Large-Scale Simulator

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Executive Summary

This report describes the project activity carried out by HES-SO as part of Task 5.7 of the SEMIAH project.

The deliverable D5.2 is the large scale simulator. This document provides an overview of the deliverable, a large scale simulator aiming to simulate 500'000 households.

This large scale simulator is composed of three independent simulators interacting together to simulate an electro-thermal simulation:

- Gridsim [1] is a simulator that can model complex interactions between energy carriers. More than a simple simulator Gridsim is a framework to quickly develop a dynamic simulation.
- BehavSim [1] is a householder behaviour simulation. It provides a statistical consumption of households.
- bSol [2] provides the user with a simulation of the consumed heating energy over a typical year (hour by hour) to guarantee a minimal temperature in the building, in this simulation, bSol is used to define thermal characteristics of buildings.

The deliverable is a dynamic simulator that allows dynamic control of few devices, the heating system, such as heat pump, direct heating or water-heater.

This simulator uses the data generated by BehavSim and bSol as static inputs to Gridsim which manages the energy flow and transformation (typically electrical to thermal) while considering the influence of the external controller.

Demand-Side Management (DSM) is the modification of consumer demand for energy through various methods such as financial incentives and education. Usually, the goal of DSM is to encourage the consumer to use less energy during peak hours, or to move the time of energy use to off-peak times. DSM offers several benefits all over the grid, one can mention:

- locally improve the stability of the distribution grid, managing the local production as well as control consumption,
- peak shaving reduces the need for investments in networks.

The large scale simulator has to provide scenarios to validate DSM controllers. This is the main question the simulator has to answer is:

Has the DSM a positive impact on the grid without negative impact on the user comfort?

Abbreviations

D	Deliverable
EC	European Commission
EDM	Exploitation and Dissemination Manager
T	Task
URL	Uniform Resource Locator
WP	Work Package

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1 Introduction

This report describes the activity carried out by HES-SO as part of Task 5.7 of the SEMIAH project.

The total electricity consumption in Europe especially in the residential sector has been increasing over the years even with improvements in efficiency of the energy equipment. The residential consumption is expected to grow by approximately 50% in 2050 [3].

The energy management in residential area is therefore a major challenge; however, deploying a global controller over a real grid is not acceptable before a strong validation phase. The large scale simulator was developed to provide as real as possible scenarios of household (electrical and thermal).

To realise such a simulation, the developed simulator has to take into account different types of data therefore the development was separated into three parts:

- Determining the thermal input of a building, such as thermal loss and thermal capacity of a building as well as the solar gains depending on the weather. This part is managed by bSol.
- Determining the uncontrollable electrical consumption, such as the ICT devices, the cooking devices, etc. Even if this consumption is not controllable, it impacts the stability of the grid. This part is managed by BehavSim.
- Finally, the assessment of a controller must imply a dynamic simulation of the energy exchange as well as a dynamic reply of the influence given by the controller. This part is managed by Gridsim

Energy simulators are existing but each of them manages a single energy system (e.g. electrical or thermal). This large scale simulator combines the influence of the heating system in the consumption while taking into account the thermal inputs (such as weather, heat given by the devices or person in the building) and can be executed in real time.

1.1 Purpose / Objectives:

The deliverable D5.2 is the simulator itself rather than this report. Nevertheless, this document provides an overview of the project.

All software developed for the D5.2 is accessible publicly at:

- Gridsim: https://github.com/gridsim/gridsim
- BehavSim: https://github.com/gridsim/behavsim
- bSol was not develop under the SEMIAH project thus is not a part of the deliverable.

- The large scale simulator: https://github.com/gridsim/semsim

1.2 Main features

The main features of the simulator are listed below:

- The simulator allows defining the topology of an energy system (electrical grid, thermal characteristics, generation, consumption, storage elements and elements transforming energy from a form to another) as well as dynamic environment parameters (for example, temperature or solar radiation over time at a given point).
- An energy system is simulated over a given time period (simulation duration of typically one year) with a given unit time step (typically one minute).
- Any energy system parameter can be recorded over the simulation period.
- Each element has its own independent behaviour.
- External controllers can influence the behaviour of specific elements (i.e. boilers and heaters).

