



New  $\mu$ -CHP network technologies  
for energy efficient and sustainable districts

## GROUP WORK

# FC-DISTRICT: New $\mu$ -CHP network technologies for energy efficient and sustainable districts

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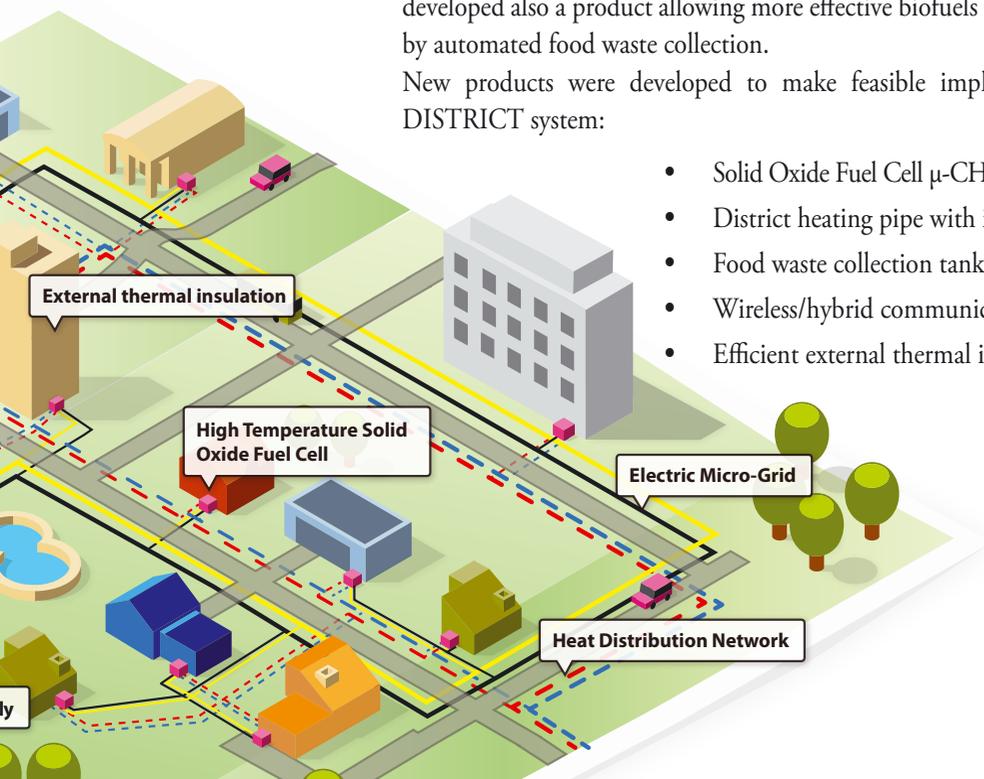
# FC-DISTRICT system

## – energy supply solution for districts

FC-DISTRICT system optimizes and implements an innovative energy production and distribution concept for sustainable and energy efficient districts. By exploiting decentralized co-generation coupled with optimized building and district heat storage and distribution network significant reduction in annual primary energy consumption at district level is achieved. The system introduces a new paradigm in energy efficiency by integrating newly developed systems, products and methodologies specifically intended for use at district level. The main principle of FC-DISTRICT system is dynamic heat exchange between the building(s), the distribution system and the customer. Four building types of different energy demand profiles have been considered: block of flats, single family houses, office buildings and hotels. In this concept buildings are fitted with  $\mu$ -CHP Solid Oxide Fuel Cells (SOFCs), for energy production collaborating with improved thermal storage and insulation building systems. Piping and district heating networks with or without a heat buffer are optimized and new suitable business and service models are created to suit considered cases. Advanced insulation materials are implemented for improvement of building and pipe thermal responses. All this actions lead to achieve energy balance at district level. Moreover, the new SOFC units are tested to be fed with mixture of natural gas and biogas. FC-DISTRICT developed also a product allowing more effective biofuels production triggered by automated food waste collection.

New products were developed to make feasible implementation of FC-DISTRICT system:

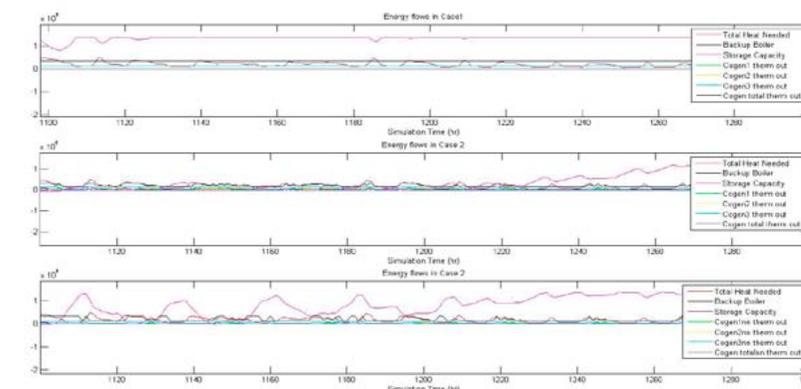
- Solid Oxide Fuel Cell  $\mu$ -CHP unit (SOFC Unit),
- District heating pipe with improved insulation,
- Food waste collection tank,
- Wireless/hybrid communication network,
- Efficient external thermal insulation system.



