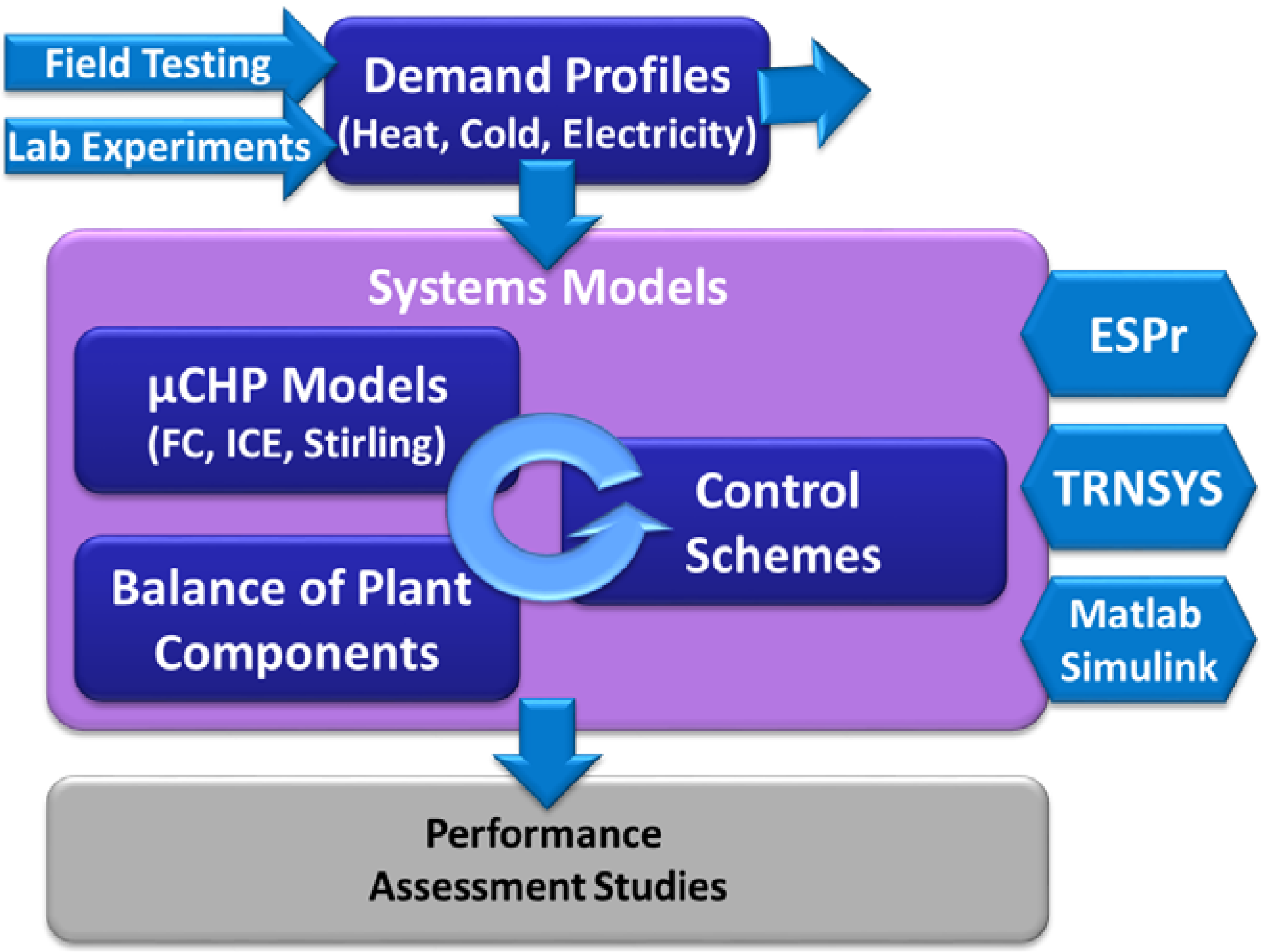
Energy in Buildings and Communities Programme

International Energy Agency

Integration of Micro-Generation and Related Energy Technologies in Buildings (Annex 54)

Project Summary Report

June 2016



EBC

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Project Summary Report

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iea Energy Technology Network

