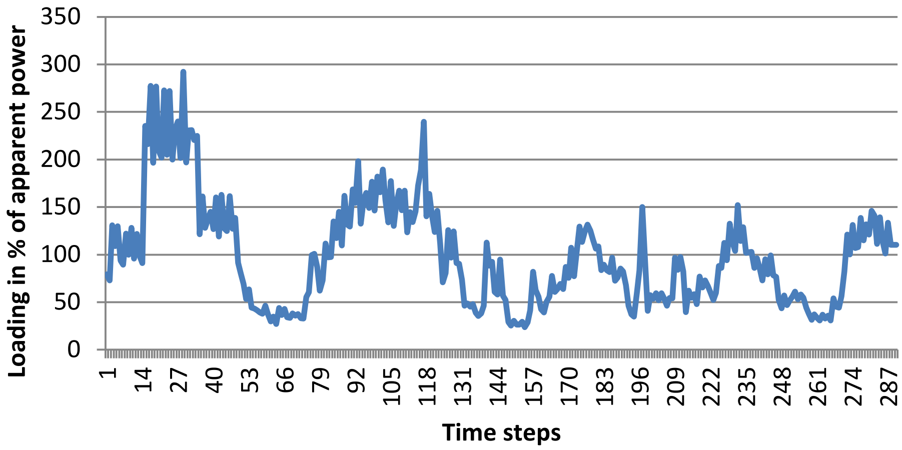


Figure 3: Example of the Impact of heat pump and electric vehicle consumption on 5th of December 2014 on the transformer loading

Figure 4 is a 3D plot that shows an example of one radial, given the information that the increased consumption of heat pumps and electric vehicles will cause huge voltage drops. The limit of 0.36 kV respectively 0.9 pu will be violated several times per day for a long time period. In particular, the longer the distance between transformer and building is, the worse the voltage at the corresponding node gets.

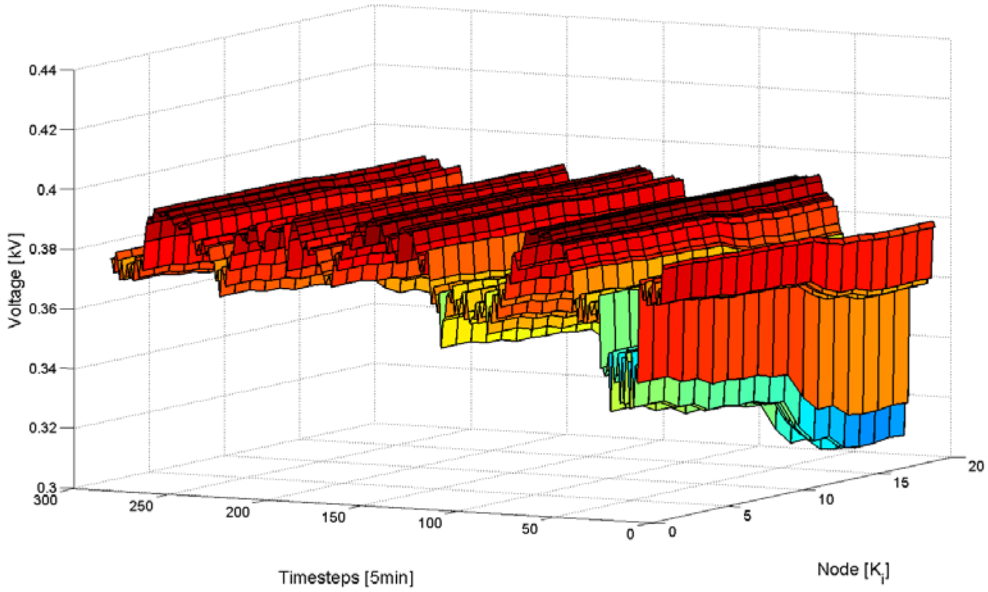


Figure 4: 3D plot of an example of a voltage profile of one radial depending on time and node for the winter scenario on the 5th of December 2014.

5.4 Conclusion simulation

The system impact analysis, taking into account a coincidence factor equal to one within a winter and a summer scenario, was done for scalability of the field trial. A main finding is that an extension of the PV installation within the system, obviously very much depending on the installed peak power, does not lead to significant troubles within the system. Meanwhile, a not adopted control algorithm for electric vehicles and heat pumps within the winter period causes both a significant voltage profile violation and equipment, such as transformer, overload. However, the g of one is a worst case scenario and results show that a change in the control algorithm that does not turn on all heat pumps at the same time step could lead to a better improvement of e.g. equipment utilisation. Still, having heat pumps in the whole area and not only at the test sites will cause overloading and significant voltage drops. According to handling the transformer loading, a transformer with an automatic tap changer could be a solution as well.