# DEPOSIT: A simulation tool for district thermal needs based on distributed cogeneration

The DEPOSIT software has been purposely developed and utilized in the context of FC-DISTRICT project to help the design and evaluation of FC-DISTRICT systems. The tool performs an hourly based numerical simulation of a predefined district accounting for the thermal demands, the piping and the heat and power generation units. It calculates the total district heat demand, including piping heat losses and pressure losses (pumping power). Various operating scenarios can be simulated for  $\mu$ -CHP units, depending on the overall target: primary energy minimization, cost optimization, maximum CHP operating hours. Both SOFC and Stirling engines have been considered as CHP units. Limitations and specifications of each type of units, such as thermal and electrical efficiency curves, start-up, gas- and electrical-consumption and modulation times, are taken into account by the simulation algorithm. Simulation results produce an hourly analysis of the district heat management via calculated energy flows from each system (CHP, buffer tanks, back-up boilers). DEPOSIT also provides the expected energy savings, as compared to the reference case, of decentralized gas boilers or  $\mu$ -CHPs Stirling units, as well as the foreseen total fuel consumption. Moreover, in order to perform system operation optimization for the next few hours, specialized neural networks have been adopted to provide estimations of either electricity prices, primary energy factor or total heat demand.

The thermal energy conversion devices (gas boilers, and CHP units/back-up gas boilers) are considered for two cases: a “Reference” case (centralized system with a gas boiler) and a “ $\mu$ -CHP” system (decentralized system with  $\mu$ -CHP units). In order to acquire realistic energy (heat) balance data, a detailed energy demand and supply simulation at district level must be performed on an hourly basis. Two district types have been considered: Residential (including Single Family Houses - SFHs) and Financial Center (including office buildings and hotels). Each district feature a different heat demand profile: the residential load fluctuates intensively, while the hotels and offices of the financial district exhibit a smoother heat load profile, but with higher total thermal energy demand.



Coverage of the heat demand by the various cogeneration units and the backup boiler, as well as storage tank charge status in all 3 operating scenarios of the SOFC units: Case 1 – full power, Case 2 – modulating heat following heat demand, Case 3 with forecasting - modulating heat output following heat demand with 7-hour optimization.

# Solid Oxide Fuel Cell μ-CHP unit



SOFC Unit

The FC-DISTRICT consortium has developed an SOFC based μ-CHP unit for supplying electricity and heat in domestic environment. The unit operates with natural gas and the electricity is generated by the integrated SOFC stack module. The maximum electrical output is 1 kW and the corresponding thermal output is 2.75 kW. The specifications of the FC-DISTRICT system follow the latest advances in the field of SOFCs as well as market requirements related to the supply of heat and electricity in domestic and small-district level. Additionally, the overall design is in compliance with European directives for safe and environmentally friendly operation.

For μ-CHP systems (< 10 kWel), a mass market is emerging from the replacement of gas heating boilers. The development of SOFC based μ-CHP systems in European level has entered since few years a phase of field-testing. The outcome of this phase is anticipated for drawing conclusions as to whether this technology is mature enough for early markets. Of course, further operating experiences and higher production volumes are required before these products can be launched in mass-markets with higher techno-economical risks. In this context, the development and field-testing of the FC-DISTRICT unit is the outcome of collaborative efforts from a group of six partners that were coordinated by the German Technical University of Freiberg (TUBAF). The FC-DISTRICT μ-CHP prototypes were integrated by the company EBZ GmbH. The SOFC stack was provided by the company sunfire (module ISM/Mk200) that uses advanced, planar (active area: 127,8 cm<sup>2</sup>), electrolyte supported cells (ESC) to assemble stacks in the 1 kW range. The integration of the ISM module in the FC-DISTRICT μ-CHP unit offers low degradation rates and robustness during cycling (start-stop) operation. For the needs of the project, sunfire adapted the ISM module in order to achieve optimal integration with the interfacing components and high total efficiency.

The stack uses synthetic gas (H<sub>2</sub>/CO mixtures) that is generated from the primary natural gas feed using a catalytic fuel processor (CPOX reformer). The CPOX reformer is attached directly to the inlet of the stack anode and it was developed with the objective of long-term durability for operation with different qualities of natural gas (e.g. G20, G21, G231) and also with biogas. For this purpose, partners involved in the development of the reformer performed extensive experimental and numerical studies regarding the selection of appropriate catalyst and component geometry.

The electrical power generated from the stack is extracted via the power electronics section that was particularly developed by IK4-IKERLAN for the needs of the FC-DISTRICT unit. The core of the power electronics is the inverter that controls the stack electrical output for energy delivery to the grid under proper electrical conditions, maintaining a safe and efficient grid connection. In contrast to commercially available inverters (mainly

for photovoltaic systems) this inverter is suitable for the voltage/current characteristics of the SOFC stacks, especially regarding DC voltage range and start-up procedures. Another important feature is the island working mode that allows the μ-CHP unit to keep running at reduced power in case of grid blackouts, and to reconnect again to the grid whenever it is available.

Due to the high operating temperature of the SOFC stack (750°C), high temperature waste heat is generated in the μ-CHP unit. The generated heat is managed with a system of two plate-type heat exchangers, and it is finally delivered to the domestic heating/sanitary water network via the heat recovery unit. All components involved in the heat management network were especially developed for the needs of the project. In order to achieve reasonable cell voltages and to protect the stack anode from oxidation, there is a certain minimum partial pressure of hydrogen required. This means that some concentration of combustible species (H<sub>2</sub> and CO) is present in the anode exhaust gas and can actually vary, depending on the operating conditions. In order to control the emissions of the μ-CHP unit and to comply with safety and environmental regulations, the anode exhaust gas is burnt in a specially developed burner (Offgas burner) before being released to the environment. The heat gained by this process is retained by the heat management network in order to make more efficient use of fuel within the unit. The design of the burner fulfils all safety aspects required for the operation of the μ-CHP unit. The CO emissions during normal operation of the unit comply with the DIN EN 50465 (CO < 1000 vol. -ppm @ 0% O<sub>2</sub>) with practically “zero” NO<sub>x</sub> emissions.