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Cover picture: Context of data and models for integration of
micro-generation and related energy technologies in buildings
Source: EBC Annex 54

Contents

Project Summary

Micro-generation is a novel way of producing heat and power on site near the end-user with the potential high reliability, efficiency and security of energy supply. The variety of micro-generation technology choices and applications strongly depends on the electric and thermal load profiles of the building to be serviced. Building integration of micro-generation systems is a challenge, as the loads are small and probabilistic by nature and the diversity is high. Given the rapidly increasing numbers of micro-cogeneration installations around the world, there is the pressing need for knowledge to enable informed choices to be made on where and when the installation of micro-cogeneration is appropriate. To properly integrate these systems in buildings, a significant number of operational and design issues need to be investigated and resolved.

This section briefly summarises the research findings of the completed EBC research project, 'Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings'. This was established in 2009 to further develop simulation models and performance assessment techniques that impact on the integration and future penetration of micro-generation systems in buildings. The research has encompassed the broad range of end uses of micro-generation and the systems within which it could be deployed. The work reflected the state-of-the-art and anticipated future performance of micro-generation including integration with energy storage and demand side-management technologies (for instance responsive loads or dynamic demand control), virtual utility and smart energy networks. Finally, given the ubiquitous nature of this technology and its broad societal impact, the research results have been made accessible to a broad range of audiences including researchers, policy makers and industry. More detailed information is available in the final report [1].

To analyse and optimize the technical performance of microgeneration systems, models of micro-generation units and system components have been developed and successfully implemented into state-of-the-art building performance simulation platforms [2]. A huge amount of country specific data has been collected from laboratory and field-testing and used to determine demand side profiles and to gain knowledge on micro-generation system integration and performance under a variety of real life operating conditions [3]. Combining available data and system models allows optimizing the design and operation of microgeneration systems to improve their performance.

Country specific performance assessments, including economic as well as environmental analyses, revealed generic performance trends and 'rules of thumb' for appropriate deployment of micro-generation technologies [4]. The developed assessment methodology [5] established common reference points for performance comparisons, an assessment methodology and metrics. Generic non-country-specific factors affecting the viability of micro-generation system and their appropriate deployment in buildings were also identified [6].

A selection of the range of support mechanisms to incentivize the adoption of microgeneration has been analysed. It is recognized that supporting schemes can change quickly and as such the country-specific sets of incentives and grants has been examined over the lifetime of the project. As such, the related reports [7, 8] provide a snapshot of feed-in tariffs, grants, building regulations and the role of micro-generation and associated technologies in smarter energy systems.

Project duration
2009 - 2014 (completed)

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Further information
www.iea-ebc.org

Project Outcomes

Background and Aims

The starting point of the completed EBC research project, 'Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings', was the work performed within an earlier EBC project on small scale cogeneration units. This earlier project focused on the modelling of single fuel cells and other micro-cogeneration devices [9].

Given the rapidly increasing number of micro-cogeneration installations around the world, there was a pressing need to conduct further research to enable informed choices to be made on where and when the installation of a micro-cogeneration system is appropriate. Therefore, the research of this follow-on project encompassed the broad range of end-uses for micro-generation, and the systems within which it could be

