# Evaluation of micro combined heat and power systems in the Walloon residential sector through dynamic simulation

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## 1. ABSTRACT

Combined Heat and Power (CHP) systems are known for a long time and are well established especially in the industrial sector where they allow interesting energy savings. However, the application of this technology in the residential and small tertiary sectors remains difficult due to the irregularity and the low heat demand during certain months of the year. The “Smart Micro Cogen” project focused on evaluating the potential of micro CHP systems (≤ 50kW$_e$) in the Belgian building stock (residential and small tertiary sector) by means of dynamic simulation using TRNSYS 17 software.

This work provides the hypotheses allowing representing the Belgian residential building stock and the different elements taken into account in the modelling and simulation of a complex HVAC system including a micro CHP system.

Some results of the various simulations performed will be presented to show the robustness of the proposed modeling.

**Keywords:** Combined Heat and Power, CHP, Complex HVAC system simulation, Dynamic simulation, TRNSYS

## 2. FIRST LEVEL HEADING

### 1. Introduction

According to the European Commission (2013), buildings are responsible for 40% of primary energy consumption in the EU. Improvements of the buildings energy efficiency are therefore crucial to ensure that EU meets its energy and climate ambitious targets by 2020.

One target of the 2020 Climate & Energy package is a 20% improvement of energy efficiency. In this context, the 2012 Energy Directive establishes measures to help countries to reach this target. One of them is to achieve an equivalent level of savings through alternative heating systems reaching the same level of efficiency.

Combined Heat and Power (CHP) is one of the option available within these measures in order to help the EU to achieve his goal of energy efficiency improvement. These systems are known for a long time and are well established especially in the industrial sector where it allows interesting energy savings. However, the application of this technology in the residential and small tertiary sectors remains difficult due to the low and intermittent heating demand during certain months of the year. Nevertheless, this technology is being continuously improved and new options are now available. Micro-CHP systems (≤ 50kW$_e$) are entering the residential heating market and seem to be an attractive solution with both environmental and economical potential benefits.

The Smart Micro Cogen (SMC) took place in this context with the funding of the main belgian electricity producer. The aim of this project was to evaluate the potential of the micro cogeneration in the Belgian existing real estate in the current and future context of smart grids. CHP products electricity that, injected on the grid atthe right moment could help to balance grid. The aim of the SMC project was to evaluate the impact on the grid of this technology and the cost for all actors in stake. This paper focuses on the only Energy aspect in residential buildings.

A state of the art of CHP technologies and a state of the market in Wallonia was carried out. Four buildings and two CHP technologies considered as the most interesting and mature were selected. The selected cases were simulated in order to evaluate their performance. The use of TRNSYS 17 allowed the modelling of the complex HVAC system (CHP system, storage tank, emission systems, DHW,...). In these first simulations, two CHP systems (Internal Combustion Engine (ICE) and Stirling) were controlled according to the heat demand. The electrical storage use was also studied.

In a second set of simulations, the analysis took into account the control of the CHP system in order to minimize its impact on the grid by allowing electricity production only at the appropriate times.

As CHP is often presented as a solution to reduce primary energy consumption, this criterion was evaluated as well as other relevant criteria: the cost of use, electricity self-consumption, electricity coverage, injection on the grid... For bothCHP technologies (ICE, Stirling) simulations were carried out.

## 2. Hypotheses and modelling

### 2.1. Buildings

Four relevant buildings were selected in order to be the most representative of the Belgian real estate according to the TABULA (Cyx, Renders, Van Holm, & Verbeke, 2011) and PROCEBAR (Georges, Gendebien, Bertagnolio, Dechesne, & Lemort, 2013) studies. The buildings in Figure 1 -are considered as the the most interesting for the use of CHP technology (with sufficient heat demand and sufficient potential electric production). They represent a total of 40% of the Belgian building stock with consequently a large potential impact.

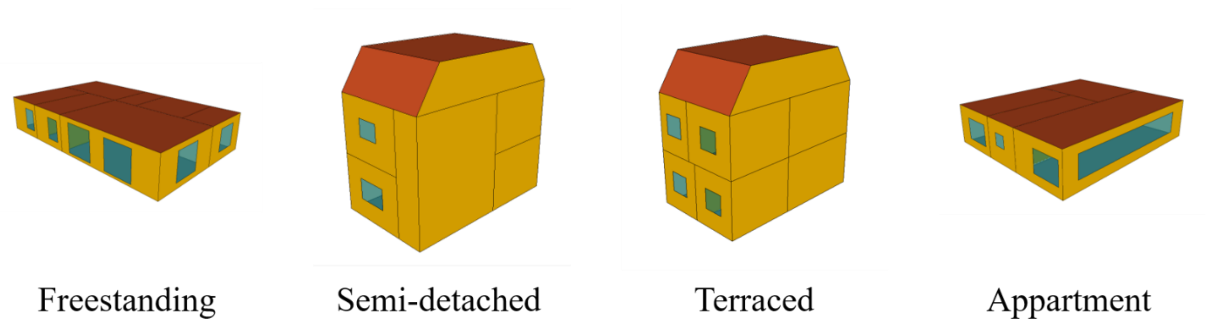


*Figure 1 : Sketchup models of the selected buildings*

General characteristics of buildings are described in table 1

*Table 1: General characteristics of buildings*

| | Freestanding | Semi-detached | Terraced | Appartment |
|---|---|---|---|---|
| Building U-values ($W/m^2K$) | Uwall = 1.771<br>Uroof = 0.435<br>Ufloor = 0.729 | Uwall = 2.259<br>Uroof = 3.995<br>Ufloor = 3.379 | Uwall = 2.259<br>Uroof = 3.995<br>Ufloor = 3.379 | Uwall = 0.491<br>Uroof = 0.435<br>Ufloor = 0.729 |
| Area ($m^2$) : | 112 | 113 | 133 | 171 |
| Number of occupants | 4 | 4 | 4 | 4 |

Rooms were divided in three types in order to apply different heating schedules: day occupied room, night occupied room and bathroom. In each room type, different temperature set points were applied corresponding to three types of consumers: low, medium and high consumer.

