

**INTRODUCTION OF MICRO COMBINED HEAT AND POWER
GENERATION UNIT FOR RESIDENTIAL USE IN GERMANY**

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ABSTRACT

A micro cogeneration unit for single family homes in Germany has been developed. The mCHP (=Honda micro Combined Heat and Power generation) unit comprises of a small gas engine that produces hot water and electricity for residential use in a highly efficient way. Decentralized energy which helps to reduce grid losses is provided.

The unit is an evolution of the previous model sold in Japan since 2003. Now Honda has developed a dedicated mCHP unit for the German market. The following three main development goals had to be achieved to help assure full compatibility with German requirements and to meet customer expectations.

The first goal was the adaptation to German requirements (such as indoor installation in the basement) and corresponding standards (especially emission- and safety related). In accordance with these requirements the control devices of the mCHP unit incorporate a redundant circuit design of the safety related functions. Externally a combined, coaxial intake / exhaust pipe has been installed for clean indoor operation.

Second target was a technical evolution of the existing Japan model. The cogeneration unit has been fundamentally enhanced to achieve a higher electric efficiency and an overall efficiency of 92% at LHV basis. Total package became more compact. One key-technology to enable these enhancements is the so-called EXlink - Extended Expansion Linkage Engine - based on the Atkinson cycle. Using a multiple linkage system to optimize the thermodynamic process the engine's fuel efficiency could be enhanced.

And thirdly in order to provide high efficiency as well as heating and hot water comfort at all seasons the mCHP unit has been integrated with an advanced Vaillant heating system. This includes a condensing gas-boiler, a heat storage tank and a hydraulic interface to transfer the heat from the mCHP unit to the heat storage and a new system controller. Besides the styling was adapted resulting in an integrated system design "of a piece".

This is the first micro CHP with an internal combustion engine in the 1kW (electric) category especially designed for energy-efficient use in single family homes in Europe.

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PAPER

2.1. INTRODUCTION

Energy is inevitable as the base of economical wealth and important to help assure quality of life and comfort for people all over the world. Under the basic conditions of limited resources, the need for CO₂ reduction and growing concerns about nuclear power the question how to provide safe, secure, clean and reasonably-priced energy for an increasing demand is one of the fundamental challenges on today's agenda.

In this situation energy efficiency offers an alternative approach with a large saving potential. A quick implementation is possible using proven technology such as CHP (Combined Heat and Power). The valuable resources of fossil fuels and especially gas can be exploited in the most efficient and environment-friendly way. This also contributes to help assure a stable energy supply.

In view of these advantages the EU is promoting a wider CHP use in order to achieve the goals of a 20% energy reduction in line with a 20% CO₂ reduction by 2020. On a national level Germany has defined targets to double the CHP share from currently 12% to 25% by 2020. Various support schemes have been introduced on national and regional level to achieve this target.

In fact the total final Energy consumption in the EU is largely determined by the sectors of transport (33%), industry (27%) and households (25%). This means a quarter of total final energy is consumed in households. In Germany buildings are responsible for around 40% of final energy consumption. The saving potential in this field is huge as the majority of heating installations uses outdated technology and e.g. non-condensing boilers are still the predominant installations in Germany.

Nevertheless, regarding CHP for residential use in Europe so far, the available units provide a thermal output of about 5 to 15 kW. These so-called Mini CHP units (like the Vaillant ecoPOWER 4.7) are well suited for multi-family homes (row housing, multi apartment buildings etc.) and hotels, gym etc. with a high heat demand. But their thermal output is too high to supply economical heat and power for single family homes. Therefore, based on the experience in Japan, Honda developed a new micro cogeneration unit for detached houses in Germany (**Fig. 1**).



Fig. 1: New generation Honda mCHP unit (German model)

The mCHP (=Honda micro Combined Heat and Power generation) unit comprises a small single-cylinder gas engine driving a three-phase multi-pole generator. Based on the highly efficient cogeneration process, it can reduce customers' energy bill, contributes to a significant CO₂ reduction, and provides decentralized energy which helps to reduce grid losses. The generated electricity is preferably "own-used" in the customer's house or can be fed into the grid depending on local regulations. In Germany this electricity is reimbursed according to actual electricity prices plus some compensation for environment-friendly energy.