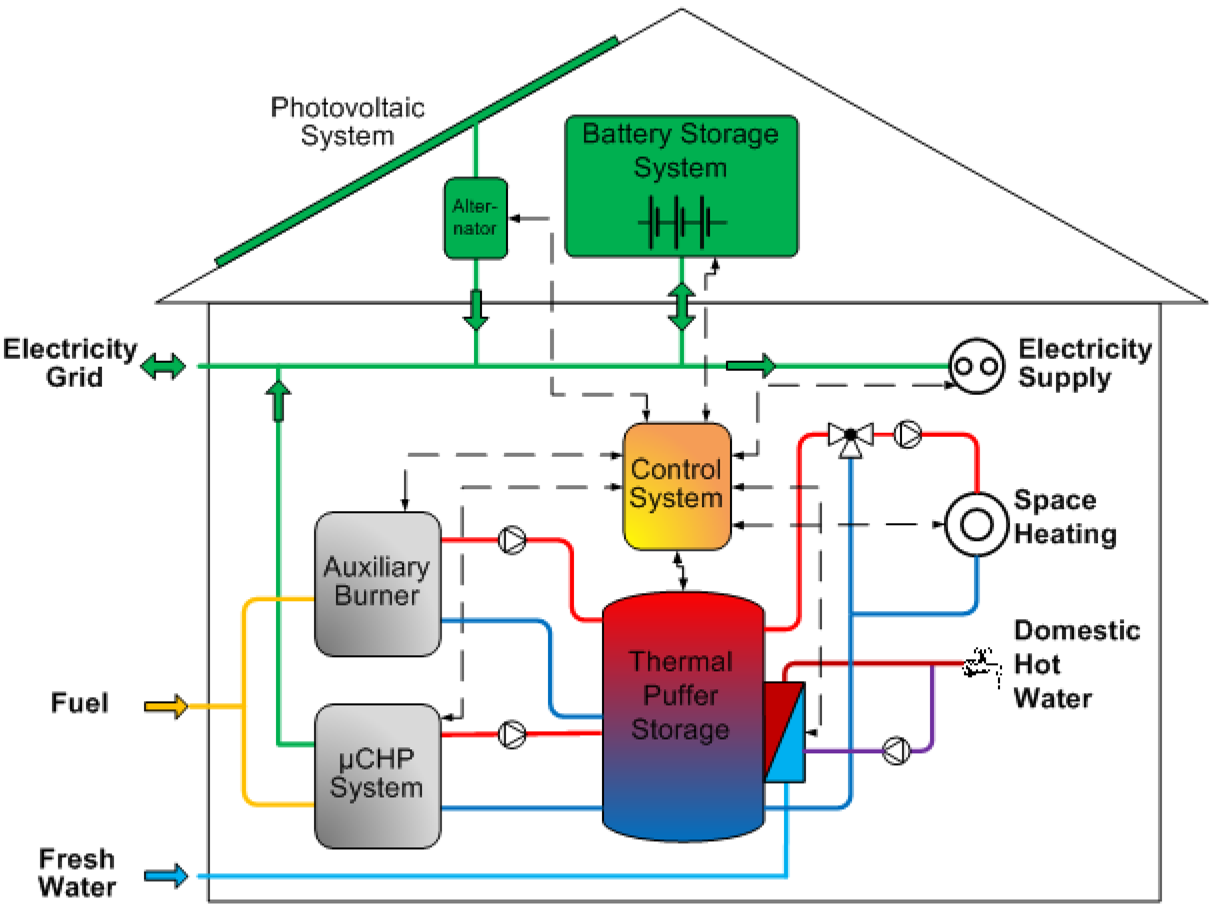

Figure 1. A schematic of a building integrated microgeneration system.

deployed. Furthermore, the work needed to properly reflect the state-of-the-art and anticipated future performance of micro-generation, including integration with energy storage and demand-side management technologies (for example responsive loads or dynamic demand control). Finally, given the potentially ubiquitous nature of this technology and its broad societal impact, the research results were required to be accessible to a broad range of audiences including researchers, policy makers, and industry.

The aim of the project was to analyse and to improve the performance of building integrated micro-generation systems. Therefore, state-of-the-art simulation tools have been used. Figure 1 shows an exemplary building integrated system, including several optional components. The demand side is considered as load profiles, or as related simulation outputs, in terms of electrical energy use, space and domestic hot water demand and cooling demand. The supply side encompasses numerical models of heating systems (for example gas furnaces, heat pumps, cogeneration systems), electricity generators (for example cogeneration systems, photovoltaics), cooling devices, as well as thermal and electrical storage devices, balance of plant components and control systems.

Micro-Generation Technology

Micro-generation comprises technologies that provide energy to buildings by small-scale systems of up to some ten kilowatts. The combined production of heat and power (CHP) in a single small-scale process is called micro-cogeneration (micro-CHP, CHP). This can be extended to a micro-trigeneration system if additionally cooling power is produced. Renewable resources can be introduced into the system using photovoltaics, solar collectors or heat pumps. A micro-generation system may consist of several of the following components:

- a micro-cogeneration unit (micro-CHP) to produce heat and electricity with high efficiency,
- a thermal or electrical driven cooling system if required,
- devices to make use of renewable energy such as photovoltaics, solar collectors or heat pumps,
- a thermal buffer storage, used for the decoupling of heat and electricity and to increase micro-CHP runtime,
- an auxiliary burner for thermal peak load coverage,
- a battery storage system to store surplus electricity and to cover peak loads,
- an electrical grid connection for surplus feed in and peak load coverage, and
- an advanced control system for optimal operation of the components.

