Connecting know-how for a sustainable world

Sixteen Partners from nine EU countries contribute to the E-Hub Project

www.e-hub.org

How do we connect to a sustainable world?

'Energy-addicted' society

Every day, we are extracting an enormous amount of oil, gas and coal from the earth. We are consuming solar energy that was captured over millions of years by plants and converted into 'fossil fuels'. The **amount of fossil energy in our earth is huge, but limited.**
The limited fossil energy offer and the rising demand of our 'energy-addicted' society is not the problem of a country or a continent, but is **the problem of our planet**.

Thinking inside the box

To connect to a sustainable world new forms of collaboration need to be set up. Our thinking is still contained in a box; so far our society is not ready for new joint efforts between:

- countries;
- private and public oranisations;
- industries;
- customers and suppliers;

who have not yet worked together.

To boost the consumption of green energy

People are becoming **increasingly aware** that one day, fossil fuels will run out. In addition to the global development of large-scale decentralised production (biosteam power plants, wind turbines, etc.), Europe is focusing on **multiple medium-scale, decentralised plants with local distribution** in an effort to substantially boost the consumption of green energy. One problem associated with decentralised production is the **local burden** that is placed on the power grid. This capacity-related issue is both an economic as well as an environmental difficulty (limitation of green initiatives).

Mismatch

The problem with renewable sources is that the energy they supply is **"never there when you need it"**; photo-Voltaic panels deliver most of their electricity on sunny days around noon, while the highest demand for electricity (in dwellings) is in the evening; solar thermal panels supply heat in summertime, whereas the highest demand is in wintertime.

Consume when you can, not when you want

In the (nearby) future, the rules of demand and supply will apply to a greater extent to the energy market. Energy will be **more expensive in times of supply shortages and cheaper in times of abundant supply.** Energy tariffs will vary from hour to hour rather than the flat tariff in use today.
When a home-owner wants to save on his energy bill, he can sit and wait next to his energy price indicator for the price to go down. Or he may use a smart control mechanism to do this for him, ensuring the highest possible comfort at the lowest possible price.

The 'power' of the community

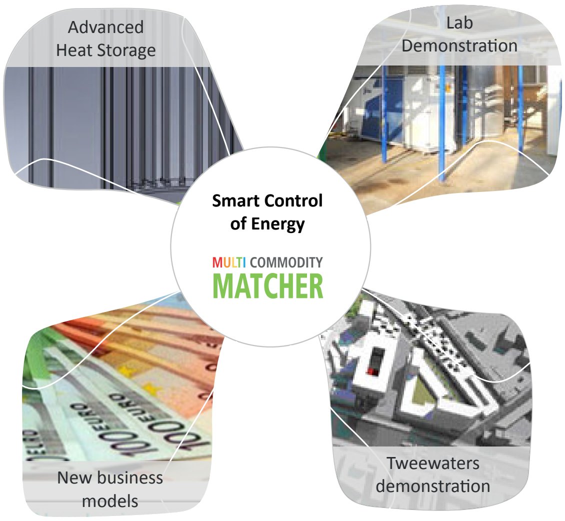
A sustainable society has, in addition to caring for the individual, an **important focus**

on the community. Energy and water consumption, waste processing, mobility, consumer goods can be treated differently at community level. A local offer of local goods and services can increase the comfort of life, decrease (family) expenses and raise awareness of an ecological way of life.
At community level the core of sustainability can be reached; an **economic, ecological and social balance.**

The E-Hub solution

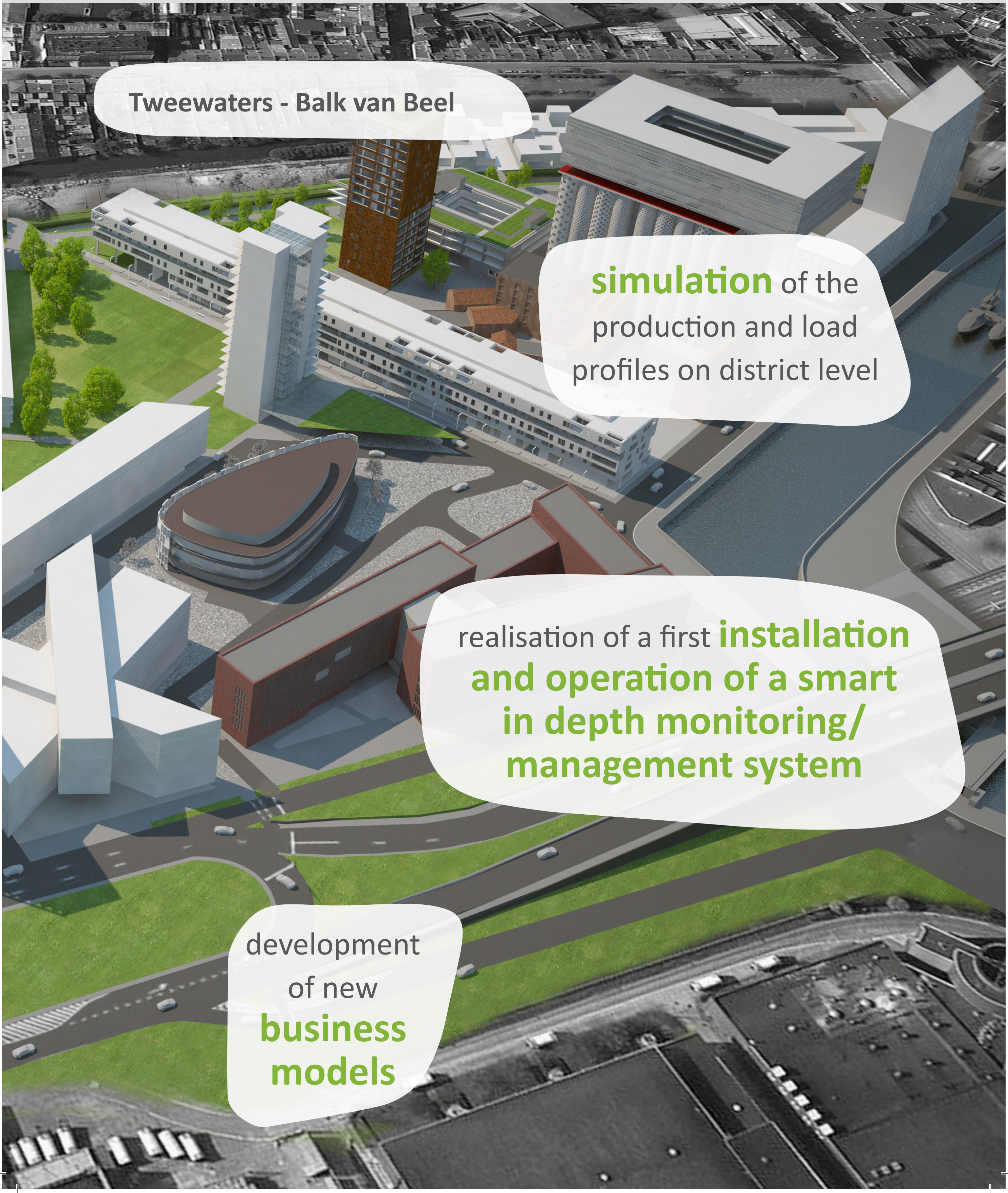
The Energy Hub is a collaborative €11.66 million European project, partly funded by the EU under the Seventh Framework Programme. The project aims **to demonstrate the full potential of renewable energy** by providing 100% on-site renewable energy within an "Energy Hub District" and **an integrated and smart system to match the district's multi-commodity energy supply and demand.**