In each building, the internal gains and occupation rate were taken into account. It was considered that a family of four people with one full time working parents lived in the buildings.

These hypotheses led to three heating demands for each building as shown in Table 21.

*Table 21: Yearly heating demands*

| **Building** | **Low consumer** | **Medium consumer** | **High consumer** |
|---|---|---|---|
| Freestanding | 24 913 kWh | 33 570 kWh | 48 425 kWh |
| Semi-detached | 23 409 kWh | 32 609 kWh | 39 442 kWh |
| Terraced | 19 152 kWh | 26 258 kWh | 31 758 kWh |
| Apartment | 10 823 kWh | 13 791 kWh | 16 627 kWh |

Note that assumption in specifications of the project was that buildings envelope were not changed. Only the heat production system could changed (from boiler to CHP)

### 2.2. Weather data

Weather data used in the TRNSYS simulations are Meteonorm data from Uccle (Belgium).

### 2.3. Electrical consumption

Scenarios of the building's electrical consumption has been established on the basis of the "CIEL"1 (Commission des Communautés Européennes, n.d.) and "REMODECE"2 (Enertech, ADEME, & Union Européenne, 2008) studies which include the hourly consumptions (in Wh/h) for each electrical appliance.

From these curves, daily usage profiles for each month and for each electrical appliance were determined. A method was then used to re-establish annual scenarios on a stochastic basis.

When the profiles of the various elements are aggregated they should match a profile similar to the total home consumption profile obtained from “Synthetic Load Profiles” curves leading to three electrical consumptions as shown in Table .

*Table 3: Yearly electrical consumptions*

| | **Low consumer** | **Medium consumer** | **High consumer** |
|---|---|---|---|
| Yearly electrical consumption | 2 600 kWh | 3 500 kWh | 4 400 kWh |

### 2.4. DHW consumption

Hot water consumption is an important assumption for the simulation of a residential house or a rest home. Statistical values were produced by IEA Annex 42 (Knight, 2007) with a time base of 15 minutes.

Consumption of water at 60 °C from mains water at approx. 10 °C (ΔT = 50°C)) is assumed.

For the three consumers types, the values are shown in Table .

*Table 4: Hot water consumption*

| | **Low consumer** | **Medium consumer** | **High consumer** |
|---|---|---|---|
| Hot water consumption | 25 L/person.day (2 100 kWh/year) | 37.5 L/person.day (3 200 kWh/year) | 50 L/person.day (4 400 kWh/year) |

### 2.5. HVAC system

The most important part of this work was to model the HVAC system of the buildings in order to correctly assess the impact of the CHP systems integration.

After a state of the art of micro-CHP technologies, two of them were selected that could be qualified as mature in terms of both their development and their presence on the Belgian market for the residential sector: ICE and the Stirling engine. Two dynamic models of these technologies were calibrated and used in the different simulated cases for comparison with a conventional boiler.

Based upon these technologies, two configurations of the HVAC system were modelled as shown in Figure 2 where it can be observed that the ICE did not internally include an auxiliary boiler. This is due to the model of CHP (see below “CHP model”). CHP models were not developed in the project and some adaptations between existing CHP models and HVAC system were mandatory.

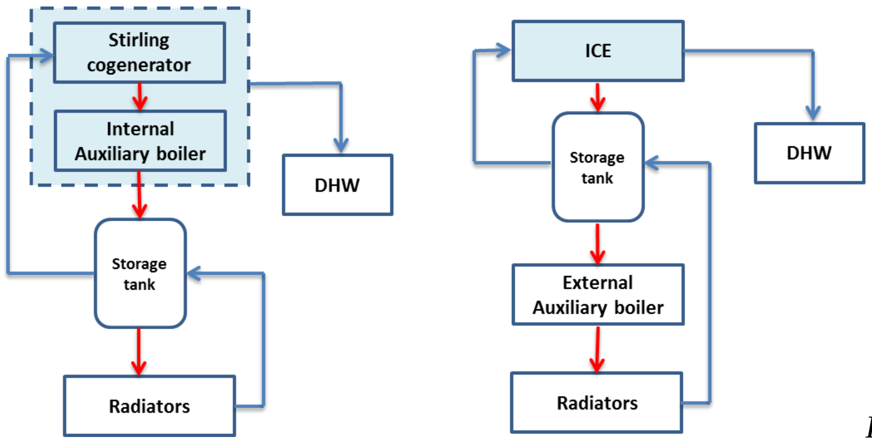


*Figure 2: Configurations of the HVAC system according to the CHP technology*

A choice has been made not to include pipes, pumps and heat exchangers in the modelling of the HVAC system.In order to optimise the use of the electricity produced, the use of a battery was also evaluated.

#### 2.5.1. CHP models

Three models of CHPs were studied in order to choose those that would best show the impact of such technologies.

Two TRNSYS types were choosen and both of them took into account the transient states of cogeneration systems (ignition, full speed operation and shutdown).

The ICE model was developed by Rosato & Sibilio (2012) and the Stirling model was developed by Bouvenot, et al. (2014).