Co-generators using conventional combustion engines (ICE) in the scale of several hundred kilowatts are widely implemented. In the range of micro-CHP, ICE co-generators with 1 kW to 5 kW electrical and up to about 12 kW thermal outputs have been on the market for about a decade. Stirling engines in the range of about 1 kW electrical output have recently become available on the market. These small systems are also suitable for single family houses.

A lot of development work on fuel cell micro-CHP has been done, for instance in Japan, where this technology is already on the market. Meanwhile, the first fuel cell micro-CHP systems are also now available in Europe and North America. The advantages of fuel cells are a high electrical efficiency, and the high power to heat ratio correlates well with the requirements of future low energy buildings with low heat demand, but still with significant electricity consumption. Market prices for these systems have decreased significantly within recent years, but are still very high compared to other technologies.

At present micro-CHP systems are mainly fuelled by natural gas, but also LPG or fuel oil can be used. Small-scale systems running on renewable resources as vegetable oil, biogas or wood pellets are not yet commercially available.

Technology Assessment and System Optimization

One of the core aims of the project was to perform a technology assessment on microgeneration at the building level. To do so, it was necessary to determine the technical performance. One key parameter therefore used for microgeneration is efficiency: This is defined as the output of useful energy in terms of heat and electricity

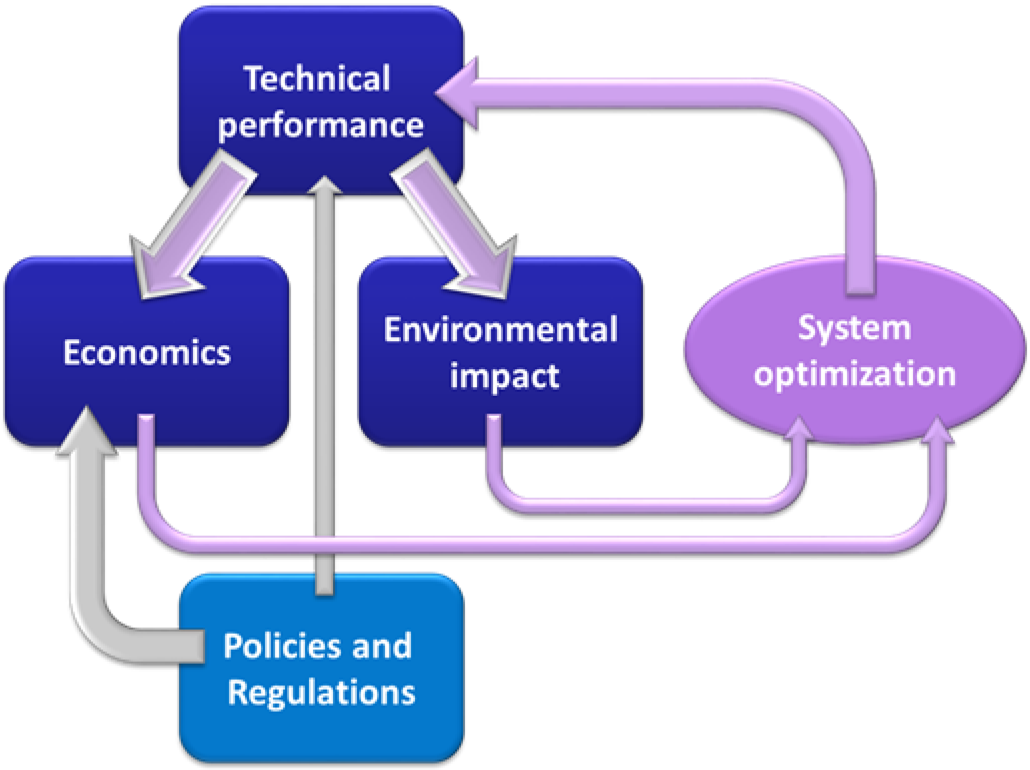

Figure 2. Schematic of the research approach.

in relation to the input of final energy, generally natural gas. The efficiency of such devices was determined by measuring relevant parameters during laboratory and field tests. Typically, the electrical efficiency of a micro-CHP unit lies in the region of 25% for ICE systems, 15% for Stirling systems and up to 50% for systems using fuel cells. Also taking into account the delivery of useful heat yields a total efficiency in the range from 85% to 95%.