- Work package 1 categorized **different district types** and examined their **different load profiles**.
- Work package 2 mapped the **equipment** that can be used in an E-Hub district and examined their **performance curves**.
- Work package 3 did research into **new ways of heat storage**.
- Work package 4 developed a **district model** simulating a quarter's production and load profiles in a business as usual and a smart (steering supply and demand) scenario.
- Work package 5 **synchronized a research project implementation with an actual commercial building site erection, equipment installation and operation with real tenants.** It realized a first **installation and operation** (demonstration) **of a smart in depth monitoring/management and data analysis system** in the first phase of the district Tweewaters, the Balk van Beel, equipped with an integrated building management system and multi-commodity gateways, smart heat and power meters, submetering and smart household appliances at dwelling level.
- Work package 6 mapped **different European energy collaboration schemes** and **developed new business models** taking into account the project's technical potential.



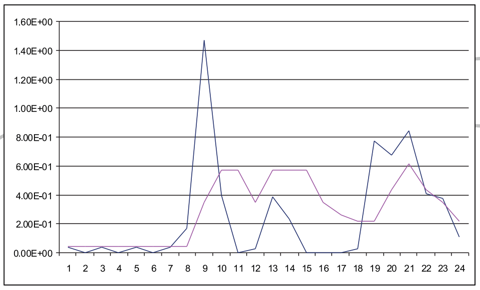
The E-Hub project in a nutshell

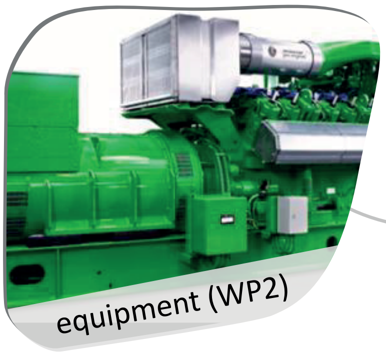
District Heating, Cooling & Power with
on-site renewable energy


Tweewaters - Balk van Beel
simulation of the production and load profiles on district level
realisation of a first installation and operation of a smart in depth monitoring/ management system
development of new business models