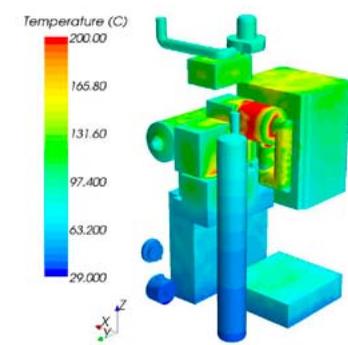
The FC-DISTRICT μ-CHP unit has an innovative design with its fuel processing and low-cost afterburner, and in combination with the sunfire SOFC stack technology, it makes a competitive μ-CHP prototype. The company sunfire is already using the results of the project in order to manufacture stacks that have higher electrical power and improved features for integration into CHP applications. The developed inverter is going to be used in future projects that will require similar components for power adaption, not only in the fuel cell sector but also in other expanding areas that they are active, like the electrical storage. The TUBAF has already filed a patent application for the developed Offgas burner and it will be used for further projects related to the combustion of gaseous fuel mixtures. The experiences from integration and testing of the unit are of great importance for the company EBZ that is active in the field of integrating SOFC based systems, not only for domestic use but for other types of applications, like APUs (Auxiliary Power Units) for large vehicles, e.g. trains and trucks.



Developed anode  
Offgas burner

*EBZ developed new control and safety strategies for operating the SOFC μCHP. EBZ also used new hardware components for safety and control functions (for example PLC from B&R). For using this in our systems we developed new software modules. Several parts of these new developed modules are used in our products (test rigs and demonstrators) since 2013. They make it possible for EBZ to produce more flexible products for our customers.*

- Rene Littwin



Surface temperature

# District heating pipe with improved insulation

The new hybrid insulated district heating pipes were developed to meet the idea of reducing the heat losses in district heating distribution networks. The pipes have an additional insulation layer that ensures the improved insulation capability. The new pipe concept has been verified by use of laboratory experiments, calculations and field measurements. Short and long term characteristics have been considered. The hybrid insulated pipe with the twin pipe assembly meets mechanical demands and improves the insulation capability. In comparison with the standard solution, the test series verification showed that vacuum insulation panels have slightly worsen mechanical parameters of the pipes somewhat. Although the key parameters are still in the acceptable range according to the EN 253 standard. The pipes are suitable for low temperature district heating networks and also when the energy costs are high. The design of new district heating pipe networks does not differ from designing conventional pre-insulated pipes system. To meet the requirements of adhesion between the service pipe and the casing pipe it has been chosen to install the panel in a twin pipe assembly, where the flow pipe, with the highest temperature, is surrounded with high efficient insulation vacuum panels. This significant reduction of heat losses was achieved by introducing advanced high performance insulation materials. A portion of the traditional insulation material (polyurethane) in a pre-insulated district heating pipe was replaced with advanced high efficient vacuum insulation panels or nanoporous blankets



Cross-section of hybrid insulated district heating pipe

Hybrid insulated district heating pipes in excavation



with low thermal conductivity. The thermal conductivity of the panel is 0.008-0.011 W/mK (depending on dimensions) and the blanket is around 0.017 W/mK. The insulation capability of the district heating pipes with twin pipe assembly has been improved. The losses from the flow pipe were reduced by about 50%, when vacuum insulation panels were introduced around the flow pipe in the twin pipe assembly for services pipe dimensions less than DN80. The total losses from the flow and return pipes were reduced by about 30%.

Hybrid insulated district heating pipes delivered to construction site



*So far, the hybrid insulated pipes have been ordered to two commercial projects. One of the orders is already produced and delivered, the other one will be produced and delivered in July. These first orders were relatively small but can be followed by larger orders.*

*- Göran Johansson*



# Efficient external thermal insulation system

An External Thermal Insulation Composite System (abbr. ETICS) is by definition a system for thermal insulation of external walls of buildings. ETICS as part of the shell of the building has to fulfill requirements such as:

- Thermal insulation,
- Fire protection,
- Sound insulation,
- Stability,
- Protection against condensation,
- Protection against driving rain,
- Durability,
- Optical function.

ETICS have to be adapted to local climatic conditions and essentially they must offer:

- Low thermal conductivity,
- Water-tightness,
- Long shelf life,
- Easy and safe installation,
- Impact resistance (wind loads and seismic resistance).

In order to meet the above requirements an innovative ETICS combining VIPs (Vacuum Insulation Panels) with Dry Wall Construction techniques has been developed for the FC-DISTRICT needs.

The main technical challenge was the development of a system that is easy to apply, robust (difficult to puncture the VIPs) and of improved overall thermal performance (minimization of thermal bridges as a result of panel design and installation methodology).

The new system is based on pre-formed “mineral wool-VIP-mineral wool” sandwich panels with special openings for dowels. Zero thermal bridge



Panel cross-section

VIP Barrier envelope

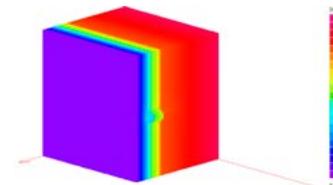


VIP Core material



hammer dowels with plastic-steel nail were developed. They are used for the panel installation, together with purposely modified glue/adhesive. Adhesive and basecoat mortar for application without reinforcing mesh have also been developed. Computational studies supported the selection of the dowel position in the panel.

Field tests showed that, in comparison to conventional insulation materials, the new ETICS reduce the thermal transmittance of the lightweight wall while retaining a low overall thickness. Up-to-date results have shown that the new ETICS is water tight and is easy and safe to install. It has been hydrothermally monitored for two years showing no deterioration and promises a long service life. It offers the end-user the advantage of lower thickness of external insulation system (reduced weight and loss of space), potentially leading to faster building completion.