The unit is an evolution of the previous model sold in Japan since 2003, and developed in parallel with a new model for Japan.

This paper introduces background for the development, technical features, structures, and an integrated heating system of the mCHP with especially for the German model.

2.2. BACKGROUND AND mCHP DEVELOPMENT

Honda Environment Strategy

To cope with the challenges of environment and energy Honda established its own company strategy to proactively develop technologies in response to the various environmental requirements. **Fig. 2** shows these requirements and their priority over time with air pollution as an initial issue. Today's main focus is on climate change and how to reduce CO₂. Thirdly the saving of resources and energy is of growing importance. The corresponding Honda technologies, offered and developed to reduce each environmental issue, are shown on the right side.

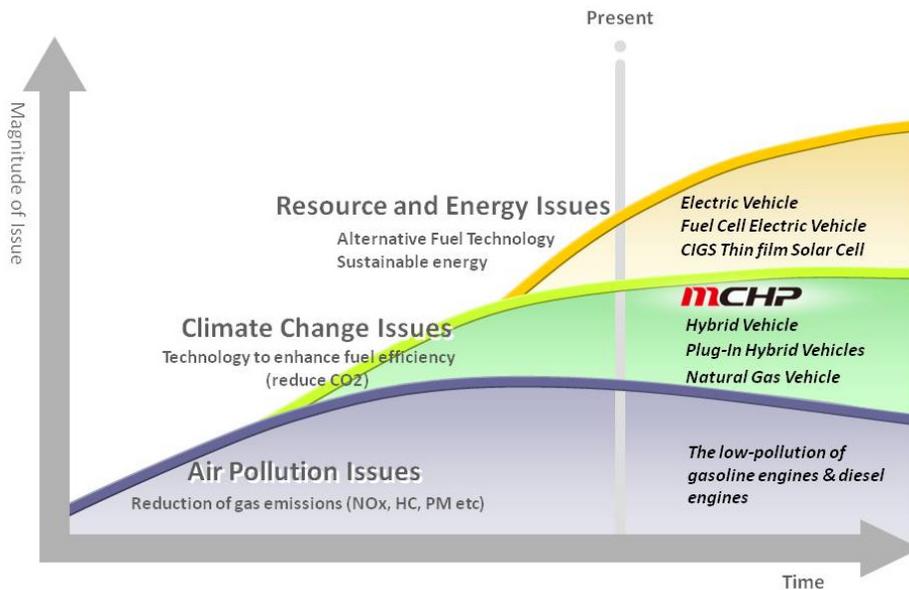


Fig. 2: Honda environment strategy

Honda recognizes that micro cogeneration systems, in which field Honda can utilise its core engine technologies for efficiency enhancement, can play an important role to these environmental challenges.

Honda's mCHP Experience

Under these circumstances, Honda started research and development of a highly efficient mCHP unit powered by natural gas for residential use since early 2000s. In 2003, the first mCHP unit was released to the market in Japan under the brand name of "ECOWILL" through natural gas utility companies. This mCHP system (**Fig. 3**), via a model change in October 2006, reached over 107,000 units in the cumulative sales in Japan as of May 2011. Moreover, based on the experience in Japan, a similar model was developed and introduced to the US in 2007. Some modifications, such as a higher electricity output than Japanese model, were made to the US model so that it suits the way of life in the US due to more electricity consumption on average when compared to Japan.



Fig. 3: Honda mCHP system in Japan

In line with the expansion of mCHP business in Japan and US, Honda has been studying the possibilities and approach to offer the mCHP unit in Europe.

Approach for Europe

Studies in Europe showed that the requirements for heating systems are different depending on the circumstances such as climate, preferred energy, style of houses, customer expectations etc.