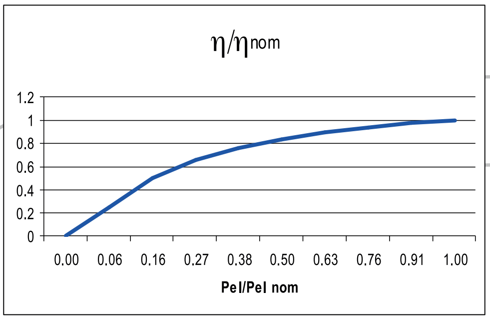
Work packages

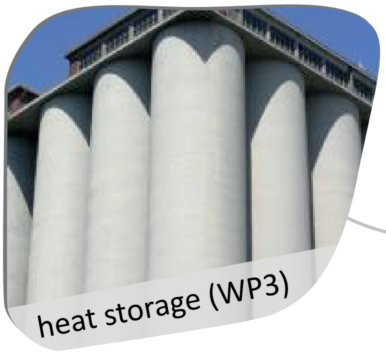
load profiles



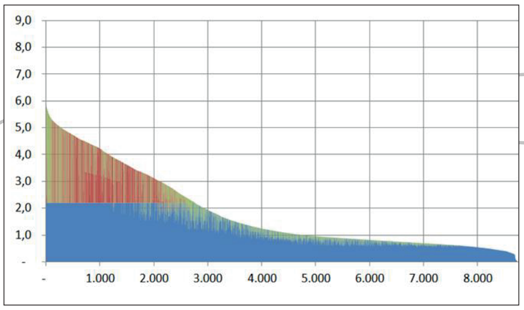


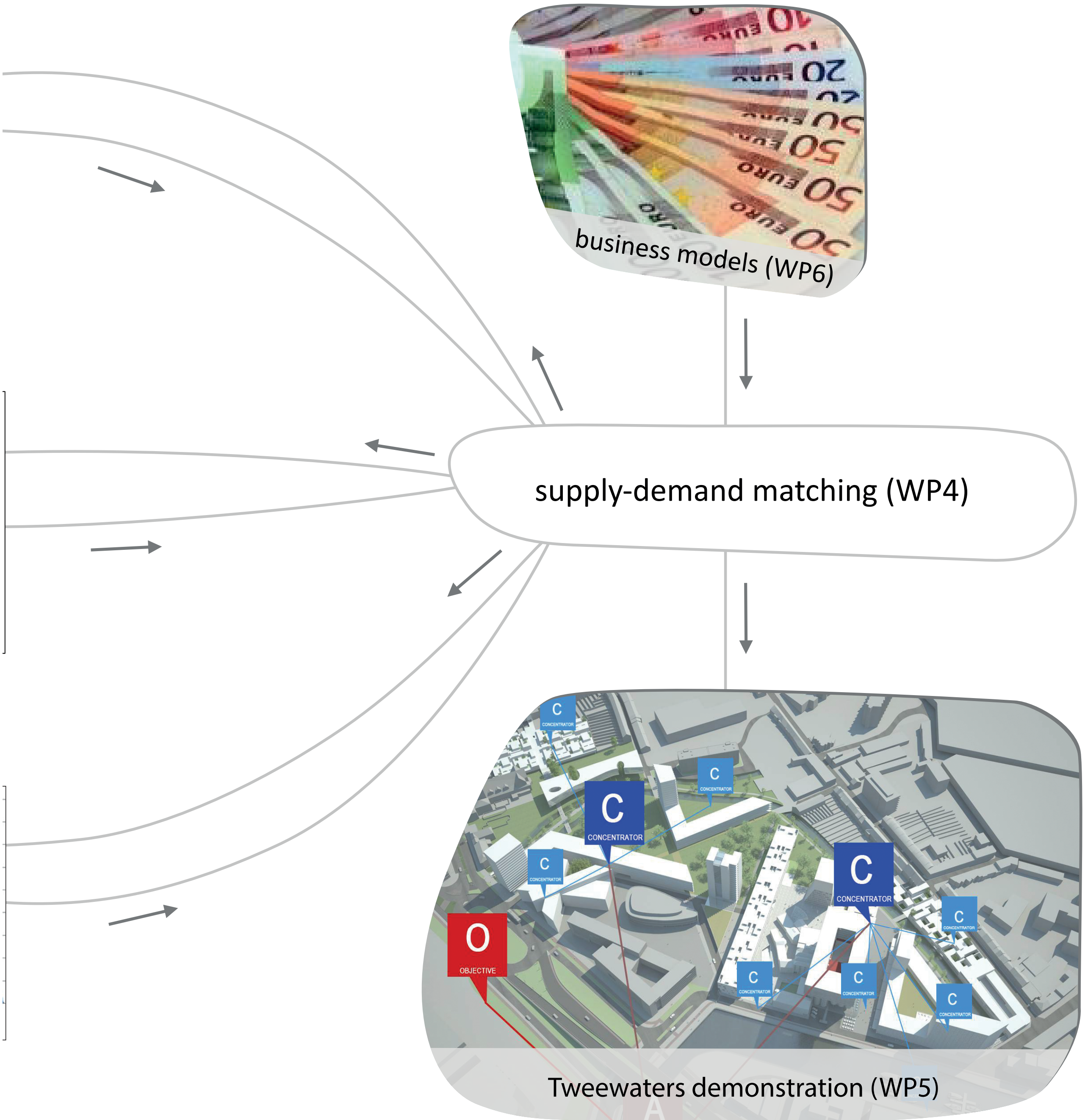
performance curves





models

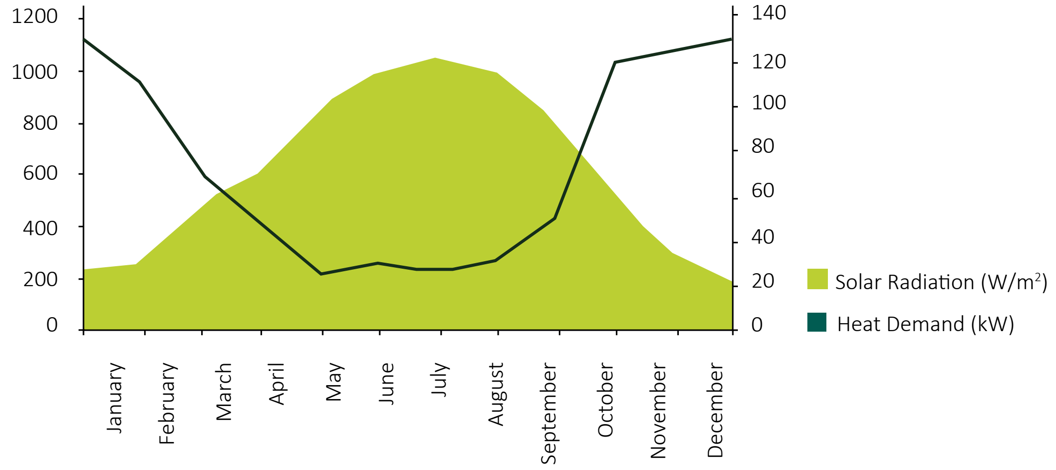



business models (WP6)
supply-demand matching (WP4)
C
CONCENTRATOR
C
CONCENTRATOR
O
OBJECTIVE
Tweewaters demonstration (WP5)

The E-Hub Challenge

The share of renewable energy needs to increase drastically

To achieve low energy or even energy neutral districts, the share of on-site renewable energy needs to increase drastically over present levels. However, a complicating factor is the fluctuating character of the energy supply from a wind turbine or a photovoltaic (PV) field. As a result, most of the time the supply from renewables will be either too large or too small to cover the momentary energy demand. The mismatch between supply and demand plays on hourly level but also on seasonal level and it plays for heat as well as electricity.



Mismatch between solar radiation and annual heat demand.

Solution

The mismatch may be solved by a combination of thermal storage and electrical storage, and intelligent control of equipment. The latter may entail postponing the operation of heat pumps or washing machines in times of electricity shortage, as long as the desired temperature range (for heating or cooling) is respected.