Dowel in the middle of the VIP sandwich element, without joint, with cut-out in VIP

Installation of the new ETICS

*FC-DISTRICT generated new knowledge on high performance insulation materials introduced in ETICS for dry wall construction and gives us the opportunity to investigate the long term hydrothermal performance and aging effects of super-insulators (VIPs) in South European climatic conditions. The new ETICS paves the way towards holistic building envelope design approaches. However, the prototype ETICS currently installed at the demo site in Greece, have been hand-produced and further research is needed to develop methods for mass production and fast installation. Technical (e.g. durability), economic and environmental feasibility of the new ETICS needs to be proven before commercialization. KNAUF Gips KG and NTUA, based on the experience gained within FC-DISTRICT, initiated a new FP7 collaborative project “ELISSA: Energy Efficient Lightweight-Sustainable-Safe- Steel Construction”, that targets the development and demonstration of nano-enhanced prefabricated lightweight steel skeleton/dry-wall systems with improved thermal, vibration/seismic and fire performance.*

– Prof. Maria Founti



# Food waste collection tank



Food waste tank

The tank used is installed with Food Waste Disposers (FWD) for food waste collection. This innovative solution for the waste management has never been applied before. It allows the collection of the highest quality material for biogas production in an easy way, and with no impurities that could affect the anaerobic digestion process efficiency. The food waste collection tank promotes the development of a completely novel method for organic kitchen waste collection. This assists citizens in the separate waste collection, as well as the Waste Management companies in reducing the frequency of waste collection and providing an ideal substrate for anaerobic digestion in order to enhance biogas production. Different solutions for the tank have been identified and tested particularly focusing on the optimization of the filtering system (mesh dimension and material), as well as on the control of the liquid level inside the tank. A customized solution has been identified and successfully tested, in order to optimize the management of the different phases of filling and emptying the tank, minimizing the frequency of collection. In particular, the new method principle is based on the presence of a series of light emitters and receivers (opto-sensors) placed inside a protective transparent pipe. According to the signal received it is possible to derive the height of the solid part and the floating part. The measuring system is also provided with a cleaning system to guarantee accuracy in measurements. The tank has the option to filter the ground waste separating the solid content from the liquid. This eliminates the water excess via settling of the solid phase in order to obtain a compacted waste, ready to be pumped out to the trucks, with low water content. The tank is realized in polypropylene, having excellent mechanical properties as well as resistance to a wide range of chemical compounds. Moreover the simple geometry of the tank is able to reduce cost for its realization as well as to optimize its installation, management and maintenance. The tank is also equipped with a cleaning device (sliding cleaning ring), a removable filter, a pressure transducer (to control the level of the filtered water) and two pumps (one to empty the filtered water, the second to boost the water pressure feeding the cleaning ring).

Level metering system



Food waste tank



The monitoring of levels inside the thickening volume of the tank and the filtered water is fundamental to program with an adequate advance the operations for emptying the tank (2 days), in order to optimize the collection of waste minimizing its costs. The present solution is an improvement over prior art devices as it uses no moving parts and provides a simple and accurate liquid level measuring system with respect to other types of devices.

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*A strategy, which looks to optimize the food waste collection, have to deal with two challenges: its logistic (lower collecting frequencies) and its recycling. Both the aspects have the equivalent relevance in getting the best solution. In fact the people want live in tidy cities, while the sustainability claims to recover the waste. The model proposed by FC-district has been conceived looking to these two aspects providing: a reduction of volumes, a "once-a-week" collection, a high quality of collected waste, a maximization in the potentially producible biogas. In my opinion the success of this technology will come out from the joint effort of the companies delegated to the waste and waste water management, the real estate developers, under the supervision of the political authorities which have to define the strategic frame where the other players have to operate.*

*- Piero Rusconi*



# Wireless/hybrid communication network

The purpose of the implemented wired/wireless IP telecommunications network is to enable the monitoring and control of all sensors in the FC-District systems. This was achieved whilst allowing for telecommunications network expansion, either locally or by creating a network of networks. The wireless network is easily expandable, allowing for district site expansion, or for the inclusion of further districts. The technical specifications of the communication system were assessed for monitoring and control, components selection, testing and implementation. The telecommunications infrastructure implemented was an IP hierarchical hybrid point to point/MESH system. The developed system is a single integrated solution with specialised hardware and software for intelligent building systems management which provide reliable, dynamic, mesh communication network. The data network infrastructure allows to: Deploy sensors at different remote points of the district and gather data at a central location Control of SOFC units and other devices deployed in the district Provide reliable, dynamic, mesh communication network Provide internet access through linked Wi-Fi base stations. Excess bandwidth

based, the network components can be based on a number of different yet fully compatible networking architectures, such as:

1. Point to multipoint WiMAX
2. Ad-Hoc MESH multipoint to multipoint PodNode
3. Point to multipoint WiFi combination of the above has been used to deliver wireless telecommunications to the district.



