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Dwellings electrical and DHW load profiles generators development for µCHP systems using RES coupled to buildings applications

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Abstract

The micro combined heat and power (µCHP) is the simultaneous and decentralized production of thermal and mechanic/electrical energy at low scale (low electrical power output below than 50 kW_{el}). A wood pellet steam engine and a gas (or biogas) Stirling engine µCHP devices have been tested at the laboratory of INSA Strasbourg in order to characterize their performances in steady and unsteady states. Two realistic and dynamic models based on these experimental investigations have been developed in previous works [1, 2] in order to predict their energy performances and their pollutant emissions. These models have been implemented in the TRNSYS's numerical environment where an optimization platform has been implemented. Thermal and electrical energy storage systems and energy management controller have been implemented in this platform which is used to optimize the coupling between buildings and this kind of innovative devices by considering energetic, economic and environmental criteria. Dynamic thermal simulations (DTS) only computes dynamic heating loads but the other most crucial parameters of the platform are the DHW load profiles and mainly the electrical load profiles in buildings which needs to be realistic, variable, suitable to the French context and with a low time step (2 min). Existing data basis are weakly suited to our platform because of their lack of precision (more than 5 min time step), their lack of information (no information about the load profiles for each electrical appliance) or their non-relevance in the French context. The paper deals with the creation of a low time step electrical and DHW load profile generator well adapted to the French context by using a "bottom-up" method aggregating the electrical load of each electrical appliance or specific DHW draw-off by a stochastic way. This work presents the platform and the electrical and DHW load profile generator. A sensitivity analysis shows that low time resolution (2 min) is required to obtain reliable and realistic results.

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Keywords: micro combined heat and power (µCHP); TRNSYS; electrical load generator; time of use (TOU); bottom-up

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1. Introduction

The micro combined heat and power (μCHP) or micro cogeneration is a technology which produces simultaneously decentralized thermal and electrical (or mechanic) energy at low power (electrical power < 50 kW_{el}). This technology recovers the "fatal heat" losses considered as "heat waste" produced in thermodynamics or thermochemical cycles for mechanic energy production. This heat can be used to cover buildings heating and domestic hot water (DHW) needs. The μCHP matches the two goals of energetic system efficiency and greenhouse gas emission reduction by converting more efficiently the primary energy in final energy [3]. Besides, the integration of these low thermal and electrical power systems within the energy consumption places lets to self-consume the produced energy, to relieve the grid mainly during peak demand hours and to avoid grid losses. The evaluation of the energy, environmental and economic relevance of these solutions coupled to the buildings requires precise and accurate energy load profiles (thermal and electrical). Heating loads can be supplied by dynamic thermal simulations (DTS), DHW can be given by standards and classical methods [4, 5] and electrical needs can be given by data basis [6]. However, the platform requires precise (low time steps), variable and well adapted to the French context load profiles. The specific power needs (excluding any electrical heating) are a crucial factor to assess the energy, environmental and economic relevance of μCHP solutions. There are several databases for electrical needs for countries in North America or Europe specifically dedicated to studies on μCHP or micro generation [6]. However, these data are often not suited to our platform especially about the time step (15 min), the level of detail (need of each electrical appliance load profile) and the French context (French mean consumptions are lower than North American consumptions).

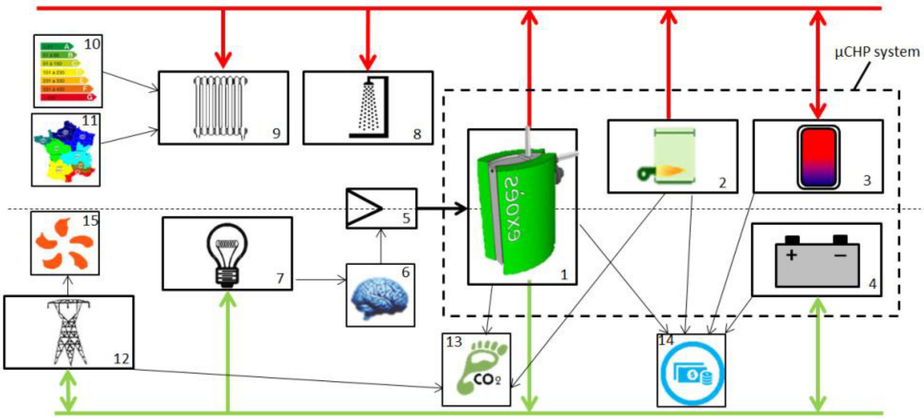
Nomenclature

E	electrical energy, J
P	power, W
SCR	self-consumption rate, %
t	time, h or s

Subscripts and superscripts

DHW	domestic hot water
el	electrical
FE	final energy
moy	thermal
th	thermal
trigger	trigerring
SC	self-consumed

2. Method : numerical platform description



1: μCHP device
2: auxiliary boiler
3: TESS
4: EESS
5: system control
6: smart power management
7: electrical energy needs
8: DHW needs
9: heating needs
10: building energy performance
11: climatic zones
12: grid
13: CO_2 emissions calculations
14 : economic calculations
15: electrical energy costs

Fig. 1. Principle scheme of the optimization platform.