Key elements

Thermal storage and smart control are key elements of the E-Hub project which aims to maximise the amount of renewable energy at the district level. An important element is acceptance of such an advanced energy control system by the users. The development of new business models and service concepts that are attractive to both energy suppliers and end-users is crucial.

The E-Hub challenge is to control the integration of sustainable technologies, to recycle heat from summer to winter, to reduce waste and to work in balance with nature.

What is an E-Hub?

Energy capture, storage, control and delivery within districts

In this project we define an E-Hub as a system for capture, conversion, storage, distribution and control of energy, aiming to maximise the use of on-site renewable energy at the district level.

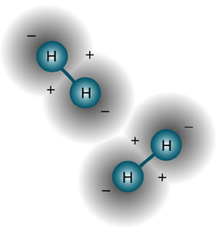
Capture of energy
- solar thermal collectors (sunlight → heat)
- road solar collectors (sunlight → heat)
- photovoltaic collectors (sunlight → electricity)
- wind turbines (wind energy → electricity)

Conversion of energy
- a boiler (fuel > heat)
- a sorption cooler (heat > cold)

Storage of thermal energy
- heat can be stored in water in insulated vessels
- thermal piles can be used to store heat underground
- energy can be stored in thermochemical materials

Distribution of energy
- electric grid
- gas grid
- heat network
- cold network

Management of energy
- information grid
- control of energy capture
- control of energy conversion
- control of energy storage
- control of energy delivery
- time shifting of energy load demand to suit energy supply availability
- matching supply and demand
- energy management system



Thermal Storage

Important technologies for matching supply and demand

Thermal energy storage is a critical asset for enabling a control system to match supply and demand of heat. Renewable heat can be stored underground via thermoactive foundations or boreholes. Naturally occurring energy can be collected in summer, stored underground and then recycled in winter using seasonal thermal energy storage. Heat can also be stored in distributed heat storage or in thermochemical materials (TCMs) for later use in periods of high demand.

Thermoactive foundations or boreholes

Ground source energy can be efficient and economical for providing heating and cooling to buildings, especially where the heating load in winter is similar to the cooling load in summer. Heat exchange with the ground can be via boreholes or via thermoactive foundations.

The E-Hub project investigated the use of thermally enhanced materials for energy piles and found that thermally enhanced concrete can increase the base load heat transfer performance by up to 25% and the peak load performance by up to 30%.

Distributed heat storage

The distributed heat storage consists of a series of small scale hot water stores, distributed in individual dwellings within a district. The use of many small stores can be controlled by the E-Hub to create a distributed heat storage system that has the benefit of storing heat close to where it is needed. This concept was developed and tested in the laboratory. The results show that active control of heat stores in district heating grids creates more flexibility in matching heat supply and demand. This can double the operational profit for combined heat and power systems (CHP) in a district heating network.

Thermochemical heat storage

Thermochemical heat storage (TCS) uses the heat of reaction of a material to store and release heat. TCS allows long term heat storage with limited loss of energy, and is more compact than hot water storage. TCS can be implemented as distributed heat storage or in a central heat storage facility. The performances of two different TCS models, a closed evacuated model and an open atmospheric model, were established by simulation and by ‘proof of concept’ laboratory tests. The results indicate that both models are suitable for long term heat storage and can provide heat at the desired temperature of 60°C. The results also show that further developments of the TCS models are required to improve overall thermal storage efficiency, auxiliary energy use and the heat storage materials. The TCS simulation model is a useful tool for the future designs of TCS systems for various heat storage applications.

Open sorption storage system

Road Solar Collector

Black Surfaces Absorb Heat

Black roads can be used to collect solar heat during the summer. The temperature on a black road in full sunshine will often be 15°C higher than the air temperature in the shade, at which time the heat radiated up from the road will be as much as the heat being absorbed down from the sun. This temperature can be collected by water circulating through an array of pipes embedded in the surface of the road.

Seasonal Thermal Energy Storage

Heat is in plentiful supply during the summer – but is urgently demanded in winter. This time gap calls for Seasonal Thermal Energy Storage. The heat from the black roads can be transferred down to a thermal bank in the ground. This can be achieved using thermoactive foundations or boreholes and will increase the natural temperature of the ground (around 10°C at a depth below six metres in northern Europe) up to over 30°C.

Coefficient of Performance

The advantage of a thermal bank is that once heat is absorbed in the ground it will only release very slowly. The thermal bank can maintain its warmth until the winter, during when the warmth can be readily extracted by a suitably adapted ground source heat pump (GSHP). A heat pump has half as much work to do if it starts with warm ground so the Coefficient of Performance can be twice the level expected of an “unassisted GSHP”.

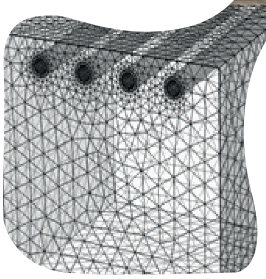
Interseasonal Heat Transfer

For a building with a cooling demand during the summer and an equivalent heating demand in winter, balance can be achieved by using the ground itself for natural thermal energy storage.

Optimisation of Road Solar Collector

Optimisations aim to increase the temperature of the water at the outlet of the collector. The higher the temperature, the higher the efficiency of the total energy system.
Research focussed on minimising the depth of the pipes in the road without compromising the structural stability of the road.
A novel element studied was the application of an epoxy resin layer on top of the road. The effect was that a redistribution of the load occurs, improving the structural behaviour of the road and prolonging its lifespan.