1.2.1 Gridsim

The main features of Gridsim are:

- Dynamic simulation of energy flows, currently thermal and electric.
- Dynamic conversion of energy, thermal to electric and electric to thermal.
- Resolution of power-flow using direct load flow or Newton–Raphson load flow.

1.2.2 BehavSim

The main features of BehavSim are:

- Provide statistical consumption of household.
- Provide user interface to define behaviour of householders.
- Generate data consumption of household.

1.2.3 bSol

The main features of bSol are:

- Provide user interface to define thermal model of buildings and average weather statistics (outdoors temperature and sunshine).
- Simulate the consumed heating energy over a typical year (hour by hour).
- Propose solution to guarantee a minimal temperature in the building, based on a given thermal model.

1.3 Architecture for large scale simulation using developed tools

The simulation of energy flow between buildings, energy consumption inside a building and energy transformation are complex systems. These systems include several interdependent models interacting together to take into account lots of internal and external parameters such as the distance between buildings, the number of person in a building, the weather, etc.

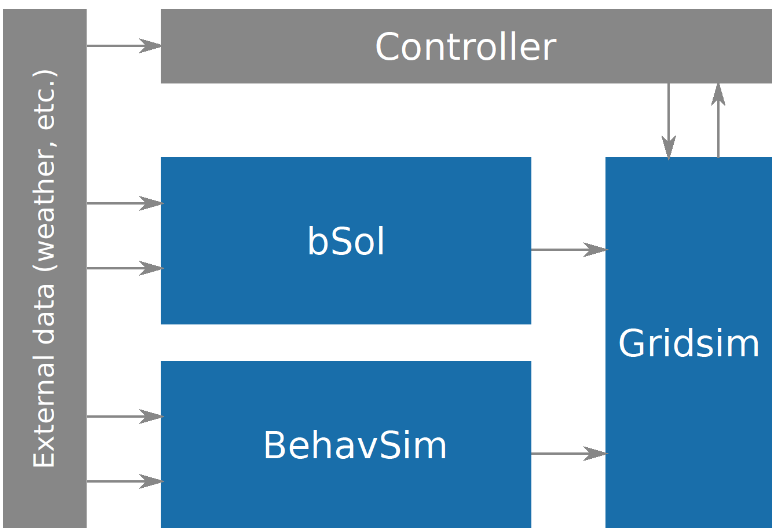

Figure 1: simulators interaction in large scale simulation

To manage the different models, the simulator is a composition of three specific and independent simulators (see section 2) that minimally interact together to obtain a complete building simulation:

- The energy flow simulator, called GridSim, manages energy exchange and transformation, taking into account dynamic influences from external tools and a possible distribution grid (grid load flow simulation).
- The thermal building energy simulator, called bSol, calculates the characteristics of the model (currently a building or a set of buildings) from external data.
- The user behaviour simulator, called BehavSim, determines the energy consumption of the users in the buildings.

Two of these simulators, GridSim and BehavSim are developed during the SEMIAH project, while bSol[1] was developed at HES-SO and is currently maintained by a spin-off, Physeos SA.

2 Software

2.1 Gridsim

Gridsim is an open-source and multi-purpose simulator that provides multi-carrier energy systems. Gridsim is separated in multiple modules in order to minimise dependencies and maximise the flexibility for the development.

It was designed and developed to be easily connected to external tools whether for receive data (e.g. for an external controller) or to send information (e.g. for data acquisition). For this purpose, the simulator architecture is based on a hierarchy. The simulator is composed of modules. A module is composed of elements which are the atomic parts of Gridsim. A Module allows interactions between its elements. Each element has its own behaviour and internal states and can be influenced by other elements of the same module. The set of modules in Gridsim can be separated into three parts:

- the core, that manages interactions between modules and time synchronisation,
- the energy management, that manages electrical and thermal energy and the transformation from an energy form to another,
- the communication, that provides input and output management. In Gridsim every property can be monitored or modify by an external tool.