To analyse and optimize possible applications, state-of-the-art simulation tools were used in the project. Certain components relevant for microgeneration have been developed [2], but these are not yet commercially available. Models of these were parameterized and validated using various sources of data from field testing and laboratory activities [3]. Finally, the models produced can be used to simulate whole microgeneration systems. Results are expressed in terms of technical performance parameters such as efficiency or final energy consumption.

For system optimization, other objectives such as reduction of primary energy, greenhouse gas emissions or costs of the system have to be defined (Figure 2). Therefore, the characteristics of the energy supply system (power generation structure) and framework conditions set by national or regional legislation and regulations are also highly relevant and have to be taken into consideration. As these parameters may vary strongly between different countries, such an assessment usually has to be done on a national or even a regional level basis.

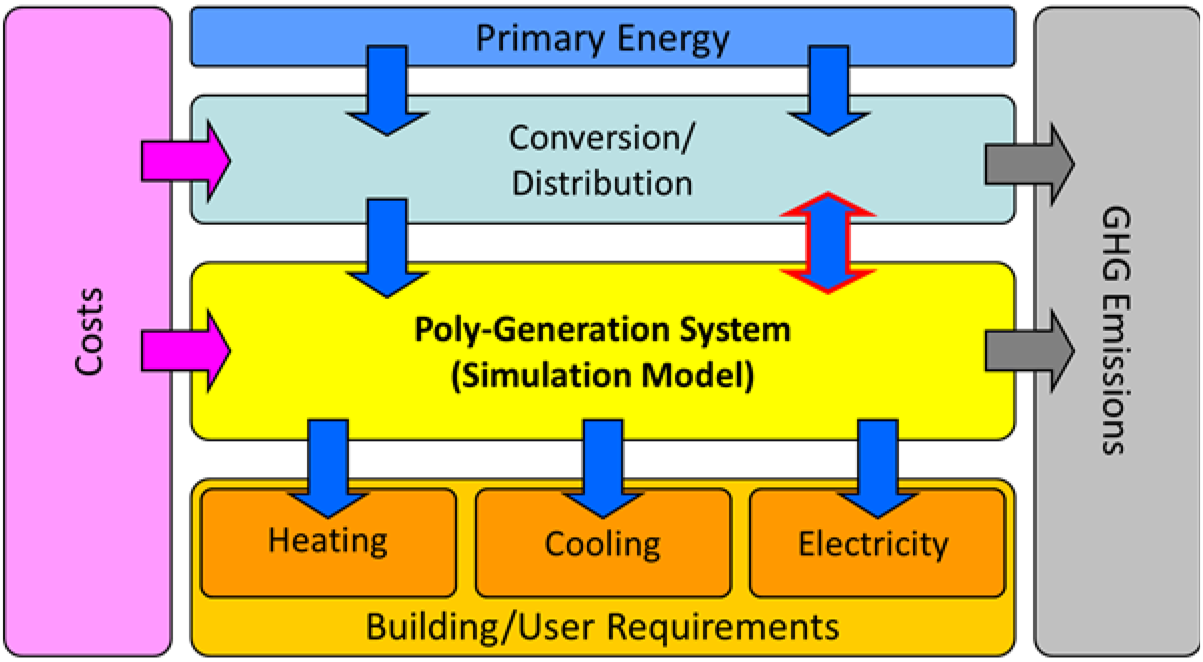

Figure 3. The scope of the 3-E methodology for energetic, economic and ecological analysis.