These influences vary from country to country and the requirements for heating appliances are not all the same over Europe. Therefore instead of trying to find a balanced solution for whole Europe Honda decided to focus on Germany to develop a dedicated mCHP unit for the specific German requirements.

Reasons to select Germany as primary market:

1. A positive legal environment for CHP i.e. the German KWK (Kraft-Wärme-Kopplung = CHP) law to promote CHP and regulating compensation for CHP electricity delivered to the grid
2. High safety and certification standards (benchmark covering most of the requirements in other European countries).
3. Considered as leading country with regard to environmental technology
4. Large market with a high acceptance of consumers in clean, innovative, and environment-friendly technologies

Honda Vaillant Cooperation

Although in Germany Honda is one of the conversant makers in the automobile- and motorcycle business, and offers a wide range of power-products for different applications, Honda is a newcomer in the field of heating and energy.

In order to provide an optimum micro CHP solution in terms of technology, product and service, Honda looked for a partner company with high expertise in heating technology and excellent market knowledge. Honda has signed an OSA (Overall Supply Agreement) with Vaillant to jointly develop the new mCHP system for single family homes, which was overlooked until recently.

Vaillant is not only one of the leading manufacturers of high-quality heating appliances in Germany but also has long-lasting experience in Mini CHP business with their ecoPOWER 3.0 and 4.7.

Joint field test between Honda and Vaillant for the new mCHP system started in late 2008. In March 2009 the partnership was announced to public with the aim to start sales in 2011.

Development Concept

For the actual development the following three main development targets had to be achieved to help assure full compatibility with German requirements and to meet customer expectations:

1. Adaptation to local requirements => “German type”
2. Technical evolution of existing model (from Japan) => “New generation”
3. Integration with Vaillant heating system => “ecoPOWER 1.0 System”

The following three chapters explain in detail how these three goals have been achieved

2.3. TARGET 1: ADAPTATION TO GERMAN REQUIREMENTS

Indoor Installation

First of all, opposite to Japan where the mCHP unit is in all cases installed outdoors, such heating appliances are installed indoors in Germany. In accordance with its typical location in single family houses the German mCHP system has been targeted to be installed in the basement as a part of an integrated heating system in order to utilize recoverable heat from mCHP unit through all the seasons.

For installation in the basement, it is important to comply with the Council Directive 90/396/EEC – EC Gas Appliances Directives – and deep consideration for safety is obliged. Among all, prevention of exhaust-gas leakage into the basement and safety for electrical components and controls are important.

Concerning the evacuation of exhaust gas, a structural technique has been applied to the German mCHP unit which provides air-tightness at the same level as what is required to type-C central heating boilers regulated by the European Standard EN483. Inside the German mCHP unit can be divided into two areas: “non air-tightness area”, and “air-tightness area”. Most of electrical devices, such as an inverter and an Electric Control Unit (ECU), are located in the non air-tightness area, and an air-intake system, an engine, a heat exchanger, and a muffler for exhaust noise reduction, are intensively located in the “air-tightness area” (**Fig. 4**).