The three CHP engines  characteristics are the following (Table ).

*Table 5: CHP parameters*

| **Technology** | **Stirling** | **ICE** | **ICE** |
|---|---|---|---|
| $P_{elec}$ | 0.9 $kW_e$ | 5.6 $kW_e$ | 1 $kW_e$ |
| $P_{therm}$ | 5.3 $kW_{th}$ | 14 $kW_{th}$ | 2.5 $kW_{th}$ |
| Nominal Efficiency (electrical, global) | $\eta_e = 0.13$<br>$\eta_g = 0.93$ | $\eta_e = 0.25$<br>$\eta_g = 0.93$ | $\eta_e = 0.25$<br>$\eta_g = 0.93$ |
| Auxiliary boiler | Integrated in the model | Not integrated in the model | Not integrated in the model |
| Power modulation | No | No | No |
| Market product | Hybris Power DE DIETRICH | AISIN System | - |

Note that model of ICE 1kWe is adapted from ICE 5.6 kWe with reduced power (flanged motor). No commercial product indeed corresponds to this model.

Time step of simulation is 1 min. This is imposed by model of Stirling with time step of 1 min maximum.

### 2.5.2. Radiators

The objective of the SMC project was to study only the choice of cogeneration over a boiler without changing the building. With this in mind, the emission system has not been changed between the "boiler" case and the "CHP" cases.

The radiators were sized in each zone of building according to the following temperature set points:

- Inlet temperature: 80°C (controlled temperature for heat supply)
- Outlet temperature: 60°C
- Room temperature set point: 20°C

In simulation, a heating curve was also taken into account to adjust the water temperature to the different radiators taking into account the outside temperature.

The choice of the different radiators was made by calculating the maximum demand for each room of the different dwellings.

In TRNSYS, the first approach was to use the Radiator Type 1231 (TESS library). However as shown in Figure 3, two problems with the return temperature of the radiators appeared. The calculated value was lower than the temperature in the rooms when the temperature set point decreased and was at certain times bellow 0°C.

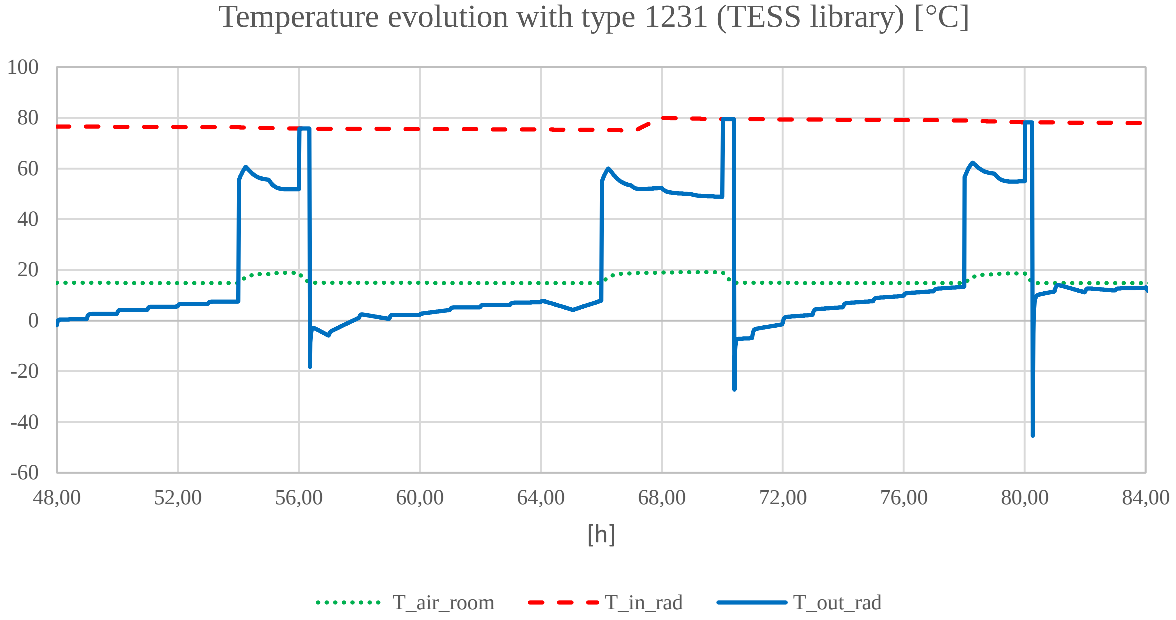


*Figure 3: Temperature evolution with type 1231 (TESS library)*

Following this, an analysis of the internal code of the type was performed. It appeared that the heat flow was correctly calculated according to the following equations:

$$\phi = \dot{m}.c_P.(t_{in} - t_{out}) \quad (1)$$

$$\phi = \frac{Q_N}{(\Delta T_N)^n}.(\Delta T)^n \text{ with } \Delta T = \frac{t_{in}-t_{out}}{\ln\left(\frac{t_{in}-t_{room}}{t_{out}-t_{room}}\right)} \quad (2)$$

where $\phi$ is the heat flow, $\dot{m}$ is the water flow rate, $c_P$ is the water heat capacity, $t_{in}$ is the temperature of the water entering in the radiator, $t_{out}$ is the temperature of the water leaving the radiator, $Q_N$ is the heat emission of the radiator under nominal conditions, $\Delta T_N$ is the mean arithmetic temperature difference under nominal conditions, $t_{room}$ is the air temperature in the room and n is the radiator exponent.

However, it appeared that the particular cases corresponding to low and high flow rates were not taken into account. Indeed, $\Delta T$ must be calculated differently when the flow is smaller than 2% of the nominal flow and when it is larger than 98% of the nominal flow (Ast H, 1986).