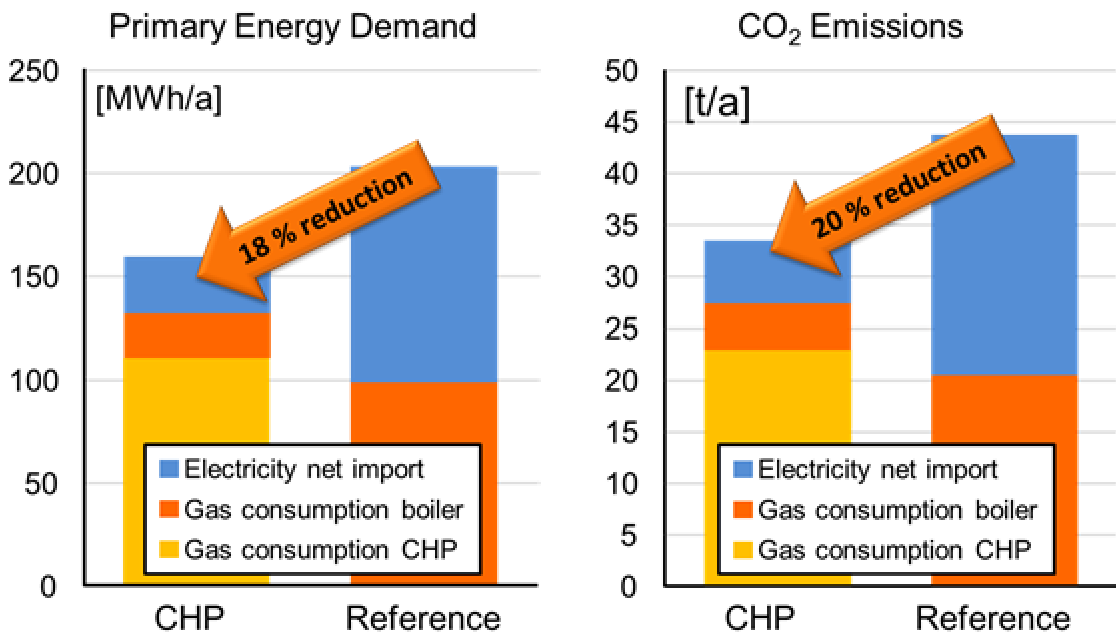

Figure 4. Primary energy savings and CO_2-emission reduction.

The approach taken to integrate primary energy, greenhouse gas emissions and costs follows the '3 E' methodology for an energetic, economic and ecological analysis (Figure 3) [5].

Finally, the optimal microgeneration system is assessed against a state-of-the-art conventional reference system [4]. Figure 4 shows an example, comparing a supply setup with a micro-cogeneration system (CHP) and a conventional system including a natural gas heater and electricity import from the public power grid.

Major Outcomes

The major outcomes of this 4-year international project are structured in the following categories: technology aspects, system performance and economics.

Technology aspects

A building's space heating and / or cooling energy demand highly correlates to the outside weather conditions, especially the outdoor temperature. Domestic hot water demand is driven by occupant behaviour, but charging of the hot water storage can be influenced to a certain degree. It was found that the models used to predict the thermal loads of a building show sufficient accuracy. Measured electricity demand data of residential consumers are highly stochastic by nature including peaks characterized by high amplitudes and short durations that makes their forecasting accuracy very limited.

Since start of the project in 2009, clear progress in microgeneration has been observed. A number of manufacturers have started market deployment of their products with variable success. Some systems have already disappeared due to funding problems, delayed market entry or technical problems. However, the latest trend shows leading HVAC manufacturers becoming involved in the development, integration and introducing microgeneration products on the market.

- ICE driven micro-CHP systems are already available from many manufacturers in a wide range of sizes.
- Stirling engine micro-CHP systems have recently entered the marked in many European countries. Most of the products are based on the Microgen Engine Corporation technology implemented by several heating appliance companies into their products.
- Fuel cells experienced irregular levels of sales in the early 2000s, but in the years since 2010, these have begun selling at markedly increased rates, and as of 2012 became the leading technology in terms of volume of units sold in comparison to the microgeneration technologies. This was driven by the high numbers of newly installed systems in Japan.
- Regarding tiny micro-CHP systems with about 1 kW to 2 kW electrical capacity, a trend is visible to integrate the cogenerator into a full scale heating appliance, with an auxiliary burner, pumps and a control system.