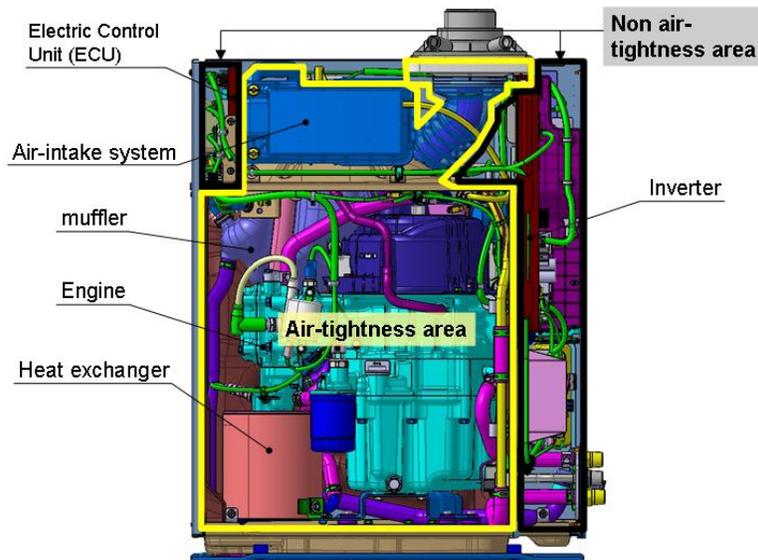


Fig. 4: Area classification inside mCHP unit

Besides, adoption of a concentric air-intake/exhaust connection port has enabled a structure for “complete surrounding of the combustion products circuit by the combustion air circuit”, and its leakage rate has reached at the same or less level of maximum admissible value which is indicated in the 6.2.2.2, Table 8, of the EN483. This structural feature helps prevent spread of exhaust gas into the basement even at a case of exhaust gas leakage from its original passage.

Redundant Circuit Design

Next, for the safety for electrical components and controls, all the control functions are classified according to the Classes of control functions regulated by the European Standard EN13611 based on the result of a risk assessment for the design of the German mCHP unit. Failure analysis (FA) and software evaluation (White Box / Black Box Test) were accordingly performed to applicable control functions, and redundant circuit designs have been provided.

The importance for safety increases in alphabetical order from Class A, B, to C. Control functions classified as Class C usually need doubled micro-processors for signal conditioning as well as doubled sensing devices. The German mCHP unit has been designed with a redundant circuit as necessity through discussions with a test laboratory to satisfy the applicable requirements of EN13611, which resulted in the certification of CE marking for the German mCHP unit.

European Gas Types

It is also required to meet a wide range of gas compositions. In Europe, due to a complicated pipeline network from various areas (such as the North Sea, Groningen and Russia) with various gas compositions, many kinds of natural gas with different heating values and Wobbe Index are distributed depending on the country or local areas. As a comparison between 13A gas, which is the most popular natural gas (over 90% share) in Japan, and European gases, **Fig. 5** shows variations of Wobbe numbers¹⁾.