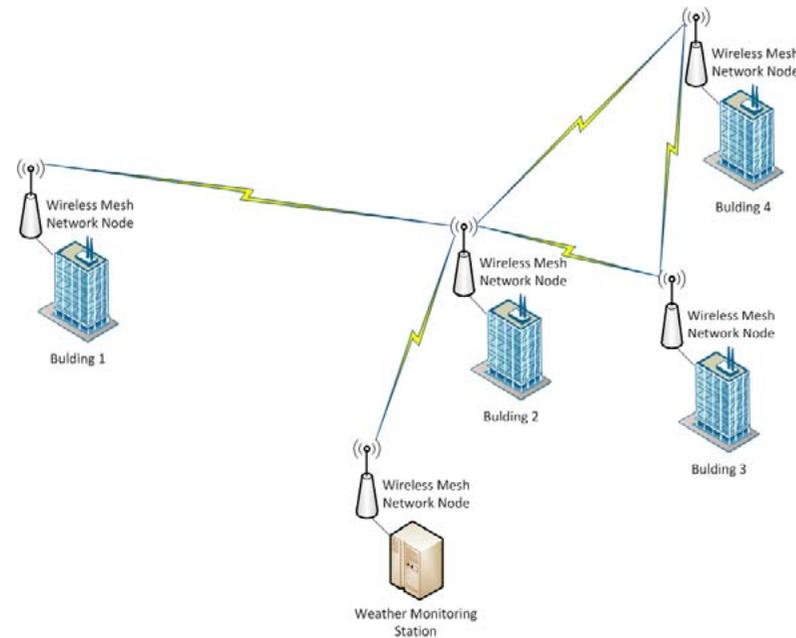
Hardware component

*The exploitation strategy employed by Rinicom for the developed wireless telecommunications network has been a two-tiered approach. Firstly, Rinicom has disseminated the Hit-Gate project to its customer base, some of whom are already involved in smart-city projects, in particular smart allocation of energy requirements. Secondly, Rinicom has been able to technologically exploit the developed telecommunications solution through demonstrating technical competence, leading to involvement in several smart city projects.*

*- Professor Garik Markarian, CEO, Rinicom Ltd.*



FC District Network Based on MESH Technology



of the telecommunications system can be employed for distribution of internet access or for the use of adhoc devices/sensors, LAN communication, surveillance systems, or virtually any IP communication. The protocol used for transportation of the data around the system is TCP/IP. Where devices are not natively IP based, IP conversion units are used. Because the system is IP



The pilot plant in Poland

## Demonstration sites

### Poland

FC-DISTRICT consortium has built a full scale pilot plant to demonstrate operation of the newly developed system. Demonstration was held in Warsaw in Institute of Power Engineering. Selected buildings were connected by one local insulated district heating network and fitted with new energy sources. New district heating system supplied three zones with heat: zone 1 with thermal demand of 7,2 kW, zone 2 with thermal demand of 5,0 kW and zone 3 with thermal demand of about 3,5 kW.

The pilot plant demonstrated main features of FC-DISTRIC system:

- external insulation systems for retrofitting and new buildings,
- new district heating piping solution,
- building fitted with  $\mu$ -CHP energy sources,
- dynamic heat exchange between building and district,
- management at district level.

In order to meet these main features following steps were performed:

- performance of external wall with innovative insulation in the new building,
- replacement of existing old district heating pipes, with newly developed pipes for one of the existing buildings,
- performance of new insulated district heating system connecting three buildings, two existing and one newly built,
- performance of natural gas network with pressure reduction points,
- space adaptation for “source rooms” in three buildings, two existing and one newly built,
- installation of  $\mu$ -CHP units in three buildings and connecting them to the new district heating and mains,
- performance of wireless hybrid communication system,
- implementation of intelligent control algorithms,
- performance of extensive monitoring system.

ETICS demonstration was performed in newly built 110 m<sup>2</sup> building. Wall of the building were covered by developed ETICS material. Moreover building was fitted with sensors which were measuring temperature, humidity and heat flux through the partitions. Collected data has been archived and used for energy balance calculations from all major surfaces. In-situ measurements of the thermal properties of elements and assemblies have been performed. Performance of space heating based on the  $\mu$ -CHP unit was evaluated. Computational tools developed for thermal and energy performance analysis were validated.



New building with developed ETICS

Demonstrated piping network system has been developed in order to achieve better efficiency. A new district heating piping solution consisted of a two steel carrier pipes in one PEHD jacket tube. Heat supply pipe has been insulated with a high efficient vacuum panels, to reduce heat losses. The remaining space between pipes was filled with PUR insulation. Temperatures on a different layers were measured and archived in order to check the performance of the new piping design.



Building district heating network with use of prototype pipes

Presenting a building fitted with  $\mu$ -CHP units was divided into two stages. In the first phase three building were equipped with Stirling engines. Each unit produced 1,0 kW of electricity and 7,0 kW of heat. All, three installed units were devices of the same type, commercially available on the market. Used Stirling engines were provided with two burners, which do not allow to work with variable power. For the FC-DISTRICT application the auxiliary burner were disconnected to optimize the ratio of heat output in relation to the amount of electricity produced.

The second stage of this part of the demonstration was replacement of the Stirling engines with prototyped  $\mu$ -CHP fuel cells. In mentioned SOFC units electricity was produced directly from oxidizing natural gas and the heat was recovered from the process. When working with full power, units produced 1,0 kW of electrical power and 2,8 kW of heat. Developed SOFCs were also designed to work with variable loads. The generated electrical power has been proportional to the heat produced.

Developed system consists of main control room, three source rooms and district heating network. Central pump, heat storage tank and expansion vessel were installed in the main control room. Production of energy for covering zone local demands was realized with priority. Energy surpluses were passed to the network, other zones or stored in the heat storage tank.



Main control room



Stirling engine installed

Crucial element of the FC-DISTRICT concept was system management at district level. Control algorithms depended on the weather conditions and expected or unexpected human behavior. The control system covered three  $\mu$ -CHP units with boiler panels and connections between them via wireless communication. This solution allowed smooth operation of energy sources, adapting number of working devices to current district heat demands. This way of management enabled to use SOFC units as an energy sources.

The communication system used to exchange the control and measuring data throughout the whole FC-DISTRICT were also demonstrated at the pilot plant. Wi-Fi connection between three buildings and electrical and Ethernet connections between particular devices formed a hybrid communication system.

All measuring data, like water flows and temperature sensors, were used to optimize the system operation.

The data collected from the pilot plant has been used to estimate the overall system efficiencies, capabilities and techno-economic features.