Development of cooling units, both absorption and adsorption chillers and their integration into micro-CHP systems, offers new possibilities to apply this technology in locations characterized with subdominant heating requirements, but with significant needs for cooling.

System Performance

The project participants were involved in several field test activities with micro-CHP systems. Energy flows of micro-CHP installations in residential as well as small commercial buildings set ups were measured and analysed. The measurements were performed over long time periods, typically one year with the following conclusion drawn:

- Electrical conversion efficiencies (based on lower heating value) were in the range of 8% to 15% for Stirling engine driven systems, 20% to 25% of ICE systems and up to 55% for systems using fuel cells. Overall (electrical plus thermal) energy conversion efficiencies range from 75% to as high as 95% (based on lower heating value). These efficiencies also consider the auxiliary power needs of the CHP system.
- System design turned out to be suboptimal in some of the monitored applications, in terms of the cogeneration systems sizing and / or their integration into the supply system. In many cases, design parameters were not properly set up to the requirements of the buildings, which led to lower overall efficiency of the systems.

Several country specific studies have been completed during the project. In each case national characteristics regarding provision of fuel and electricity were taken into account, as well as typical conventional reference systems. From these studies, the following conclusions can be drawn:

- Fossil fuel-based microgeneration systems can achieve primary energy and emissions savings in the range of 5% - 20%, depending on the type of system, its application and the carbon load of the national electricity generation. These savings increase up to 40% if in addition renewable energy technologies are included in hybrid microgeneration systems. A maximum value of 60% was found, in terms of primary energy and emission savings, when more than one renewable energy source is exploited (for example geothermal and solar energy) (Figure 4).
- If excess electricity is allowed to be exported to the grid, the best energetic, environmental and economic performance is obtained with thermal load-following micro-CHP, rather than electrical-load following systems.

Energy storage was identified as a very important component on both the thermal and electrical sides:

- Thermal storage prevents microgeneration systems from frequent on / off cycling, benefiting the system life expectancy and giving more efficient system performance. Charging the thermal storage during periods with lower heat demand can significantly reduce the auxiliary heater operation during high load demands, which would result in increased operational hours and economic benefits of the micro-CHP system.
- The integration of renewable (solar) thermal resources with thermal storage will benefit the operation, as the availability of solar energy does not usually correlate with occupant heat requirements.
- Furthermore, electricity from micro-CHP is preferably generated during time periods when it can be used on-site. Active management of the thermal storage will allow the decoupling of the heat demand from the electricity demand for these periods.

Economics

In terms of economic performance, significant cost savings (about 20% - 30%) can be obtained, but very often the initial installation cost is still considerably high, especially for very complex small scale trigeneration systems. Such systems will have quite long pay back periods, even assuming that all the support mechanisms introduced by national legislation are effectively achieved. Therefore, specific financing mechanism should be promoted in order to overcome the problem related to high investment costs, such as third party financing and favourable access to national and international government funding. Moreover, there is a need to further improve the economic performance of microgeneration systems, and to increase the cost savings with respect to conventional systems. A reduction in the installation costs driven by manufacturers and distributors of high efficiency energy conversion devices is also essential. The following can be concluded from analysing economic and support mechanisms:

- The benefits increase when the utilization time of the microgeneration system increases, as this is the most crucial parameter.
- The economic performance of microgeneration systems strongly increases with electricity use on site.
- The economic feasibility of microgeneration systems is very sensitive to the electricity purchase costs and the investment costs.
- With higher market penetration of microgeneration technologies, lower investment costs and higher economic benefits can be expected.
- The expected long term increase in fossil fuel energy prices is likely to coincide with decreasing microgeneration costs, leading to stronger economic benefits of these new technologies.

Towards Smart Local Generation

Many countries have set targets to move away from carbon intensive fossil fuel based energy supplies towards more sustainable systems by adopting energy saving actions and introducing significant use of renewable resources in their supply systems.

On a building level, microgeneration technologies contribute to both reduction of final energy use through high efficiency devices and application of renewable energy supplies. However, most of the related systems already installed are not operated in a way to optimally contribute to the above targets.