6. Conclusion

The trial demonstration in the WP2Horsens trial is considered as being very successful. Five of the six evaluation criteria originally defined for the trial have presently been addressed. The fact that the experiments have been performed with real users in their daily environment has resulted in many important findings both in relation to user behaviour and as input to improving the technical solutions.

On the technical setup, the trial has shown that it is possible to build a smart energy solution for a private home based on existing components that are not all designed for this purpose. However, this requires equipment built for an integration in a smart home setup in order to build in solutions that are cheap and easy to install. Furthermore, it has been demonstrated that a system based on existing standard components and internet communication can be used to shift energy consumption. The energy consumption can be moved in time to where the consumption is “best” according to both individual constraints (such as price) and global constrains (such as overall load of the grid). The demonstration has been performed on EV charging but methods and technology can be extended to consider a combination of EV charging and heat pump usage.

Simulation of the grid impact of scaling the solutions has been performed for one summer and one winter scenario. During the project planning, Insero did not initially succeed in engaging the local DSO in the project due to their lack of interest. However, the DSO has subsequently been very interested in the simulation results and has supplied the needed grid information. The results show that the grid can handle the increased load in most cases. In one case, controlling the EV charging resulted in charging the EV during a peak load from the heat pump. Scaling this resulted in overloading a transformer station. This shows that consumption optimisation should be performed across the different components that have a significant grid load in order to avoid creating new peak load situations.

A number of GEs have been evaluated and tested in the trial site setup. In conclusion, the overall impression of the GEs is positive, but the overall maturity has not yet reached a level suitable for a critical infrastructure. Further work is still needed to build completely reliable solutions.

From a human insights perspective, a dedicated user involvement program has been successfully implemented and a number of methods have been tested. The design of the user involvement activities has been planned across four focus areas, hence findings and learnings are with strong reference to these areas. Overall, it is confirmed that users are willing to enter the ‘green’ transition and have an interest in adapting to the smart technologies enabling this. In most cases, the users indicate a need for advice and guidelines to act around an intelligent system and adopt the new role as a ‘prosumer’. Furthermore, users express a “what’s in it for me” mentality, calling for a sense of achieving something and being rewarded in terms of either less money spent or experiencing more comfort in their everyday lives.

Being actively involved in own energy consumption and production is new for the users, and there is a need for advice and guidelines of best practices. The external control has been an interesting feature for many, however, intangible and difficult to understand in terms of gains. In relation to this, the availability of the energy visualisation platform has been vital and to some extent paving the way for accepting the external control, as users could see and follow energy production and consumption and additionally control individual comfort settings. Although being a tangible feature, many cases of information overload were seen.

7. References

N/A

8. List of Abbreviations

B2B	Business to Business
BMS	Building Management System
CAPEX	CAPital EXpenditure
CENELEC	European Committee for Electro technical Standardization
CEP	Complex Event Processing
COTS	Commercial off-the-shelf
CPMS	Charge Point Management System
CSA	Cloud Security Alliance
EMS	Decentralised energy management system
DER	Distributed Energy Resources
DMS	Distribution Management System
DMTF	Distributed Management Taskforce
DSE	Domain Specific Enabler
EAC	Exploitation Activities Coordinator
ERP	Enterprise Resource Planning
ESB	Electricity Supply Board
ESCO	Energy Service Companies
ESO	European Standardisation Organisations
ETP	European Technology Platform
ETSI	European Telecommunications Standards Institute
GE	Generic Enabler
HEMS	Home Energy Management System
HV	High Voltage
I2ND	Interfaces to the Network and Devices
ICT	Information and Communication Technology
IEC	International Electro-technical Commission
IoT	Internet of Things
KPI	Key Performance Indicator
LV	Low Voltage
M2M	Machine to Machine
MPLS	Multiprotocol Label Switching
MV	Medium Voltage
NIST	National Institute of Standards and Technology
O&M	Operations and Maintenance
OPEX	OPerational EXpenditure
PM	Project Manager
PMT	Project Management Team
PPP	Public Private Partnership
QEG	Quality Evaluation Group
S3C	Service Capacity; Capability; Connectivity
SCADA	Supervisory Control and Data Acquisition
SDH	Synchronous Digital Hierarchy
SDN	Software defined Networks
SDOs	Standards Development Organisations
SET	Strategic Energy Technology
SET	Strategic Energy Technology
SG-CG	Smart Grid Coordination Group
SGSG	Smart Grid Stakeholders Group
SME	Small & Medium Enterprise
SoA	State of the Art
SON	Self Organizing Network
SS	Secondary Substation
TL	Task Leader
TM	Technical Manager
VPP	Virtual Power Plant
WP	Work Package
WPL	Work Package Leader