## Italy

After the development of the preliminary activities devoted to identify suitable locations for the Demo installation, the selected site for demonstration activities has been identified in Italy, in Milan city not far from Ecofast premises, guaranteeing a fast intervention time for installations and testing development. In the table below, the main characteristics of the demonstration site have been reported. The installation has been placed in a building located in Bonnet street n. 6/b in Milan (Italy). The building is divided in two kinds of apartments: residential and offices. Thus, part of the people living in the buildings are present temporarily, part permanently. The residence's apartments are occupied approximately 75% of the year. Three FWDs have been installed in three different residence's apartments. This was possible because the three FWDs were connected to one draining line free from toilets discharge. The draining line has been equipped at the end with a diverting valve. Other three FWDs have been installed at the half floor in a dedicated area with three sinks. There the people not having a FWD installed in their kitchen can dispose the food waste.

The draining system is characterized by two lines. The first discharge line comes from the residence kitchens. The line is connected to the Self Thickening Tank. The diverting valve is highlighted by the red circle in the picture (see picture beside). The second discharge line, that comes from the three FWDs located at the half floor, is new.

This line starts at the half floor and goes down to the 2nd underground floor, joining the previous line down to where the thickening tank is installed.



Demonstration building in Italy



Food waste tank

# Greece



Residential building in Stanos Amphiloikia (Western Greece)

## The Demo house

The demo house, located at the premises of KNAUF Gypsopiia ABEE in Amphiloikia – Greece, comprises a load-bearing steel frame combined with gypsum plasterboard wall assemblies. It is a two-storey building with a total surface of ca. 152 m<sup>2</sup> (heated area 128.42 m<sup>2</sup>). Gypsum or PCM plasterboards are installed in double cladding layers in accordance with the Greek fire-resistance, thermal and sound insulation requirements. The demohouse’s HVAC equipment includes: solar panels (heating, DHW), heat pump (heating, cooling, DHW) and buffer tank (storage of hot water for heating and DHW). The potential integration of a  $\mu$ -CHP SOFC based system to collaborate with the already installed systems has been examined.

The thermal behaviour of the building is continuously monitored and evaluated. Temperature, heat flux sensors are installed in different locations within and on the wall, floor and ceiling elements of each room. Energy balances are calculated for each major surface in each zone of the building. Measurements of heat fluxes, internal air temperature, surface temperature of walls and finally humidity are available on the public monitoring site.

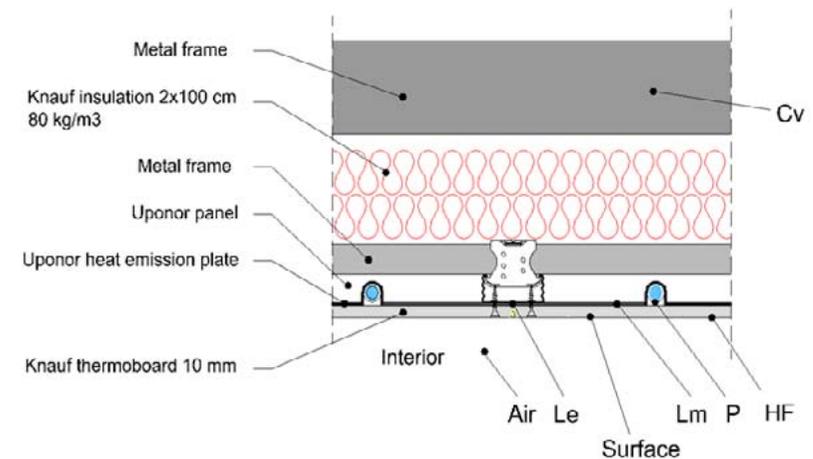
The Greek demo house, is a very low energy consumption residential building of typical architectural design, and serves as a paradigm towards the design of sustainable buildings featuring novel energy systems. Within the FC-District project, the combined performance of the HVAC system and of the PCM gypsum boards installed in the lightweight residential building in Greece have been extensively monitored. The data have been used for the validation of purposely developed simulation tools that allowed the estimation of the energy saving potentials. The so far acquired monitoring results offer a unique opportunity for establishing an “energy efficiency in buildings” awareness campaign. Within FC-DISTRICT, an advanced control strategy and a specialized Building Management System (BMS) accounting for the collaboration of the various energy sub-systems has been developed. It accommodates the individual control characteristics of each component (in particular communication between the under floor heating system, the suspended ceiling cooling system and the heat pump/solar panels). The additional complexities resulting from the potential installation of the  $\mu$ -CHP SOFC fuel cell system have been considered.

It is the first time that a “high-performance” residential lightweight building, characterized by a very low space heating-cooling demand is openly and continuously available for inspection and training of engineers, technicians and end-users.

As the result of the FC-DISTRICT developments, KNAUF Gypsopiia ABEE has introduced the demo house in its training - technical education seminar series. Trainees are introduced into the construction characteristics, the installed energy systems, the thermal storage system

and the advanced BMS architecture and strategies. They have the opportunity to visit the house and observe its performance such as the thermal and electrical energy consumption.

FC-DISTRICT has allowed KNAUF Gypsopiia ABEE to expand the existing professional training activities to include new building technologies and construction techniques and to reach new target groups. The building performance training activities at KNAUFABEE have been configured so that the trainee can benefit the maximum within minimum time. These activities take place at four training centres, located in Athens, Thessaloniki, Amphiloikia (where the FC-District demo house is built) (Greece) and in Cyprus. Knauf Gypsopiia ABEE, in collaboration with NTUA, will continue to monitor and expose the demo house as an effective example of research collaboration serving the needs of industry.