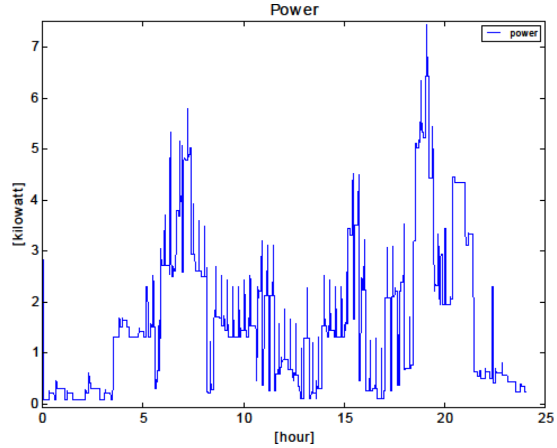

Figure 2: Example of output of Gridsim: 1-day consumption of a household

Gridsim will continue to evolve and latest version can be downloaded at:

https://github.com/gridsim/gridsim

[1] http://www.physeos.ch/fr/outils-metiers/133-presentation.html

2.2 BehavSim

BehavSim is codded in Python and has a Graphical User Interface consisting of a set of buttons dedicated to the different appliances to simulate. When the user selects an appliance by clicking a button, a message dialogue appears asking the user to provide a simulation name, the number of daily curves to generate and the relevant stochastic parameters of the appliance. BehavSim creates a directory for the simulation. This directory contains the generated data stored in CSV files with the different stochastic parameters and each daily curve is saved in a CSV file together with a time vector.

The devices simulated by BehavSim are: fridge and freezer (cold chain), dish washer, washing machine and tumbler dryer (white appliances), oven and stove (cooking appliances), audio visual and ICT (home, electronics), lighting, and base load (appliances turned on 24/7).

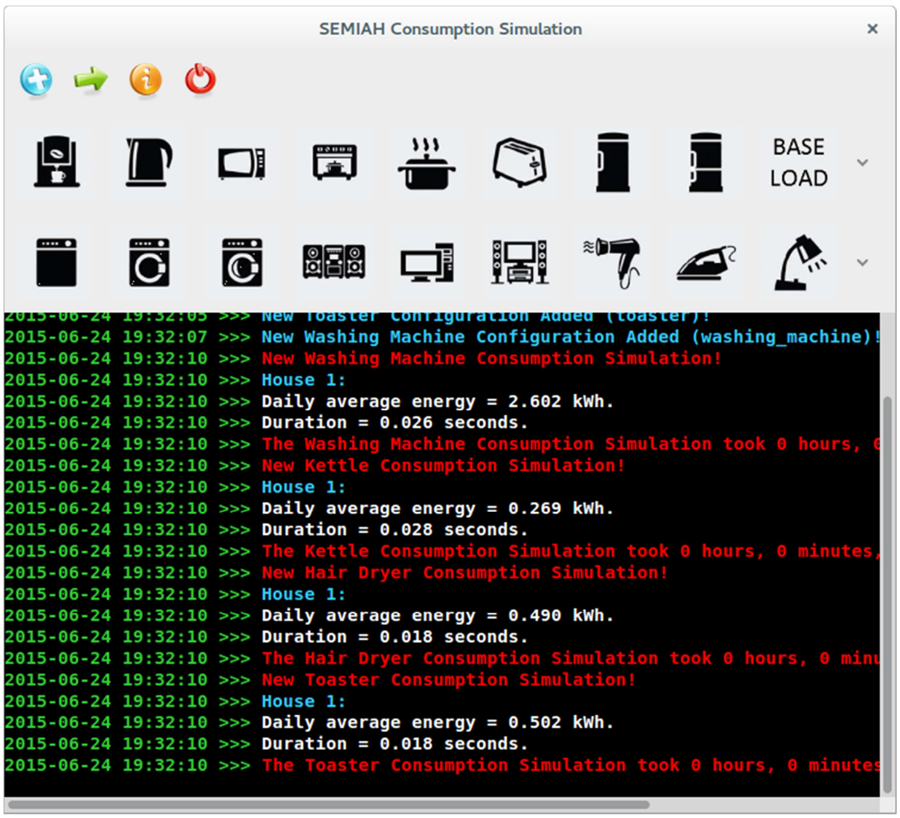

Figure 3: Graphic user interface of BehavSim

BehavSim will continue to evolve and latest version can be downloaded at:

https://github.com/gridsim/behavsim

2.3 bSol

The bSol software is dedicated to the management of buildings in terms of energy. More precisely, this software provides the user with a simulation of the consumed heating energy over a typical year (hour by hour) to guarantee a minimal temperature in the building, based on a thermal model of the building and average weather statistics (outdoors temperature and sunshine).

The idea here is to use bSol not to generate heating load curves but to generate the thermal parameters of the household and the weather information given the location and the characteristics of a household. These thermal parameters are separated into two parts. The first part concerns the building characteristics:

- the thermal capacity, C represents the thermal energy that can be stored in the building walls,
- the thermal loss, K, represents the thermal energy dissipated outward.

The second part concerns all thermal inputs influencing the thermal building:

- The solar gains
- The heat provided by the devices when they are switched on
- The heat of the person living in the building

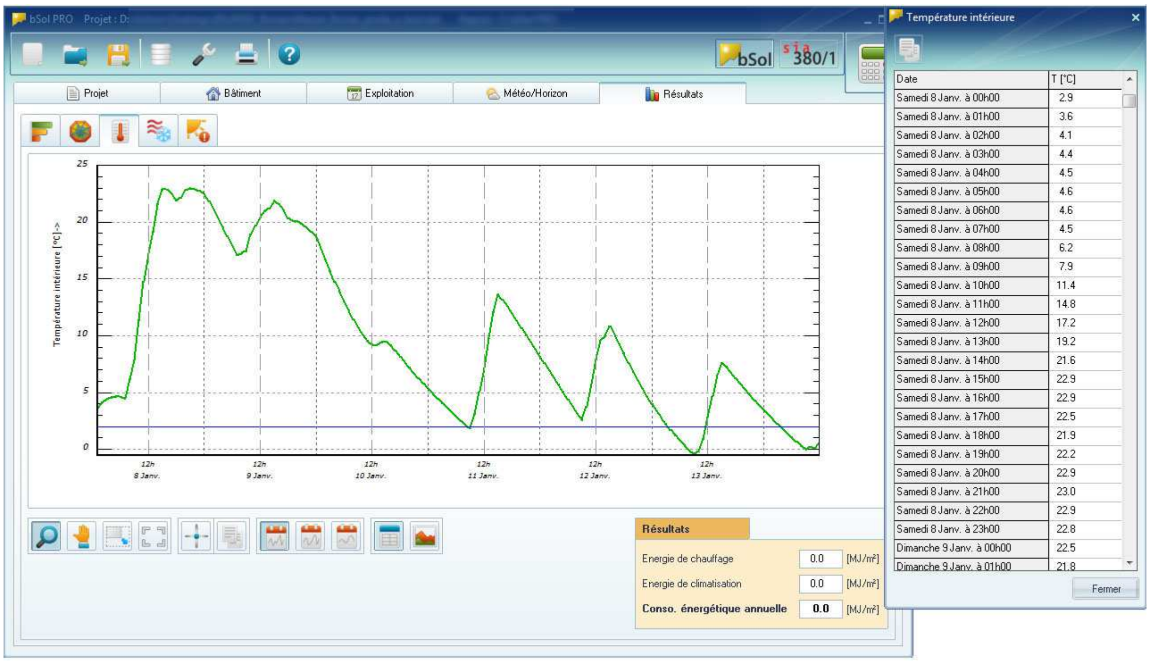

Figure 4: Graphic user interface of bSol

bSol was not develop under the SEMIAH project but information can be found at:

http://www.bsol.ch

2.4 SemSim: The large scale simulator

By combining these three simulators, one can develop a large scale simulator. bSol and BehavSim can generate all static data (data that cannot be modified during a run of simulation). During a simulation these data are read by Gridsim to manage electrical and thermal simulations. Gridsim can also receive dynamic influence from other software (typically external controllers) to modify the behaviour of the controlled devices (i.e. heaters and boilers) in order to change the global consumption.