Concrete solar collector



Finite element model of pipes in asphalt

Structural tests carried out at Mostostal

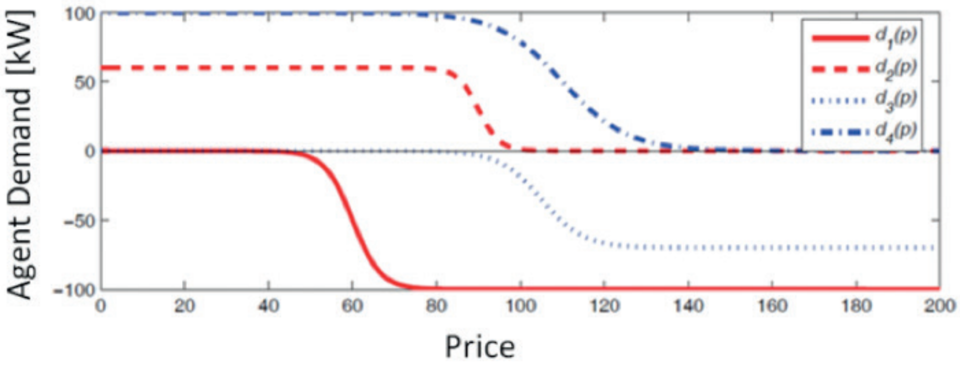
Smart Energy Control

Multi Commodity Matcher

In the E-Hub project, a smart energy control system is being developed to match supply and demand of electricity and heat simultaneously at district level.

Agent based technology

Agent based technology can be used to match supply and demand of energy. Let's take the case of electricity. All consumers and producers of electricity are represented by an agent, connected to a matching auctioneer agent.



Bid curves offered by the agents to the auctioneer agent

Each agent offers a bid to the auctioneer in the form of a bid curve (see figure). The bid curve shows how much electricity a device is willing to supply or consume at different prices. Producers of electricity are interested in supplying electricity at high prices. This is reflected in the red curve below. Consumers on the other hand are interested in consuming electricity when the price is lower, reflected by the blue line.

The auctioneer aggregates ('sums') all bids to a price at which electricity demand and supply are balanced. Each device then receives or produces an amount of electricity that corresponds to the amount of electricity in its bid curve at this price.

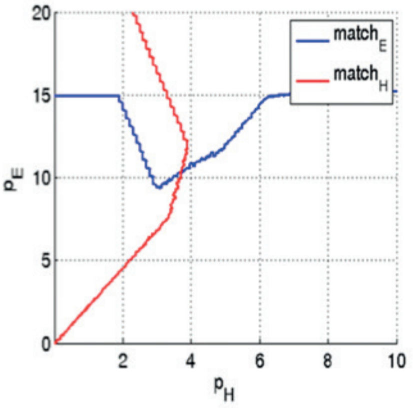
When sufficient agents are in the network, with each trying to optimise the interests of its device, the result is that on a macro level, electricity supply and demand are matched at the lowest (dynamic) price.
The mechanism offers the possibility, through an 'objective agent' or 'business agent' to represent an external factor to affect the price on the energy market, satisfying the interests of a particular stakeholder.

Multi commodity agents

The E-Hub project uses agent based technology like Powermatcher® software and other smart grid technologies. These incorporate bi-directional information and energy grids. The Multi Commodity Matcher developed in this project is an extension of the Powermatcher® concept (which is for electrical power only) to electricity and heat, inheriting its advantages of scalability and autonomy.

Defining two 2-dimensional bid surfaces

For each multi-commodity agent, the bid surfaces represent the willingness to consume or produce electricity and heat at a range of electricity and heat prices. As an illustration, the figure at the right shows the bid surfaces of a heat pump. The x-axis shows the heat price pH , the y-axis the electricity price pE. The colours represent the amount of power the heat pump is willing to produce as a function of the prices of heat and electricity.



Energy control system implementation

The control system was implemented and validated for both a ‘hardware-in-the-loop simulation’ as well as in a real life setup (Tweewaters).
While the first, a district heating network including 100 hot water buffer vessels of which 4 actually present and 96 simulated, focussed on the dynamics of thermal systems, the latter, 120 households, is seen as proof of concept for all integration aspects of the control technology in a real operating environment.

Hardware setup for thermal dynamics

Business models for E-Hub districts

Must be understood by users as well as suppliers

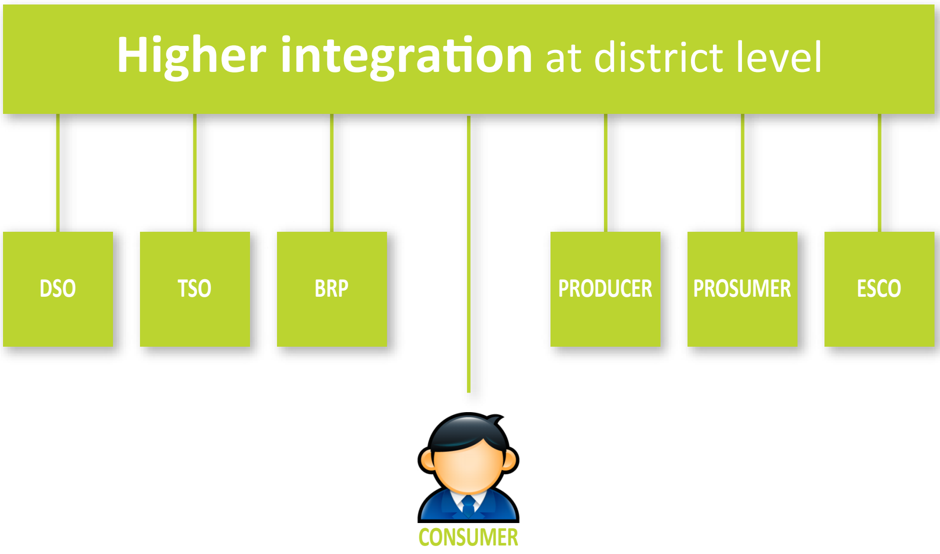
The project developed a collection of new potential business and service concepts for different stakeholders within E-Hub districts. The businesss models proposed are all based on the flexibility of the energy consumed or produced within the district.

The E-Hub project has focused on the transition towards smart energy districts, which aim to maximize the integration of renewable (intermittent) energy within the district by optimizing the energy flows. In these kind of districts, flexibility and smart energy management are key elements. All types of flexibility available within in a district have been considered:

- flexible local generation (e.g. a CHP can be modulated to decrease/increase its output);
- flexible loads (e.g. a washing machine can delay its start);
- thermal storage (e.g. a heat pump with thermal energy storage can decouple the hot water demand from the electric power demand);
- electrical storage (e.g. a battery offers flexibility, both while charging, as while discharging).