The following additional equations were therefore implemented in the Type 1231:

$$\text{If } \dot{m} \geq 0{,}98.\dot{m}_N : \Delta T = \frac{t_{in}+t_{out}}{2} - t_{room} \quad (3)$$

$$\text{If } 0{,}02.\dot{m}_N < \dot{m} < 0{,}98.\dot{m}_N : \Delta T = \frac{t_{in}-t_{out}}{ln\left(\frac{t_{in}-t_{room}}{t_{out}-t_{room}}\right)} \quad (4)$$

$$\text{If } \dot{m} \leq 0{,}02.\dot{m}_N : t_{out} = t_{room} \quad (5)$$

where $\dot{m}_N$ is the nominal flow rate.

### 2.5.3. Thermostatic valves

The thermostatic valves were implemented in TRNSYS after the creation of a new type based on the physical equations (Stephan, n.d.):

$$\text{If } \Delta t_c \geq \Delta t_{C,P} \text{ then } \frac{\dot{m}}{\dot{m}_N} = \frac{\Delta t_{C,P}}{\Delta t_{C,N}}\left(a_v + \left(\frac{\Delta t_{C,P}}{\Delta t_{C,N}}\right)^2 . (1 - a_v)\right)^{\frac{-1}{2}} \tag{6}$$

$$\text{If } 0 < \Delta t_c < \Delta t_{C,P} \text{ then } \frac{\dot{m}}{\dot{m}_N} = \frac{\Delta t_C}{\Delta t_{C,N}}\left(a_v + \left(\frac{\Delta t_C}{\Delta t_{C,N}}\right)^2 . (1 - a_v)\right)^{\frac{-1}{2}} \tag{7}$$

$$\text{If } \Delta t_c \leq 0 \text{ then } \frac{\dot{m}}{\dot{m}_N} = 0 \tag{8}$$

where $\Delta t_C$ is the temperature difference between the instantaneous temperature of the thermostat and the temperature, when the valve is just closed, $\Delta t_{C,N}$ is the nominal range of temperature difference $t_c$, $\Delta t_{C,P}$ is the proportional range of temperature difference $t_c$ and $a_v$ is the valve authority.

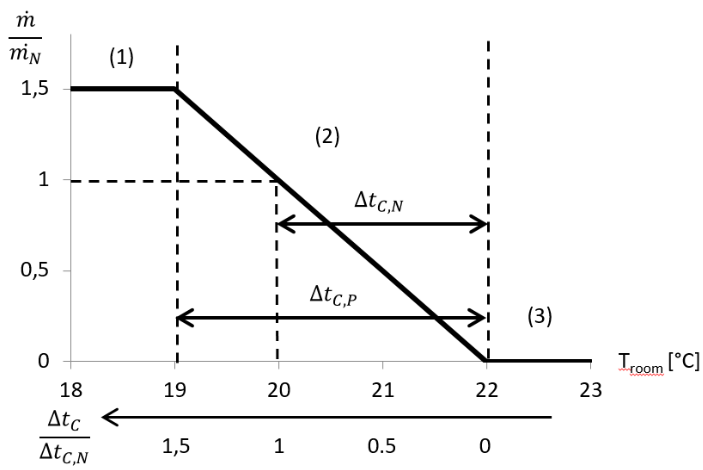


*Figure 4: Evolution of the relative flow rate trough a thermostatic valve*

### 2.5.4. Hot water tank

The type 543-NOHX (TESS library) was used for the hot water tank. The tank was divided in 7 nodes in order to consider the temperature stratification and the parametrization was made according to an existing model(VPS ALL-STORE from Vaillant).

A preliminary study was conducted in order to determine to ideal tank size. Three volumes were selected: 300L, 800L and 1000L. This study was conducted with the CHP Stirling model.

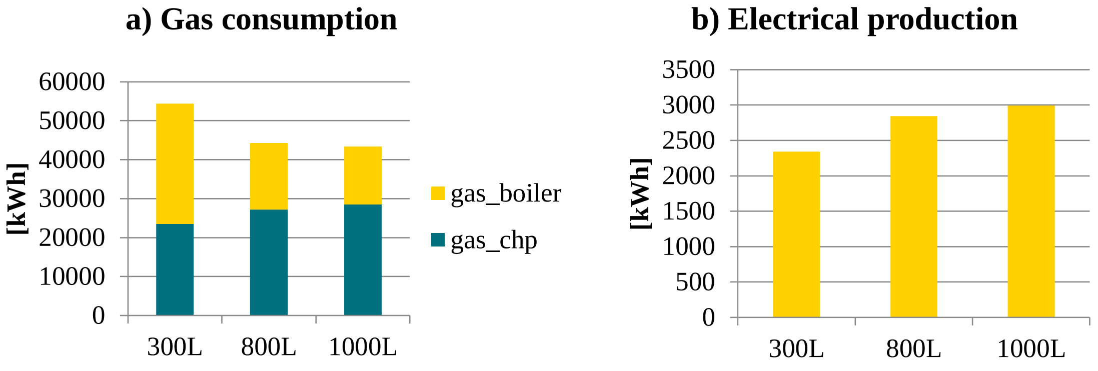


*Figure 5: a) CHP and boiler gas consumption for different hot water tank sizes; b) CHP Power output for different hot water tank sizes*

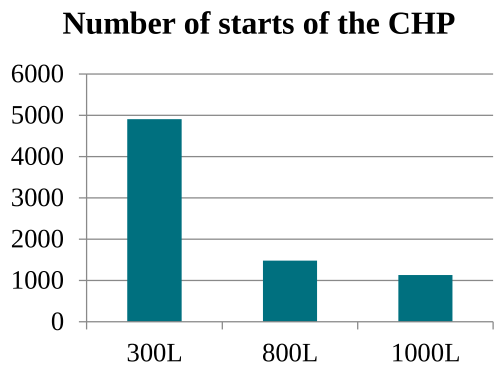


*Figure 6: Number of starts of the CHP for different hot water tank sizes*

The study showed that the best choice was the 1000L hot water tank for multiple reasons:

- The total gas consumption decreases when the tank size increases (Figure 5a).