2.1. µCHP models

The µCHP numerical models have been developed in order to be suitable with annual dynamic thermal simulations (DTS). They are based on experimental studies which led to semi physical and dynamic models [1, 2]. In particular, the thermal and electrical power outputs and the fuel power inputs in steady state are computed according to the inlet cooling water temperature, to the water mass flow, and to the part load ratio. In unsteady state, these quantities are computed according to delay times, stop/start time constants and power ramps.

2.2. Energy storage systems

The platform integrates thermal energy storage systems (TESS) and electrical energy storage systems (EESS) models. TESSs are simulated by multi-nodes cylindrical vertical buffer tanks (existing type 534 on TRNSYS). The model parameters are the tank volume, the tank height, the walls heat loss coefficient, the tank nodes number, the ports number and locations (cold water entry, heating water entry/exit, heater network entry/exit and DHW exit). EESSs are simulated by electrical batteries models which are either static (basic storage) or mobile (if embedded in electric cars). Specific models have been developed on TRNSYS by using data from Eddahech works [7]. EESS models parameters are the charge efficiency, the calendar losses, the cycling losses, the maximum number of cycles, the maximum specific power, the minimum state of charge and a presence scenario (if electrical car).

2.3. Hydraulic configurations

The numerical platform is adapted to 6 different hydraulic configurations given in Fig. 2. (if there is not TESS, the thermal energy demand is" run-of-river" covered):

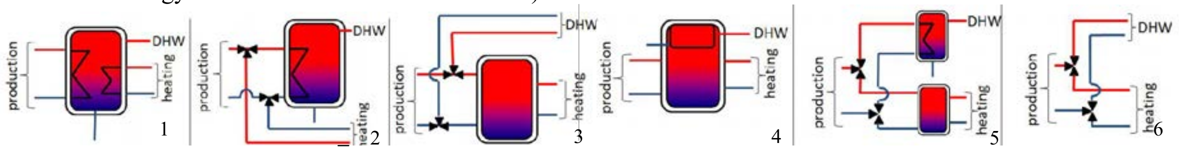


Fig. 2. Hydraulic principle schemes.

3. Load profiles

3.1. Heating needs

The platform proposes 8 climatic zones defined in the French thermal regulation whose choice involves the use of a specific real 15 min time step meteorological file for a given year (2010 to 2014) of a city located in the climatic zone. Besides, buildings are classified according to their energetic performance and surface. We distinguish 6 energy classes defined in the French thermal regulation according to their thermal needs (see Table 1):

Table 1. Building energy classes.

class	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Thermal needs (kWh$_{FE}$/m²)	<50	<75	<150	<200	<250	<350	<500

3.2. Stochastic electrical load profile generator

A random generator of electrical needs profiles using a 1 minute time step has been developed. This generator is based on statistical profiles of frequency of use: "time of use". It aggregates the power consumption of each electrical appliance based on use probabilities depending on the time of the day, the type of day (weekday or weekend) and the season: it's a "bottom-up" method [8]. The triggering time of the device is determined by using a frequency of use based on experimental data and a random Monte-Carlo method : random points are generated in the "probability fields" until there is below the probability curve (see Fig.3).

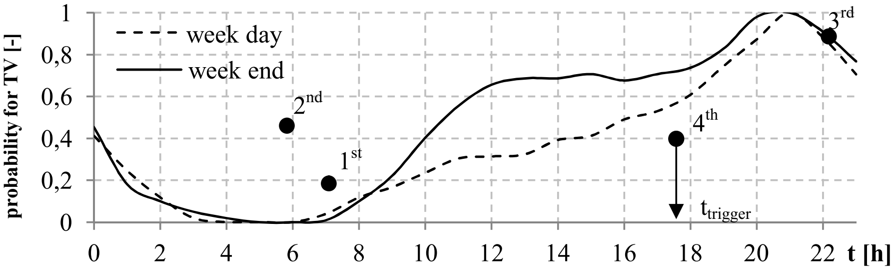


Fig. 3. TV triggering time determination by use of "time of use" (TOU) method and a random Monte-Carlo method.