The flexibility can be deployed for different aims and to the benefit of several stakeholders:

- the DSO (Distribution System Operator) is responsible for the operation of the grid, and can use the flexibility to manage the local network;
- The flexibility available within the district can also be used as an extra balancing option for the TSO (Transmission System Operator) to restore the balance between supply and demand at system level, or;
- for a BRP (Balance Responsible Party) to restore the balance within its own portfolio (day-ahead and intraday);
- moreover, all stakeholders whose business consists of buying and selling energy can use this flexibility to maximizing their margin between purchases and sales of energy;
- if consumers would have access to more dynamic energy tariffs, they would be incentivized to adapt their energy behavior accordingly in order to lower their energy bill;
- also to promote the integration of more local renewable generation, both producers and prosumers, seeking to maximize the income from their local generation, and;
- ESCOs (Energy Service Company) acting on behalf of consumers, should be given the proper incentives and means to sell the (surplus) generation from local sources;
- finally, society as a whole, will benefit from optimizing the energy flows within a district, as this will allow a higher integration of renewable energy.



End user involvement

Consumers will be actively involved in energy management and may also be producers of renewable energy. The consumer acceptance is a key success factor for the diffusion of new energy management solutions. The user acceptance and the adoption of new energy technologies is dependent on how they fit into daily household practices. Consumers are afraid of losing control over the use of services in the household. For user awareness and acceptability it is important that users find the system useful, easy to use and pleasant to use. To enhance the user acceptability it is important that the new technological solutions are developed from the end user perspective.

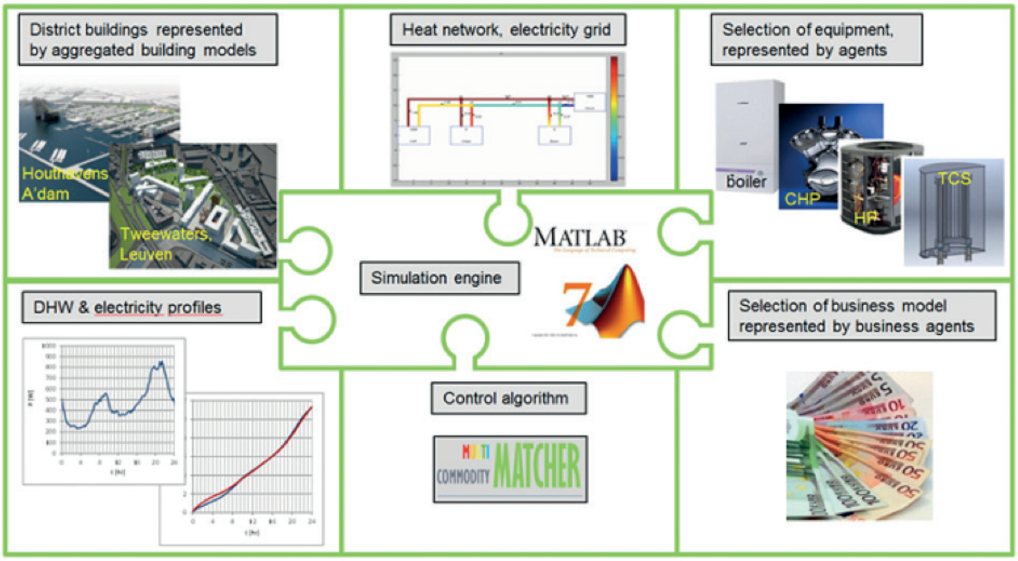
Simulation Platform

Matching supply and demand

A simulation platform has been produced using the programming language MATLAB®. The tool will allow municipalities, DSOs (Distribution System Operators) and other parties to assess the possibilities (and limits) of a smart energy system in achieving energy efficient or energy neutral districts.

The main elements in the simulation platform are:

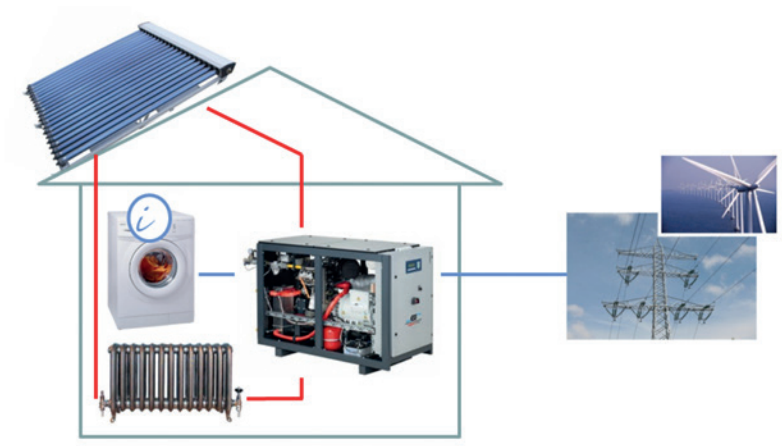
- Simplified dynamic models characterizing the buildings in a district (dwellings, offices etc.), being the main consumers of heat for space heating.
- Characteristics of different equipment for generating and storing heat, cold and electricity.
- A heating network and electricity grid connecting consumers and producers of energy.
- Business models intended to maximise the interests of a particular stakeholder. This may be the end user interested in a low energy bill, a DSO (Distribution System Operator) interested in peak shaving or in reducing imbalance in the grid or society as a whole interested in CO2 mitigation.
- Smart control of heat, cold and electricity by the Multi Commodity Matcher (MCM).