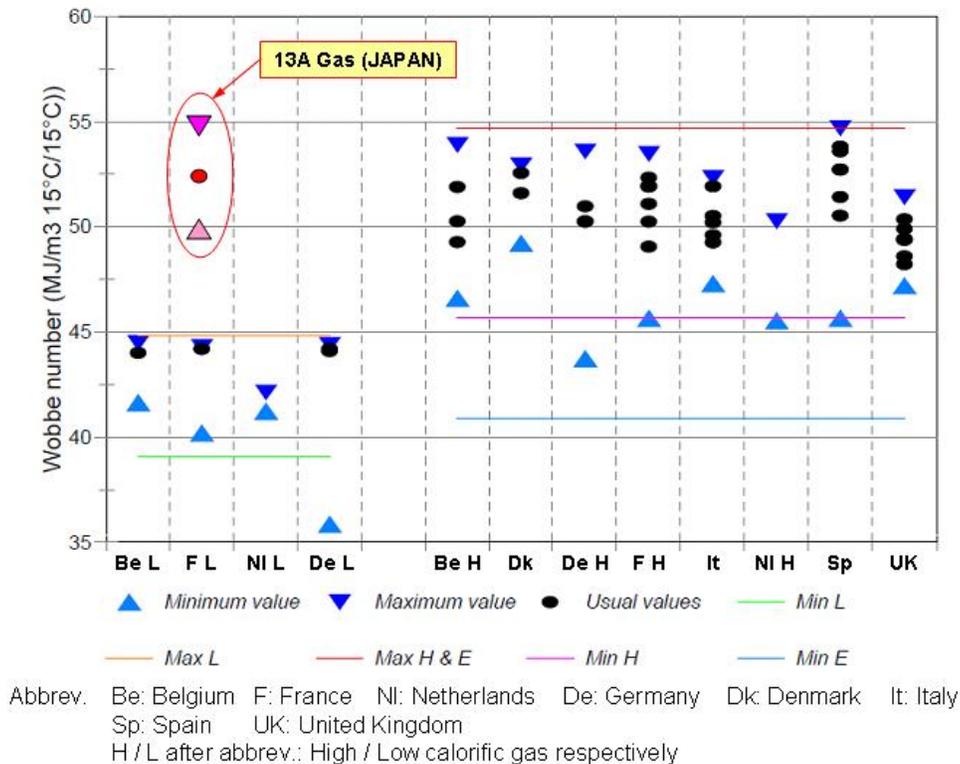


Fig. 5: Wobbe variations and groups of the 2nd gas family (EN437)

In order to meet this variety of the gas, the European Standard EN437 classifies several gas groups based on the Wobbe index, and also regulates test gases for each gas group. The German mCHP unit has passed combustion performance tests by the test gases for Group E and Group LL to meet the gas category I_{2ELL} , which suits most of natural gases widely distributed in Germany.

2.4. TARGET 2: TECHNICAL EVOLUTION (NEW GENERATION)

EXlink - Extended Expansion Linkage Engine -

The new cogeneration unit has been fundamentally enhanced to achieve a higher electric efficiency of 26.3% and an overall efficiency of 92% (both at LHV basis). One key-technology to enable these enhancements is the so-called EXlink - Extended Expansion Linkage Engine - based on the Atkinson cycle. The original idea for this technology was developed about 130 years ago but it was never implemented for small engines.

Linkage mechanisms such as a trigonal link, swing rod and eccentric shaft were added to the connecting rod and crankshaft of a conventional engine. An Atkinson cycle, with the intake/compression stroke length and the expansion/exhaust stroke length of unequal-lengths, was realized by making a 1/2 synchronous rotation between the eccentric shaft and the crankshaft²⁾⁻⁷⁾. (Fig. 6, Fig. 7)

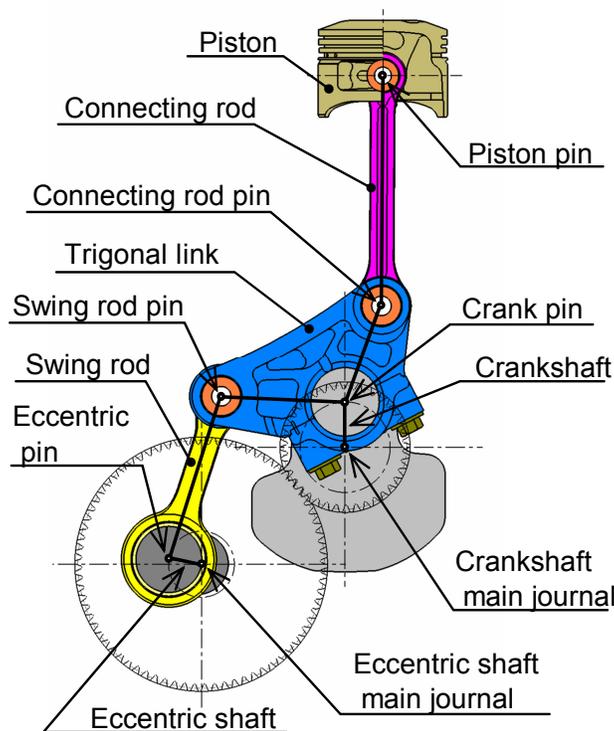
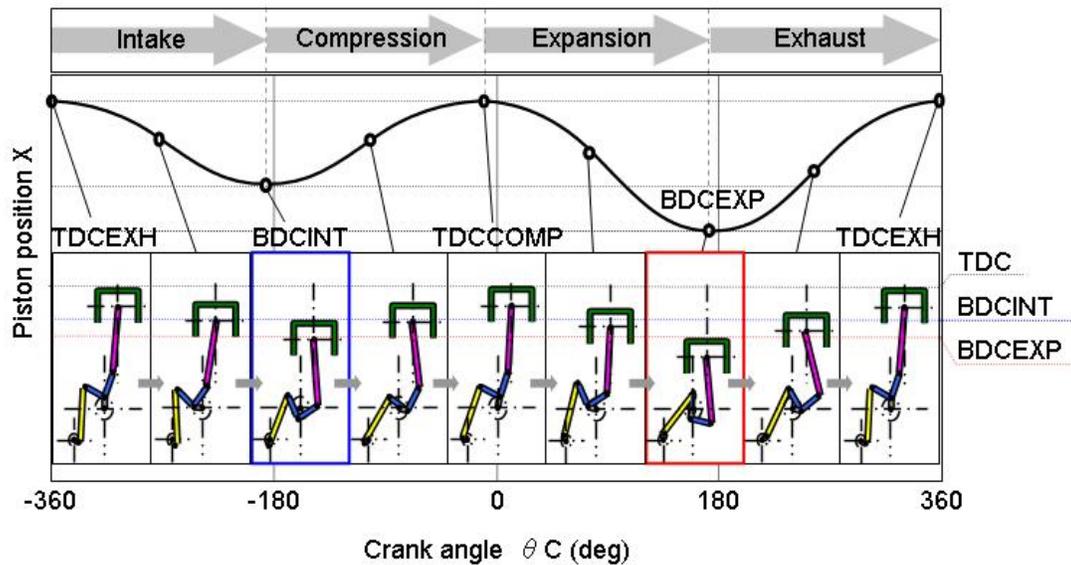