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- The part of gas consumption from CHP increases while part of gas consumption from boiler decreases when the tank size increases as shown on figure 5a. That means that production from CHP increases. This is also highlighted by Figure 5b "Electrical production from CHP"

- The number of starts of the CHP module decreases when the tank size increases (Figure 6).

Those observations lead to a better use of the CHP with the 1000L hot water tank. Indeed, longer heating periods increase the number of working hour and improve the electrical production efficiency .

#### 2.5.5. DHW tank

The DHW tank was also modelled using the type 543-NOHX (TESS library) and parametrized like the hot water tank.

A preliminary study was conducted in order to determine the best way to produce DHW. Two methods were evaluated: using the heat produced by the CHP and using the electricity produced by the CHP. Second method allows to increase the self-consumption.

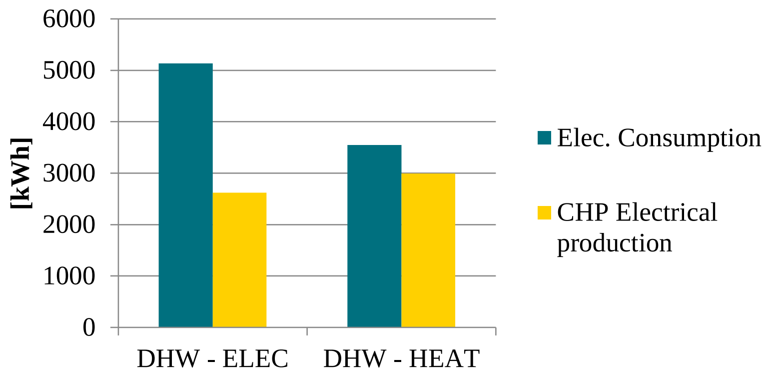


*Figure 7: Comparison of electricity consumption and CHP power output according to the DHW production method*

The study showed that using the heat produced by the CHP was the best way since it implies a higher production of electricity and a lower electrical consumption (Figure 7).

### 2.5.6. Controls

Strategies for steering cogeneration are a key point of the work. In this study, different management strategies were compared. These strategies include controls to optimize production of heat, electricity, grid assistance...

It should be noted that in all types of control, there was never waste of heat produced by cogeneration. This means that CHP was only allowed to start up when sufficient heat was required (possibly coupled with other conditions).

Moreover, the house was never considered as a “mini power plant”. There was no power generation strategy for the sole purpose of rejecting to the grid.

It should also be noted that all simulations take place at "equal comfort". All simulations include a CHP system paired with an auxiliary boiler.

Where cogeneration does not produce enough heat to fill all the needs of the building (for different reasons of sizing choice, control...), the auxiliary boiler brings the necessary supplement to satisfy the thermal comfort of the dwelling.

Three controls were implemented to the HVAC system using hysteresis.

It must be noticed that DHW heating needs are the priority. If the cogenerator is not sufficient to heat the DHW tank, an electrical resistance is present as an extra device to ensure that the temperature set point is reached.

### 2.5.7. Battery

Modelling an electric storage battery was not really planned or envisaged at the start of the project. Batteries remained a very marginal technology in the residential sector due to the lack of technological maturity, the cost of such systems and the lack of product available on the market.

However, quick evolution of the market lead to foresee this system

The electrical storage model used in the simulations was relatively simplified: the electrical storage was charged and discharged like a “water reservoir” without taking into account transient effects nor losses.

Capacity of the battery was set to 10 kWh. This value was chosen according to available product on market.

## 2.6. Controls description :

### 2.6.1. Heat driven

If no heat is required for the DHW tank, the CHP can feed the storage loop. The control temperature is the one at the outlet of the storage tank to the radiators (Tin_rad):

- If Tin_rad < 75°C: the CHP is turned on.
- If Tin_rad > 80°C: the CHP is turned off.

If the CHP is not sufficient to meet the storage heating needs, the auxiliary boiler can fill the gap. The controlled temperature is still the one at the outlet of the storage tank:

- If Tin_rad < 73°C: the auxiliary boiler is turned on.
- If Tin_rad > 78°C: the auxiliary boiler is turned off.

The electricity produced by cogeneration is first self-consumed to meet the electrical needs of the building. If the electricity produced by the CHP is not consumed, it is rejected to the network.

### 2.6.2. Grid control

In order to integrate the buildings in  smart grids, the CHP is controlled according to the grid status.

In this case, the CHP will only be allowed to operate and inject electricity to the grid when the grid needs it.

In order to control the state of the grid, the choice was made to use the Belgian “NRV” (Net Regulation Volume) indicator which is the difference between the sum of volumes of all control action “upwards” and the sum of volumes of all control actions “downwards” requested by Elia (Belgian network operator) in order to balance the electrical network, (Elia, 2018).

The CHP is then allowed to be turned on only if NRV is positive (when Elia had to request more actions upward than downward).