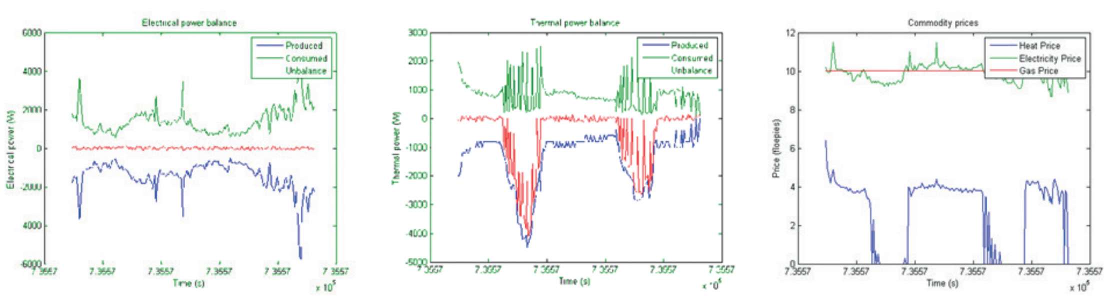
Main elements in the simulation platform used to assess new types of district energy systems

District Energy Management System

The simulation platform is demonstrated below with a simple configuration consisting of a house with a smart whitegood appliance, but with an otherwise ‘uncontrollable’ energy demand for space heating, electricity and domestic hot water. The house has a solar thermal collector on its roof and it is connected to the electricity grid, which is fed by an ‘uncontrollable’ producer of renewable energy (wind farm). The configuration and the results of the simulation are shown in the pictures below.



Simple configuration consisting of a house connected to the grid.



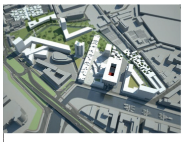
Electricity balance (left), thermal balance (middle), prices (right) over two days.

The left figure shows how supply and demand of electricity are very nearly balanced (the red line slightly varies around zero). The middle figure shows that a thermal balance cannot be reached during the day because the heat supplied by the solar collector is too large to be consumed by the house, even when the MCM tries to increase consumption by lowering the price of heat (right figure) to practically zero. A thermal storage unit (not implemented in this example) could have stored the excess heat for use later that day.

Assessing Other Districts

Using the MATLAB® simulation platform to assess districts

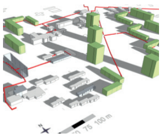
The simulation platform can be considered as a prototype of a user friendly tool to assess new types of energy systems for existing and new build districts. Within the E-hub project, the simulation platform has been applied to a number of districts across Europe. The figure below summarizes the innovative energy concepts of these different districts. Common features are: local generation of renewable energy, low energy (or even climate neutral) buildings and energy management to match supply and demand.



Tweewaters (BE)
- Supply: CHP + boilers, heat storage + DH
- Demand: low energy buildings
- Flexibility: CHP + smart appliances

Houthaven (NL)
- Supply: HPs, PV installations, waste heat (from incineration plant), ground source cold storage,…+ DHC
- Demand: climate neutral / low energy buildings
- Flexibility: battery system

Bergamo (IT)
- Existing energy concept: CHP + boilers, heat storage + DH – shutdown of CHP
- Energy vision: Different alternatives for heat generation (centralized boiler(s), boilers at building level, at individual house level, biomass,…) and electricity generation (PV installations,...)



Freiburg (GE)
- Supply: CHP + boilers, heat storage + DH
- Demand: existing buildings - refurbishment
- Flexibility: CHP + smart appliances

Dalian (CN)
- Supply: CHP + peak boiler+ sewage source / seawater source HP + solar energy collectors + DH
- Demand: residential buildings
- Flexibility: CHP + smart appliances

For each of the districts an environmental impact assessment and a cost-benefit analysis of the business model has been done. Three scenarios are considered:

1. Reference scenario: the energy demand of the district is met with conventional sources
2. Green scenario: local (renewable) energy generation is introduced within the district
3. Smart scenario: the flexibility within the district is used to optimize the energy flows

The MCM control algorithm was tested in the case studies. Within the smart scenario a specific business case for the flexibility available within the district is applied. Within the Tweewaters, Dalian, Freiburg and Bergamo districts, the flexibility is used to optimize the energy flows within the district based on external market signals (day-ahead electrticity market prices), whereas within the Houthaven case, the flexibility is used to maximize the local consumption of locally generated electricity.
See further details of the Bergamo district simulation at www.e-hub.org/bergamo.html

The simulation tool calculated a number of kpi's (key performance indicators) on energy demand (electricity and heat) and costs. The simulations showed the potential and the limits of applying a smart control system.

TPG Laboratory Testing

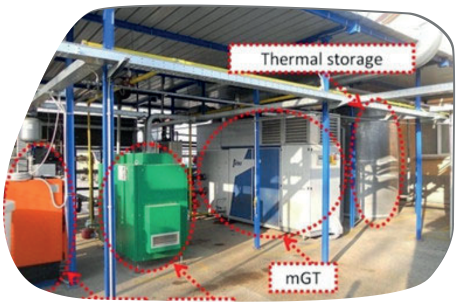
Emulating a mini district heating system

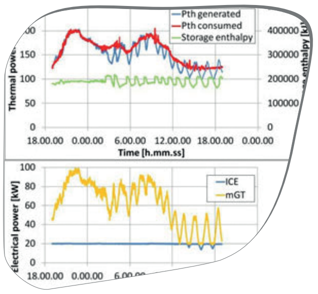
The smart control algorithm has been demonstrated at the laboratory of the Thermochemical Power Group (TPG) of the University of Genoa. The lab, with different pieces of heat and electricity generating equipment, including thermal storage, emulates a mini district heating system. The smart control algorithm 'Multi Commodity Matcher' was implemented and compared against the ECOMP software from TPG.

A number of heat and electricity generating systems have been individually tested:

- 20 kWe CHP based on an Internal Combustion Engine
- 2 kWe CHP based on a Stirling engine
- 100 kWe Micro turbine
- 100 kWth Absorption cooler
- Hybrid system composed of 80 kW microturbine and 370 kW emulated Solid Oxide Fuel Cell

Presently, most pieces of equipment are thermally and electrically connected. Preliminary tests were carried out on pieces of equipment in combination with thermal storage. Oscillations were found to occur in thermal outputs that may be attributed to sudden changes in the measured water temperatures inside the storage vessel leading to misinformation on the SoC (State of Charge). This was investigated by TPG and VITO.