Micro-CHP systems can be viewed as an illustrative example: These are often referred to as ‘power generating heating systems’, and are operated in a heat led mode similarly to conventional heating appliances. This means they supply heat to the building when needed and feed the cogenerated electricity into the public grid if it cannot be used on site. This does not take into account whether or not additional electricity is actually needed in the grid and does not contribute to grid stability or electricity supply security.

The focus of this project has been on integrating microgeneration technologies to single buildings and optimizing the operation of these systems. However, implications beyond the building level also have been addressed [6]. The project outcomes can also be used as a basis for future work using the models and methodologies developed.

Together with building energy management using advanced controls, thermal and optional electrical storage capacities, microgeneration offers possibilities for aligning electrical power generation and demand locally, in an interconnected smart grid environment.

Project Participants

Country	Organisation
Belgium	Catholic University of Leuven
Canada	Natural Resources Canada National Research Council Carleton University
Denmark	Dantherm Power A/S
Germany	Research Center for Energy Economics (FfE) Technische Universität München (TUM) University of Applied Science of Cologne
Italy	Università degli Studi del Sannio Università Secundo di Napoli National Agency for New Technologies, Energy and Environment (ENEA) Università Politecnica delle Marche Università degli Studi e-Campus Università Trieste
Japan	Tokyo University of Agriculture and Technology Osaka university Nagoya University Tokyo Gas Osaka Gas Toho Gas Saibu Gas Mitsubishi Heavy Industry Ltd Yanmar Energy Systems Ltd
Korea	Korean Institute for Energy Research (KIER)
The Netherlands	Technische Universiteit Eindhoven (TU/e)
United Kingdom	University of Strathclyde Imperial College London University of Bath
USA	National Institute for Standards and Technology (NIST)

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EBC and the IEA

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 29 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes. The mission of the IEA Energy in Buildings and Communities (IEA EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA EBC Programme was known as the IEA Energy in Buildings and Community Systems Programme, ECBCS.)
The R&D strategies of the IEA EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. These R&D strategies aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five areas of focus for R&D activities:

– Integrated planning and building design

– Building energy systems

– Building envelope

– Community scale methods

– Real building energy use

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*):

Annex 1:	Load Energy Determination of Buildings (*)
Annex 2:	Ekistics and Advanced Community Energy Systems (*)
Annex 3:	Energy Conservation in Residential Buildings (*)
Annex 4:	Glasgow Commercial Building Monitoring (*)
Annex 5:	Air Infiltration and Ventilation Centre
Annex 6:	Energy Systems and Design of Communities (*)
Annex 7:	Local Government Energy Planning (*)
Annex 8:	Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9:	Minimum Ventilation Rates (*)
Annex 10:	Building HVAC System Simulation (*)
Annex 11:	Energy Auditing (*)
Annex 12:	Windows and Fenestration (*)
Annex 13:	Energy Management in Hospitals (*)
Annex 14:	Condensation and Energy (*)
Annex 15:	Energy Efficiency in Schools (*)
Annex 16:	BEMS 1- User Interfaces and System Integration (*)
Annex 17:	BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18:	Demand Controlled Ventilation Systems (*)
Annex 19:	Low Slope Roof Systems (*)
Annex 20:	Air Flow Patterns within Buildings (*)
Annex 21:	Thermal Modelling (*)
Annex 22:	Energy Efficient Communities (*)
Annex 23:	Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24:	Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25:	Real time HVAC Simulation (*)
Annex 26:	Energy Efficient Ventilation of Large Enclosures (*)
Annex 27:	Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28:	Low Energy Cooling Systems (*)
Annex 29:	Daylight in Buildings (*)

Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO_2 Emissions Optimization in Building Renovation
Annex 57: Evaluation of Embodied Energy and CO_2 Equivalent Emissions for Building Construction
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings
Annex 60: New Generation Computational Tools for Building and Community Energy Systems
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings
Annex 62: Ventilative Cooling
Annex 63: Implementation of Energy Strategies in Communities
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles
Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems
Annex 66: Definition and Simulation of Occupant Behavior in Buildings
Annex 67: Energy Flexible Buildings
Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)

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