Fig. 6: Configuration of EXlink



Abbrev. TDC: Top Dead Center BDC: Bottom Dead Center
 INT: at Intake COMP: at Compression
 EXP: at Expansion EXH: at Exhaust

Fig. 7: Relationship between piston position and crank angle

An expansion ratio of 17.6 was set while maintaining a compression ratio of 12.2, comparable to that of the conventional model. With the extended expansion and a modified combustion chamber (size reduction of the chamber with a smaller bore, radially positioned intake/exhaust valves, and a semi-round chamber by placing a spark plug closer to the center), the electric efficiency was increased by 3.8 points to 26.3% from 22.5% including an efficiency enhancement of power conversion devices, i.e. more than 15% higher than the conventional model.

Heat Recovery and Inner Air Flow

However, this enhancement of the thermodynamic process could result in lower heat recovery, which is apt to cause lower overall efficiency. In order to address this technical trade-off, ventilation air flow was reconsidered.

As mentioned before, inside the German mCHP unit can be divided into two areas: “non air-tightness area”, and “air-tightness area”. An estimation of heat generation and actual temperature measurement of various parts were performed to each area for an optimized flow of ventilation air. As a result, necessary internal cooling was satisfied by only the engine’s air intake and natural radiation from outer panels in the “air-tightness area”, while a small axial-flow fan was employed for forced air-cooling of the electrical devices in the “non air-tightness area”. By this technique, wasted heat to the atmosphere by ventilation was minimized, which resulted in the enhancement of the overall efficiency. Moreover, this structure simultaneously helps to keep the mCHP unit secured against a potential exhaust gas leakage because there is no need to discharge ventilation air from the “air-tightness area” to the basement.

Compact Package

Total package became more compact with 33% reduced volume and less weight. This is mainly owing to the following modifications:

- Joint-fastening of a cylinder, an oil pan, and an oil tank
- Assembled air/fuel supply device: Integrated layout of a gas linear valve and a throttle valve
- Pre-foamed type, thinner sound insulating material
- Modified installation of electrical components on printed circuit boards

Specifications

The main specifications of the mCHP unit are shown in **Table 1**:

Engine:	EXlink - Extended Expansion Linkage Engine -
Generator:	3-phase 27-pole generator with starter function
Input:	Natural gas (E/LL)
Output:	2.5 kW (heat), 1 kW (electric)
Efficiency:	65.7% (heat), 26.3% (electric), 92% (overall) (at LHV)
CO ₂ reduction:	about 30% (compared to non-condensing boiler)*
Dimension	W580 × D298 × H750
Mass:	68 kg (dry)
Noise:	46 dB(A) @ 1m