Test rig at the TPG lab and oscillations in thermal and electrical power output

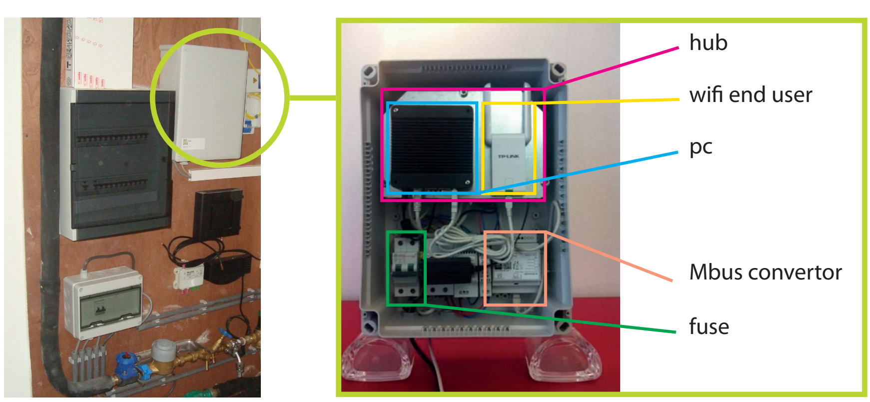
Tweewaters full scale demonstration

Emulating business cases in Leuven, Belgium

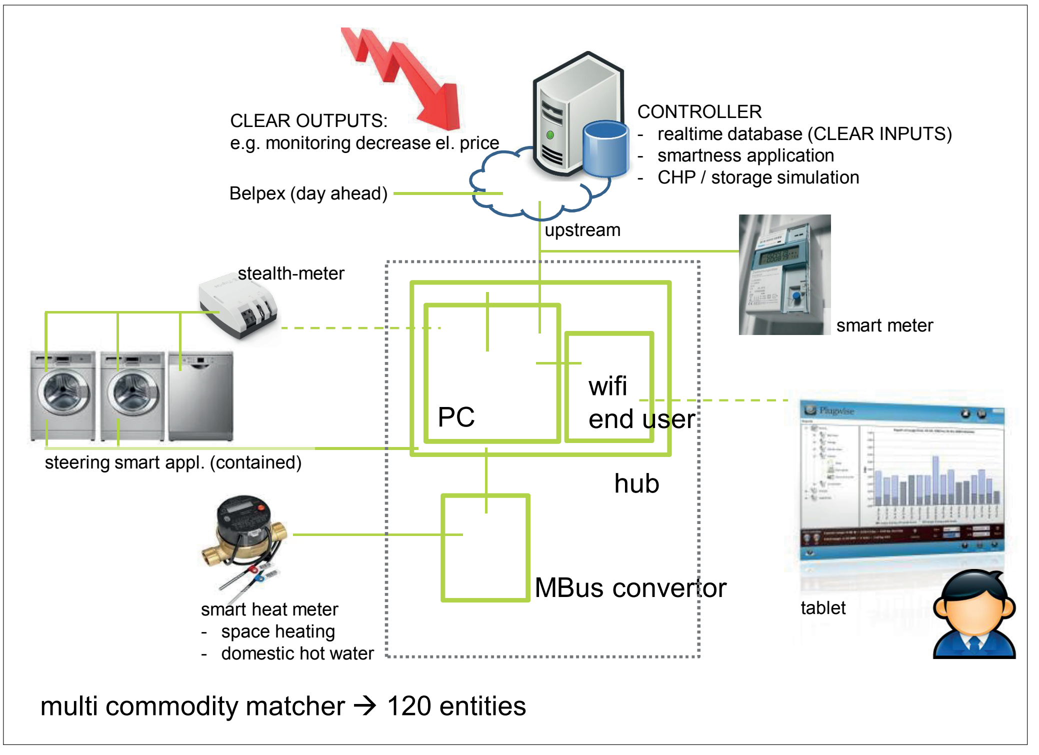
The Energy Hub system was demonstrated in the district of Tweewaters in Leuven, Belgium. The heart of the energy supply is a biomass fired cogeneration unit, which is expected to provide 80% of renewable heat and 100% of renewable electricity to the district. A new type of business model was applied, offering energy related and other services, called "MyJames". Construction of Balk van Beel with its 106 dwellings and nine commercial units was completed in December 2013.

Implementation of smart energy control system

A MultiCommodity Gateway for the agent based control system was installed in each unit of the Balk van Beel. This control box collects various data flows and forwards them to a (remote) central server that manages the interpretation and control of the energy flows. In 2014 the energy behaviour of Balk van Beel was monitored live, thereby identifying technical and financial output for the Tweewaters business case.



MultiCommodity Gateway



International recognition of the Balk van Beel

After being awarded the BREEAM 'Outstanding' certificate, the building received the 2013 BRE award. The quarter of Tweewaters and its first phase, the Balk van Beel, received a nomination for the Global Cleantech Cluster Association (GCCA) Later Stage Award and the European Corporate Social Responsibility Award (CSR). Both the building and the quarter are also being used as a model project by Leuven Climate Neutral 2030 and the Flanders in Action (VIA) programme. Due to increasing interest in the project from the outside world, Ertzberg is able to widen the scope of its dissemination activities.

End user involvement

The main challenge of the demonstration project was synchronizing a research project with an actual construction and operation of a commercial building. Interviews and group sessions with the shop owners and tenants of the 'Balk van Beel' building were part of the E-Hub project. They showed that users may have limited knowledge of (all aspects of) sustainability, but they are generally eager to engage in a process of behavioral change. They realize that it is the community rather than the individual that makes the difference.

Project partners

Acciona (Spain)
D'Appolonia (Italy)
ECN (Netherlands)
EDF (France)
ERTZBERG (Belgium)
Finlombarda (Italy)
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