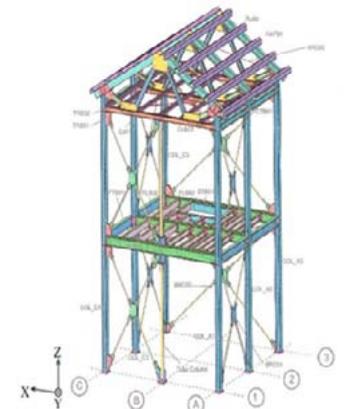
Side view of wall layers



## The Mock-up house

The new ETICS have been incorporated in a mockup two-storey building (3.65 m x 3.65 m x 7.53 m) located in the campus of the National Technical University of Athens. The mockup is a drywall construction envelope based on a cavity wall system incorporating EPS ETICS. The construction methodology follows the rules applying to steel framed buildings according to Eurocode 3. The configuration and thickness of the envelope components as well as the materials utilized are the same as in full scale buildings. Monitoring of the mock-up building has been realized through the installation of temperature, humidity and heat flux sensors.

The new ETICS have been installed on the north Wall of the building (the most shaded wall). It reduced the thermal transmittance of the lightweight wall (in comparison to the conventional insulation materials) while retaining a low overall thickness. Up-to-date results have shown that the new ETICS is water tight and it is easy and safe to install. It has been hydrothermally monitored for two years, showing no deterioration and promises a long service life. It offers the end-user the advantage of an efficient external thermal insulation system of reduced weight, potentially leading to faster building completion.



Mock-up house

# Administrative information

FC-DISTRICT project proposal has been prepared for a call opened within Seventh Framework Programme, topic EeB.NMP.2010-2 New technologies for energy efficiency at district level.

Realization of FC-DISTRICT is co-financed based on grant agreement no. 260105, signed between the project consortium and European Commission.

The consortium is composed by 23 partners from 11 EU-countries



Mostostal Warszawa S.A.: Construction company from Poland. Project coordinator.



National Technical University of Athens: High Educational School from Greece. Technical coordinator.



Acciona Infraestructuras S.A.: Construction company from Spain



TU Bergakademie Freiberg: High Educational School from Germany



Institute of Power Engineering: Research Institute from Poland



Fagor Electrodomesticos S.COOP.LTDA: Industrial company from Spain



Energy research Centre of the Netherlands: Research Institute from Netherlands



EBZ Entwicklungs- Und Vertriebsgesellschaft Brennstoffzelle mbH: Enterprise experienced in sensor production from Germany



Chalmers University of Technology: High Educational School from Sweden



Powerpipe Systems AB: Producer of pre insulated pipes from Sweden



Ikerlan S. Coop.: Non-profit technological research center from Spain



Instituto Superior Tecnico: High Educational School from Portugal



Institute Oskar von Miller SC OVM ICCPET S.A.: Research and Design Institute from Romania



RINICOM: Technology company from United Kingdom



Solintel M&P SL: High-tech SME-company from Spain



Knauf Gips KG: Producer of building materials from Germany



D' Appolonia SPA: Engineering Consulting Company from Italy



Sveriges Tekniska Forskningsinstitut AB: Technical Research Institute from Sweden



Ecofast Italia Srl: Designer and producer of devices for food waste collection from Italy



IntesaSanpaolo Eurodesk S.p.r.l.: Industrial consultancy group from Belgium



Knauf Gypsopiiia ABEE: Producer of building materials from Greece



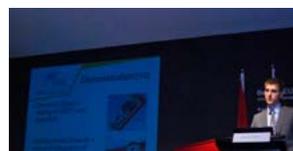
Vlaamse Instelling voor Technologisch Onderzoek: Independent Research Institute from Belgium



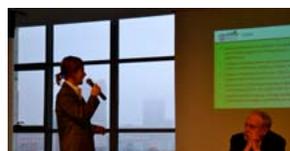
SunFire GmbH: Company specialized in developing energy conversion processes from Denmark

## Dissemination

FC-DISTRICT concept and particular results of the research performed were widely disseminated, at various scientific and commercial events in Europe and beyond.



June 2010, EU-China science week in Shanghai, China



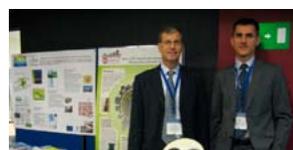
January 2011, KRAB Symposium, Warsaw, Poland



April 2011, Hannover Fair - Group Exhibit Hydrogen and Fuel Cells, Germany



October 2011, ECTP-E2B conference Warsaw, Poland



July 2012, FP7 Information Days on Research PPPs, Brussels, Belgium



September 2012, Presentation of tank prototype to UIDA DRAANIMA, Milan, Italy



February 2013, GENERA the Energy and Environment International Trade Fair, Madrid, Spain