### 2.6.3. Battery control

This control is focused on self-consumption and “islanding” of buildings. In this configuration, CHP switches ON when heating needs are sufficient AND battery loading is minimum (minimum load was fixed to 20% of maximal load).  This ensures a minimum duration to CHP work and avoid high frequency in cycle of load/unload of the battery.CHP switches OFF if heat needs are not sufficient any more OR if battery is fully charged.

# 3. Simulations and result analysis

## 3.1. *Simulations*

Simulations were carried out for the four buildings and the three consumer profiles. In addition, the three technologies (ICE 1kW$_e$, ICE 5.6kW$_e$ and Stirling 1kW$_e$) were studied for each strategy (heat-driven (HEAT), network control (NRV) and battery).The results obtained for the terraced house and a medium consumer will be presented. The results for the other cases are similar to the following ones.

### *3.2. Results*

Total heat production results (Figure 8) are similar with or without CHP (compared to boiler) whatever CHP technologies or controls considered. The use of a cogeneration system will not penalise the consumer. If the cogenerator power is not sufficient to satisfy the thermal demand, the auxiliary boiler allows for each technology considered to fill the gap.

This result appears for all residential buildings and all consumption profiles (low, mdium, high consumer) considered.

The use of a cogeneration system and its control allows equal comfort compared to a boiler.

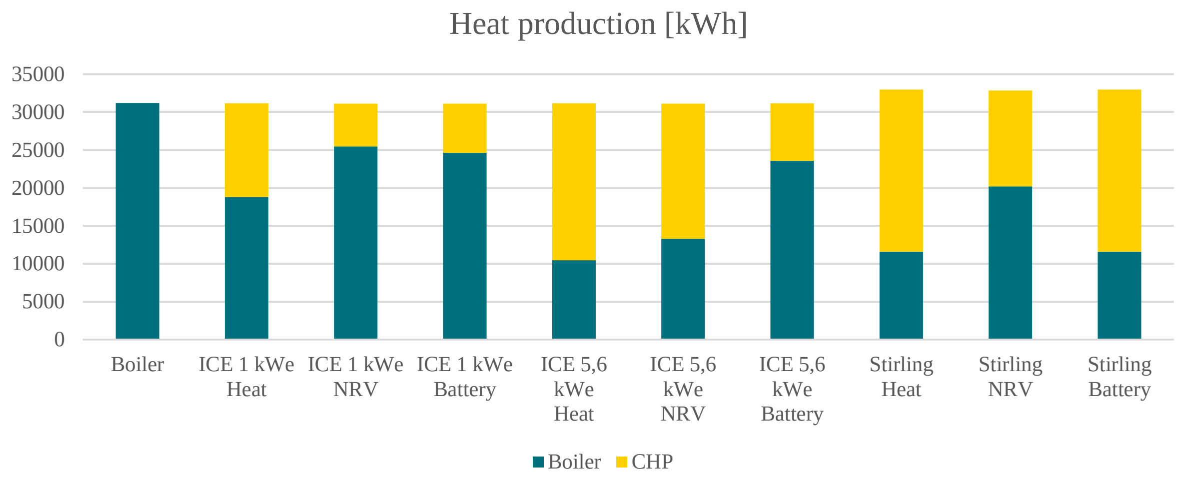


*Figure 8: Heat production comparison*

It also appeared that the Stirling system is better suited than the ICE 1kWe and equivalent to the ICE 5.6 kWe. Indeed, if scenario with heat driven (“ICE 1kWe Heat”, “ICE 5.6kWe Heat” and “Stirling Heat”) are compared, part of heat production from CHP is higher in the case of Stirling (equivalent to ICE 5.6kWe) than ICE 1KWe.

By analyzing the gas consumption of the complete system (Figure 9), it is clear that, whatever the technology considered, an excess of gas is always necessary in order to satisfy the criterion of equal comfort (boiler vs all CHP configurations). A cogeneration system always needs more gas than a boiler to produce 1kW th as a part of the energy consumed will be converted into electricity (the thermal efficiency of CHP is lower than the one of the boiler).

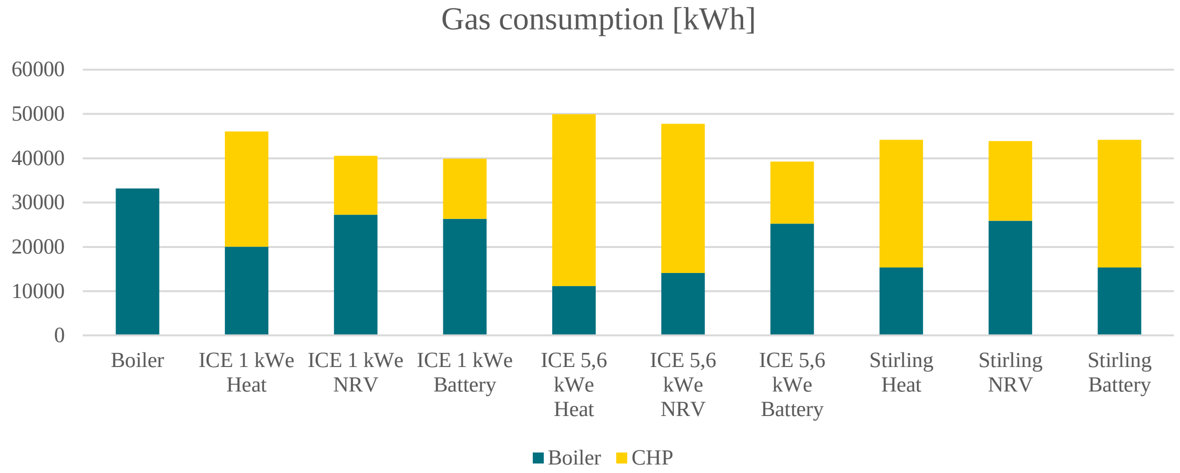


*Figure 9: Gas consumption comparison*

Cogeneration therefore requires more gas but produces electricity that can be consumed directly by the owner or sold to reduce his electrical bill. It is therefore important to analyse in detail this electricity production (Figure 10). The first analysis that can be made aims at looking if the production is directly carried out for the benefit of the owner of the system (in-situ valorisation).