**Basis: CO₂ emission factor for electric power in Germany: 0.506 kg/kWh
[Source: BDEW (Bundesverband der Energie und Wasserwirtschaft),
the German association for energy and water power.]
Efficiency of non-condensing boiler: 88% at LHV.*

Table 1: Specification and technical features

2.5. TARGET 3: mCHP INTEGRATION WITH VAILLANT HEATING SYSTEM

Background and System Overview

To make best use of a micro CHP its thermal output should be in line with the basic heat demand (heating and hot water) of a single family house (15,000 and 25,000 kWh/year) so that a long annual running time in which own electricity is generated can be achieved. This is the base of an economical and cost efficient mCHP use for detached houses.

On the other hand the thermal peak load (e.g.: during cold winter days) is higher than the mCHP unit's thermal output, therefore an mCHP unit alone cannot always provide enough heat to cover the (comfort) requirements of customers over the whole year and under all conditions. It is therefore important to complement the mCHP unit with an additional peak boiler and a heat storage tank. This also contributes to a high system flexibility because the heat of the cogeneration process can be stored allowing to generate electricity when it is especially valuable or demanded for own use.

System outline and interfaces were jointly developed by Honda and Vaillant in a close partnership based on their expertise in each field. The system includes a condensing gas-boiler for peak load (ecoTEC in 3 versions VC 146, VC 206, VC 276) and a heat storage tank (allSTORE 300l or 500l version). Both are existing Vaillant heating appliances using latest technology. Additional components are the heat recovery module and the system controller (energy manager). These components have been especially developed by Vaillant. The complete system (**Fig. 8**) is offered as one package under the name ecoPOWER 1.0.

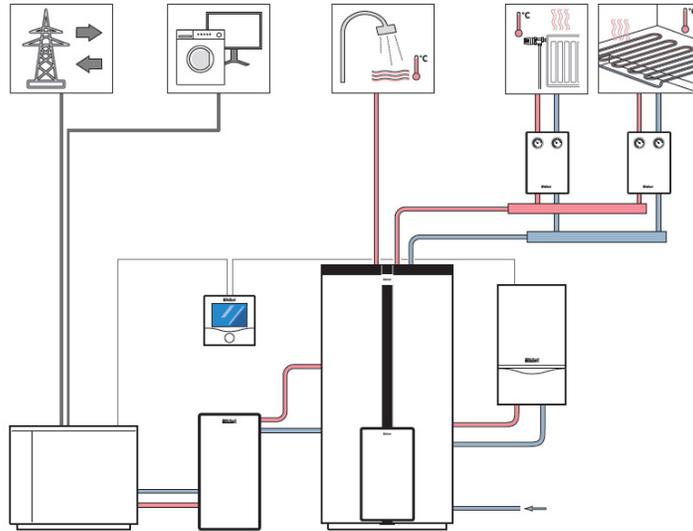


Fig. 8: System outline

Hydraulic Integration

After cooling the engine the hot liquid produced in the mCHP unit is delivered to the heat recovery module (**Fig. 9**) which serves as hydraulic interface to the heating appliances. By means of a plate heat exchanger the heat from the primary mCHP circuit is efficiently transferred to a separate circuit directly connected to the heat storage tank which provides hot water for room heating (i.e. radiators) and fresh tap water.



Fig. 9: Hydraulic integration (Heat recovery module)

Two separate circuits are necessary because the cooling liquid for the mCHP unit includes so-called Long Life Coolant (LLC) to protect the engine from inside corrosion and to help assure a high durability. Also the two pumps for both circuits are integrated in the compact hydraulic module.

Electric Integration

The total system is operated by a new system controller (**Fig. 10**) which offers a wide range of functions for easy and sophisticated control of the complete system via touch screen. It allows the owner to operate a wide range of settings according to his individual needs. The so-called energy manager provides detailed information about the state of the heating appliances and about temperatures in the storage and circuits. Also the amount of generated electricity is measured and indicated. The system controller features an interface for W-LAN connection and convenient remote control by a special i-Pad application is possible.