The operating time is variable and follows a standard normal distribution around the mean duration from statistics (see Fig. 4). Some devices have specific and regular cycles (washing, cleaning) (see Fig.4). All statistics used come from the measurement campaign at European level: REMODECE [9].

Fig. 4. Cycle time determination and example of regular cycle for a washing or cleaning machine.

The generator creates unique profiles by separating non shiftable (lighting, cooking,…) from the shiftable part (mainly cleaning and washing) according to two input parameters: the dwelling level of appliance based on REMODECE data [9] (low, medium and high) and the electrical appliances energy class based on the council of Europe directive 92/75/ EEC [10]. The separation of the electrical loads shiftable part enables intelligent energy management: an electrical device triggering can be postponed in order to match an operation cycle of the µCHP. Fig. 5 shows an example of the stochastic power consumption profile generated for a winter day in the case of a high appliance level and a B energy class where each appliance load profile is represented.

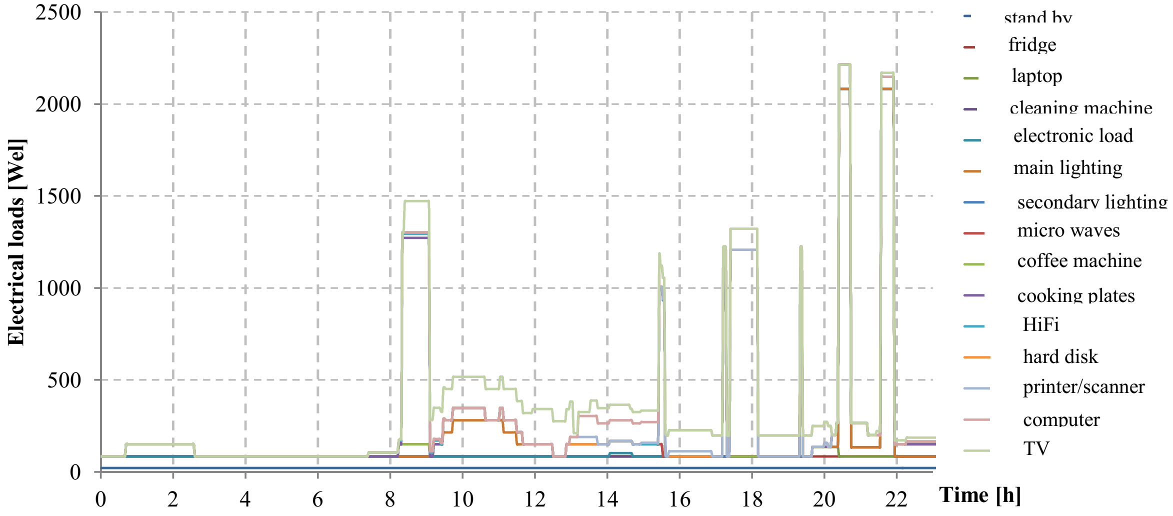


Fig. 5. *Stochastic electrical needs from the "bottom-up" generator.*

3.3. Stochastic DHW load profile generator

There are two main French standard methods for calculating the DHW needs: the AICVF method [4] which gives typical water draw-off profiles smoothed over the day and the method described in EN 13203-2 standard [5] which gives typical profiles of water draw-off which are occasional at precise hours of the day (any day of the year) for 2 types of dwelling (dwelling of 3 or 5/6 inhabitants). These profiles are not appropriate here since they are not enough realistic and variable. To incorporate variability, DHW needs are calculated stochastically by a generator similar to the power generator (see § 3.2). The generator uses a "bottom up" approach by aggregating each type of withdrawing (shower, cleaning, washing, bathing, ...) characterized by a draw-off time (variable according to a standard normal distribution around the mean time), a draw-off temperature (constant and variable depending on the use) and a draw-off flow rate (variable according to a standard normal distribution around the mean flow). The generator is based on the work of Jordan and Vajen [11] on the modeling of DHW needs for solar applications. The probability profiles of draw-off occurrences are derived from the profiles of the AICVF method [4] and the work of Jordan and Vajen [11]. The generator offers two DHW consumption levels (high and low) based on data from the NF EN 13203-2 [5]. Fig. 6 shows both 2 examples of DHW loads where we see the seasonal and variability effects.