Regarding to the technologies, a smaller engine seems most suitable. Although electricity production is lower, it is more constant and can therefore be better consumed in-situ than for a larger engine.

Regarding the strategies, the network control seems to have a small impact on self-consumption ("Heat" compares to "NRV" in the 3 technologies) even though it decreases the production but has more impact on self-sufficiency and the quantity of electricity bought (Figure 11). The use of a battery increases the self-consumption (Figure 10) as well as self-sufficiency (Figure 11 "Battery" compared to "Heat" and "NRV" for the 3 technologies) in all cases.

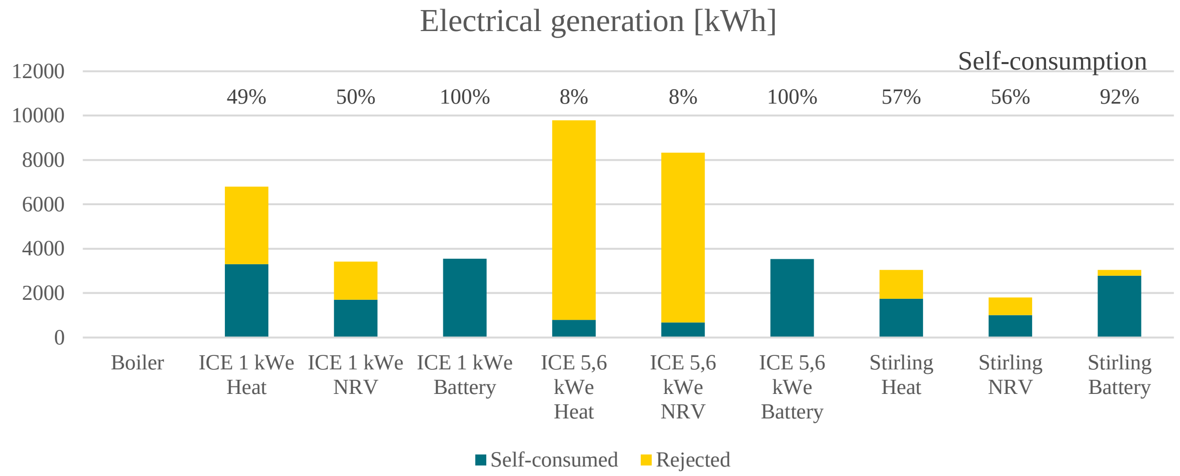


*Figure 10: Electrical generation comparison*

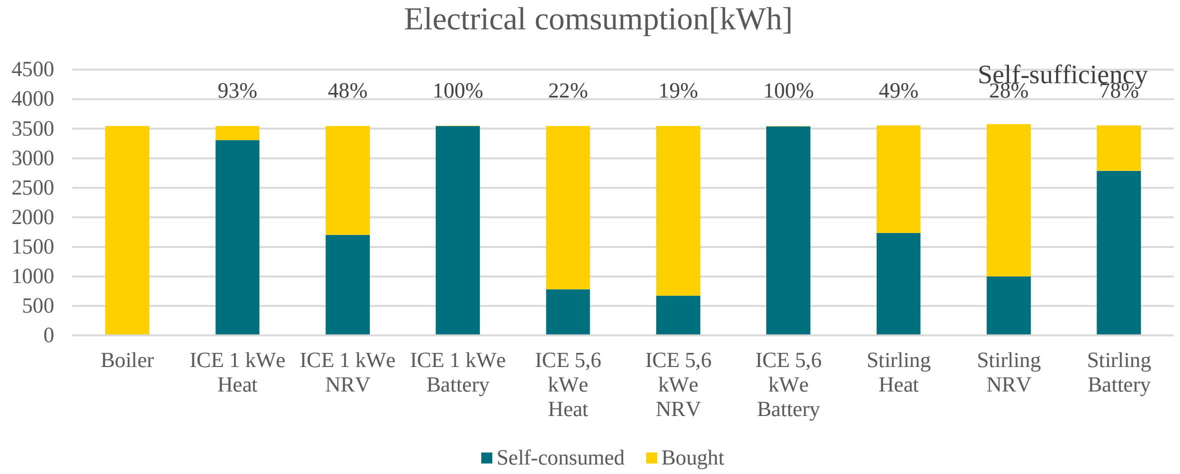


*Figure 11: Electrical consumption comparison*

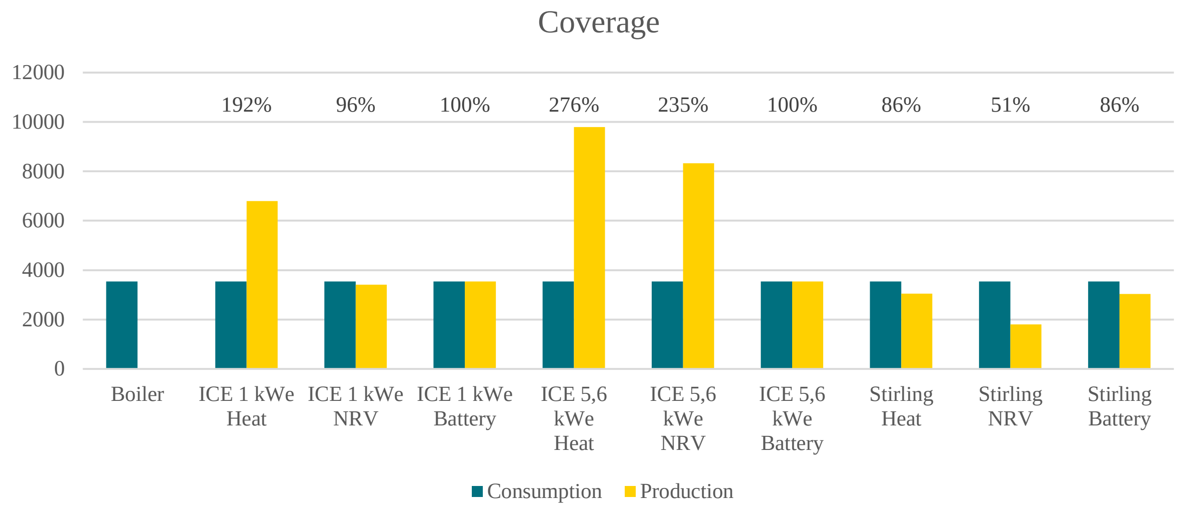


*Figure 12: Electrical coverage analysis*

Regarding electrical consumption, the ICE 1kW$_e$ seems more interesting since the self-consumption is higher (Figure 11 "ICE 1KWe heat" compares to "ICE 5.6kWe Heat" and "Stirling Heat", "ICE 1KWe NRV" compares to "ICE 5.6kWe NRV" and "Stirling NRV", "ICE 1KWe Battery" compares to "ICE 5.6kWe Battery" and "Stirling Battery") but when comparing the total production to the total needs it appears that the ICE technologies are oversized ( Figure 12).

## 4. Conclusion

The modelling of a complex HVAC system including two micro-CHP technologies with very different thermal and electrical efficiencies allowed assessing the potential of these systems in the current Belgian residential real estate according to three different strategies.

This work did not only look at the micro-CHP models but allowed to evaluate the different models of storage, DHW production and emission systems. Since some models were inexistent or incorrect in TRNSYS, the physical models were studied and implemented in the program.

Size of storage tank has been studied. Results show that a bigger tank is more interesting. Electrical efficiency is improved since longer periods of heat production occur for CHP. 1000l tank appeared to be the best solution.

In buildings, since the objective was to compare results with equivalent comfort, heat production is similar whatever CHP technologies or strategies of control. A surplus of gas is required in case of CHP since electricity is produced. This electrical consumption could be either consumed in situ or rejected to the grid.