Fig. 10: Vaillant system controller with touch-screen

The system controller is linked with the cogeneration unit and communicates to the mCHP unit by CAN bus. Honda and Vaillant Software engineers established a common communication language and parameter settings. This was one of the challenges in the development process because it concerns not only technical issues of processing signals but also the question how to treat certain messages and how to make sure that only skilled staff has access to those.

Combined Intake / Exhaust Duct

Usually for the indoor installation intake air for the mCHP unit has to be provided from outdoors and exhaust gases need to be directed to outside by a flue gas system. To help assure high safety, compactness, and easy installation, a combined, coaxial Vaillant pipe is used (**Fig. 11**). These are the same standard parts as used for Vaillant boilers. They are commonly available in a wide range of shapes and dimensions providing high layout flexibility.



Fig. 11: mCHP unit intake-/exhaust connection and coaxial Vaillant pipe

Design Integration

The mCHP unit's exterior shape has been newly designed with a simple but elegant "round shape" styling for universal installation at various locations in the house. And besides the technical integration, the mCHP unit was also adapted to match with the styling and the colour of the Vaillant heating components which results in an integrated system design "of a piece" (**Fig. 12**).



Fig. 12: Design Integration (Vaillant image sketch)

2.6. MARKET INTRODUCTION

In order to help assure a smooth market introduction of this new product logistics and service structures have been established parallel with ongoing development work and extensive field testing.

In spring 2010 Vaillant performed a large information campaign and explained the mCHP unit to their installers. In a next step technical training on installation, maintenance and service was carried out. Broad expertise has been established and meanwhile over 500 Vaillant installers successfully joined web based training and practical courses. Honda trained also 25 nationwide Vaillant service specialists to secure Level 1 and Level 2 support.

Experts and interested groups in the heating sector know well about micro CHPs for residential use but it seems that there is less awareness of this technology among the public and normal consumers. Therefore the partners Honda and Vaillant established a common PR strategy aiming to raise public attention by providing continuous information already before the launch.

In February 2011 the ecoPOWER 1.0 with the new Honda mCHP unit as core element of the system was opened and explained at a special press conference in Düsseldorf. Then one month later it was presented at the Frankfurt ISH show where it received a lot of interest (**Fig. 13**). After the ISH event Vaillant organized introduction events in their Sales-Offices and at local fairs across Germany.

Various media like newspapers, magazines and TV stations reported about the mCHP system and the sales start of EcoPower 1.0 in the second half of 2011.



Fig. 13: ecoPOWER 1.0 at Frankfurt ISH show and installation example

2.7. SUMMARY

- A dedicated micro cogeneration, mCHP unit for the requirements of the residential heating in Germany has been developed. With an output of 2.5 kW (heat) and 1 kW (electric) it is the first micro CHP with an internal combustion engine to enable an economical use of a micro CHP for single family houses.
- The new mCHP unit features an innovative engine: EXlink - Extended Expansion Linkage Engine - implementing an optimized thermodynamic process resulting in a high electrical efficiency of 26.3 % and an overall efficiency of 92 % in a very compact package.
- The mCHP system provides decentralized energy which helps to reduce grid losses, contributes to save resources and to reduce CO₂ emissions by about 30 %, it helps customers to reduce their energy bill, and provides independence from rising electricity prices.
- To help assure optimum heating comfort under all conditions the mCHP unit is integrated in an advanced Vaillant heating system including newly developed Vaillant components. The complete system is marketed by Vaillant as a package under the name ecoPOWER 1.0.

3. ACKNOWLEDGEMENT

Honda would like to thank Vaillant for the efficient and fruitful cooperation during the development of the mCHP system for Germany. Vaillant's expertise and experience was indispensable to achieve our common goals and to start the market introduction of ecoPOWER 1.0 in 2011. Also the preparation of this report has been supported by Vaillant providing a number of photos.

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