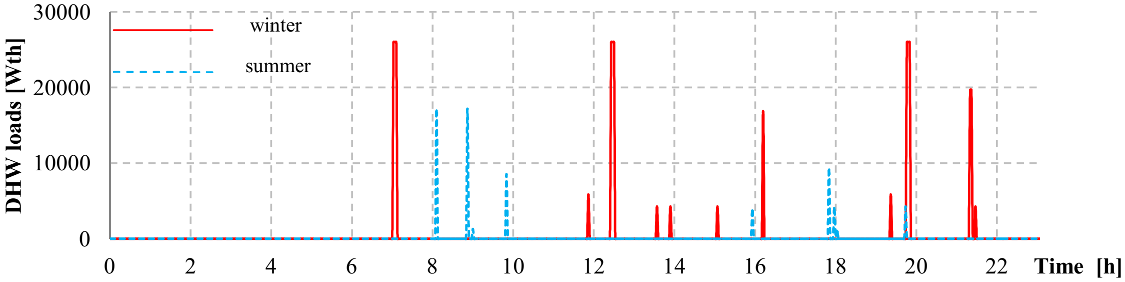


Fig. 6. *Stochastic DHW needs profiles from the "bottom-up" generator for a winter day and a summer day.*

4. Results : electrical load sensitivity analysis

DTS has been carried out on a reference case described on Table 2.

Table 2. Simulation system configuration

year	City	Energy class	Appliance level	Electrical class	DHW level	Hydraulic configuration	TESS	EESS	fuel
2012	Strasbourg	C	medium	B	high	1	750 l	-	biogas

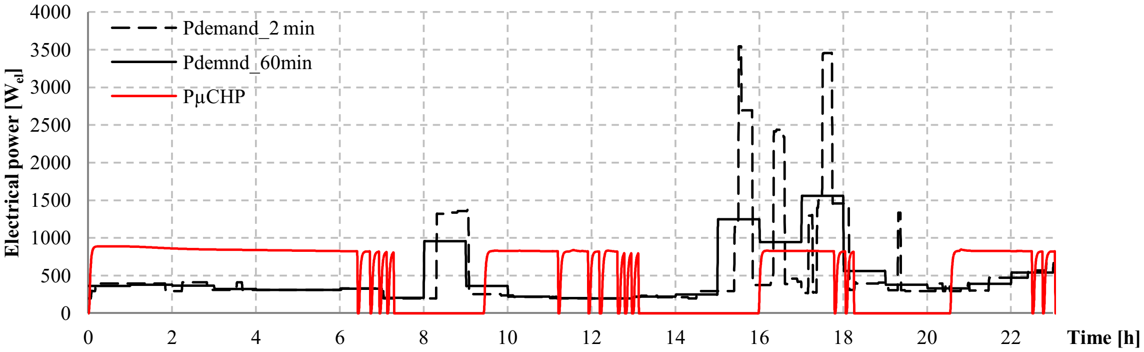


Fig. 7. *µCHP production and generated electrical loads (2 min and 60 min time steps).*

Fig. 7 shows that high time steps (60 min) smooth the 2 min time step load curves and create a numerical artefact which artificially increases the electrical self-consumption rate *SCR*:

$$SCR = 100\frac{E_{SC}}{E_{\mu CHP}} \tag{1}$$

The *SCR* is a crucial factor to assess the energetic, environmental and economic relevance of µCHP and the platform has to compute realistic and reliable data. Table 3 shows *SCR* values according to different time steps (2, 4, 10, 20, 30 and 60 min) and according to 5 electrical load profiles (time step of 2 min) generated by our tool. These 5 load profiles give a variability value linked to the dwellings load profiles diversity. Table 3 shows that it is required to use time steps below than 4 min to obtain a numerical error equivalent to the variability linked to the electrical load profile (< 1 %, each value are compared to the mean value : bold ratio).

Table 3. *SCR* sensitivity analysis.

Time step [min]	2 min	4 min	10 min	20 min	30 min	60 min
SCR [%]	**47,48 (+ 0,9%)**	47,88 (+ 0,8 %)	48,80 (+ 2,7 %)	49,89 (+ 5,1 %)	50,74 (+ 6,9 %)	53,06 (+ 11,8 %)
	47,16 (+ 0,2 %)	-	-	-	-	-
	46,91 (-0,3 %)	-	-	-	-	-
	46,81 (-0,5 %)	-	-	-	-	-
	46,88 (-0,4, %)	-	-	-	-	-

5. Conclusion and perspectives

A numerical platform has been developed with dynamic models and low time step realistic energy loads (thermal and electrical). We show that electrical loads are crucial and need to be precisely defined with low time steps to obtain reliable results. We present numerical results about a reference case where we reach SCR of 47 %. The platform will be now used to carry out energetic, environmental and economic studies to assess and improve the performance of µCHP and energy storage systems coupled to buildings.

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