March 2013, Impact of the Energy-efficient Buildings PPP, Brussels, Belgium



October 2013, Workshop for Central-Eastern Europe Countries, Warsaw, Poland



February 2014, Industrial Technologies Conference, Athens, Greece

## Scientific journals and international conferences

### Journals

1. G. Vourliotakis, G. Skevis, M.A. Founti, "Assessment of the Reactor Network Approach Integrated Modelling of an SOFC System", *Int. J. Hydrogen Energy*, Vol. 36, pp. 6112-6122, 2011.
2. G. Vourliotakis, G. Skevis, M.A. Founti "A Detailed Kinetic Modeling Study of Benzene Oxidation and Combustion in Premixed Flames and Ideal Reactors", *Energy & Fuels*, ACS publications, Vol. 25, pp. 1950-1963, 2011.
3. G. Vourliotakis, G. Skevis, M.A. Founti "Combustion Chemistry Aspects of Alternative Fuels Reforming for High-Temperature Fuel Cell Applications", *Int. J. Hydrogen Energy*, Vol. 37, pp. 16649-16662, 2012.
4. Ch. Keramiotis, G. Vourliotakis, G. Skevis, M.A. Founti, C. Esarte, M.U. Alzueta "Experimental and computational study of methane pyrolysis in a Plug Flow Reactor (PFR) under atmospheric pressure", *Energy*, Vol. 43, pp. 103-110 (2012).
5. G. Vourliotakis, G. Skevis, M.A. Founti, Assessment of Fuel Interchangeability in Domestic Scale SOFC Systems based on a Reactor Network Approach, *Energy Procedia*, Vol. 28, pp. 140-152, 2012.
6. I. Frenzel, A. Loukou, D. Trimis, F. Schroeterb, L. Mir, R. Marin, B. Egilegor, J. Manzanedo, G. Raju, M. de Bruijne, R. Wesseling, S. Fernandes, J.M.C. Pereira, G. Vourliotakis, M.A. Founti, O. Posdziech, Development of an SOFC based micro-CHP system in the framework of the European project FC-DISTRICT, *Energy Procedia*, Vol. 28, pp. 170-181, 2012.
7. Ch. Keramiotis, B. Stelzner, D. Trimis, M.A. Founti, Porous burners for low-emission combustion: An experimental investigation, *Energy*, Vol. 45, pp. 213-219, 2012.
8. J.E.P. Navalho, I. Frenzel, A. Loukou, D. Trimis, J.M.C. Pereira, J.C.F. Pereira, Catalytic partial oxidation of methane rich mixtures in non-adiabatic monolith reactors, *Int. J. Hydrogen Energy*, Vol. 38, pp. 6989-7006, 2013.
9. A. Gazi, G. Vourliotakis, G. Skevis and M. A. Founti, "Assessment of chemical markers for heat release rate correlations in laminar premixed flames", *J. of Combustion Science and Technology*, Vol. 185, pp. 1482-1508, 2013.
10. J.E.P. Navalho, J. M.C. Pereira, A.R. Ervilha, J.C.F. Pereira, "Uncertainty quantification in the catalytic partial oxidation of methane", *Comb. Theory and Modelling*, Vol. 17, pp. 1067-1095, 2013.
11. J.E.P. Navalho, José M.C. Pereira and José C.F. Pereira, Conical-shaped foam reactors for catalytic partial oxidation applications, *Int. J. Hydrogen energy*, Vol. 39, pp. 3666-3680, 2013.

12. Miguel A.A. Mendes, J.M.C. Pereira, J.C.F. Pereira, "Numerical study of methane TPOX within a small scale Inert Porous Media based reformer", *Int. J. Hydrogen Energy*, Vol. 39, pp. 4311–4321, 2014.

#### **Selected conferences**

1. I. Frenzel, A. Loukou, D. Trimis "An innovative burner concept for the conversion of anode off-gases from high temperature fuel cell systems", 11th International Conference on Energy for a Clean Environment", Instituto Superior Técnico, Lisboa, Portugal (2011).
2. G. Vourliotakis, G. Skevis, M.A. Founti, "Combustion chemistry aspects of high temperature reforming for fuel cell applications", International Conference on Hydrogen Production (ICH2P-2011), Thessaloniki, Greece (2011).
3. I. Frenzel, A. Loukou, D. Trimis, F. Schroeterb, L. Mir, R. Marin, B. Egilegor, J. Manzanedo, G. Raju, M. de Bruijne, R. Wesseling, Sofia Fernandes, J.M.C. Pereira, G. Vourliotakis, M.A. Founti, O. Posdziech, "Development of an SOFC based micro-CHP system in the framework of the European project FC-DISTRICT", Oral presentation, Fuel Cells 2012 Science & Technology, A Grove Fuel Cell Event, Berlin, (2012).
4. I. Frenzel, A. Loukou, D. Trimis; "An innovative burner for the conversion of anode off-gases from high temperature fuel cell systems", 10th European SOFC Forum, Lucerne, Switzerland (2012).
5. A. Paraboschi, I. Frenzel, E. Ferchau, D. Trimis, "Anaerobic Digestion treatment of Food Waste ground by means of a food waste disposer and intercepted by a Filtering Tank", 4th International Symposium on Energy from Biomass and Waste, S. Servolo, Venice, Italy (2012).
6. D. Giannopoulos, E. Malliotakis and M.A. Founti, Life Cycle Environmental Impacts of Heat and Electricity micro-grids covering District Energy Demands, 3rd International Exergy, Life Cycle Assessment, and Sustainability Workshop & Symposium (ELCAS3), 2013, NISYROS, Greece (2013).
7. Katsourinis, D., Mandilaras, I., Stamatiadou, M., Zannis, G. & Founti, M., "Experimental Investigation of PCM Activation on a Greek Residential Building with PCM Gypsum Board Walls", 2nd International Conference on Sustainable Energy Storage, Trinity College Dublin, Ireland (2013).
8. G. Vourliotakis, A. Gazi, G. Skevis, M.A. Founti, Some Observations of the Combustion Chemistry of C1-C2 Oxygenated Fuels in Laminar Premixed Flames, (2013), 5th International Conference on Experiments/Process/System Modeling/Simulation/Optimization (5th IC-EpsMsO) Athens, Greece (2013).
9. Evaluation of Vacuum Insulation Panels Used in Hybrid Insulation District Heating Pipes" Abstract submitted to DHC14 (The 14th International Symposium on District Heating and Cooling) 7-9 September 2014 in Stockholm, Sweden.
10. "Hybrid insulation district heating pipes – improved thermal insulation properties. Presentation in conference 'Distributionsdagarna' organized by Swedish association of district heating 18-19 Jan 2014 in Malmö, Sweden.
11. Mandilaras, I. Atsonios, G. Zannis, M. Founti, In Situ Performance Assessment of a Composite Insulation System Consisting of Mineral Wool and Vacuum Insulation Panels, IVIS2013, 11th International Vacuum Insulation Symposium, Empa, Switzerland (2013).
12. P. Rusconi Clerici, A. Paraboschi, I. Frenzel, E. Ferchau, S. Wesolowski, D. Trimis, "Biogas Yields from food waste subject to different mechanical pretreatments" 14th International Waste Management and Landfill Symposium, Sardinia, Italy (2013).



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