Regarding self-consumption, a smaller engine seems most suitable. Although electricity production is lower, it is more constant and can therefore be better consumed in-situ than for a larger engine.

Regarding the strategies, the “grid control” seems to have a small impact on self-consumption even though it decreases the production but has more impact on self-sufficiency and the quantity of electricity bought (Figure 11).

The use of a battery increases the self-consumption (Figure 10) as well as self-sufficiency.

## 5. Acknowledgements

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## 6. Nomenclature

SMC: Smart Micro Cogen

CHP: Combined Heat and Power

HVAC: Heating, Ventilation and Air-Conditioning

DHW: Domestic Hot Water

ICE: Internal Combustion Engine

NRV: Net Regulation Volume

## 7. References

Ast H (1986), IEA-annex 10 : thermostatic valves. Technical report. Stuttgart, Germany

Bouvenot, J.-B., Andlauer, B., Stabat, P., Marchio, D., Flamenta, B., Latoura, B., & Siroux, M. (2014). Gas Stirling engine - CHP boiler experimental data driven model for building energy simulation. *Energy and Buildings 84*, 117-131.

Commission des Communautés Européennes. (n.d.). *"Etude CIEL" : Maîtrise de la Demande Electrique Campagne de Mesures par usage dans le secteur domestique.*

Cyx, W., Renders, N., Van Holm, M., & Verbeke, S. (2011). *IEE TABULA - Typology Approach for Building Stock Energy Assessment.*

Elia. (2018, July 6). *Déséquilibre actuel du système*. Retrieved from Elia: http://www.elia.be/fr/grid-data/balancing/desequilibre-actuel-du-systeme

Enertech, ADEME, & Union Européenne. (2008). *Projet REMODECE : Mesure de la consommation des usages domestiques de l'audiovisuel et de l'informatique - Rapport final.*

European Comission. (2013). *Smarter, greener, more inclusive? Indicators to support the Europe 2020 strategy.* Luxembourg (LU).

Georges, E., Gendebien, S., Bertagnolio, S., Dechesne, B., & Lemort, V. (2013). *Evolution des profils de consommations énergétiques des bâtiments résidentiels en Belgique, suite à l'introduction de nouvelles technologies de chauffage, climatisation et cogénération.* Liège (Belgium).

Knight, I. (2007). *IEA Annex 42 - The simulation of Building-Integrated Fuel Cell and other cogeneration systems (FC+COGEN-SIM) : Domestic Energy Profiles.* Cardiff (UK).

Rosato, A., & Sibilio, S. (2012). Calibration and validation of a model for simulating thermal and electric performance of an internal combustion engine-based micro-cogeneration device. *Applied Thermal Engineering 45-46*, 79-98.

Stephan, W. (n.d.). *IEA Annex 10 - System simulation : Radiator.* Stuttgart (Germany).