The communication between the different software is represented by the Figure 1.

SemSim was thought as a fully parallelized simulator. As there is no interaction between each household, the simulation of the households can be easily distributed. Depending on the number of cores allocated for the simulation, SemSim evenly spreads a number of household on each core allocated to the simulation (see Figure 5).

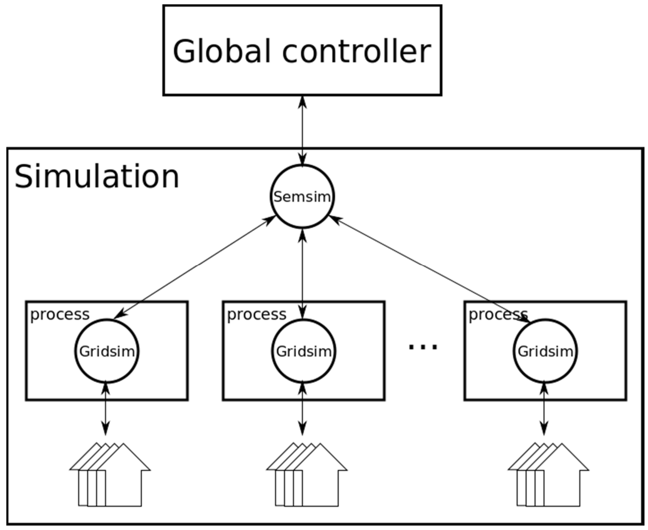

Figure 5: schema of the simulation distribution.

Therefore, the scaling capacities of SemSim are more dependent of the underlying hardware than the code of the simulator itself.

To run a simulation, configuration files have to be given to SemSim. A configuration file is a JSON file that describes the topology of the network, lists the location of the generated files and lists the data that can be observable (i.e. sent to the controller/monitor).

The Section 4 of the README.md file (provided with the source code) details the possibilities offered by SemSim to run a simulation.

When SemSim is launched, the simulator is waiting for a controller. When the controller is connected, SemSim prepares the simulation and sends the observable states of each observable component in the simulation. One simulation step is executed, then SemSim is waiting for data from the controller in order to go to the next step.

SemSim does not save any data during the simulation, therefore it is the role of the controller/monitor to save the data to process and display them.

The large scale simulator will continue to evolve and the latest version can be downloaded at:

https://github.com/gridsim/semsim

2.5 Validation of the simulator

For a simulation as real as possible energy consumption of buildings and data given by bSol and BehavSim has to be validated.

bSol is a professional software and uses the norm SIA 380/1. Moreover, it is a widely use thermal simulator around the Switzerland.

Data provided by BehavSim is based on scientific papers and analysis [4, 5].

3 Time simulation

This section presents the results of several simulations in order to shows that the simulator can simulate hundreds of thousands of households.

A scenario of 1-day simulation with a time step of 1 minute for 100, 5’000, 10’000 and 20’000 households was realised. For each run the execution time and the memory usage was recorded.

The simulations were executed on a cluster with the following properties:

- 48 CPUs with 1 core at 2.6 GHz
- 80 GB SDD HDD
- 64 GB RAM

Table 1 and Figure 6 show the time and memory needed to simulate a number of household.

It can be observed that the needed execution time increases linearly with respect to the number of households.

The most important problem arisen during the test validation was the memory usage. The limit of the cluster is reached when simulating 20’000 households. Therefore, results of the next section are based on a maximum of 20’000 households.

Table 1: Time simulation depending on number of simulated households

Number of households	Execution time	Used memory
100	40 seconds	2Gb
5’000	13 minutes	18Gb
10’000	49 minutes	34Gb
20’000	2:20 hours	64Gb

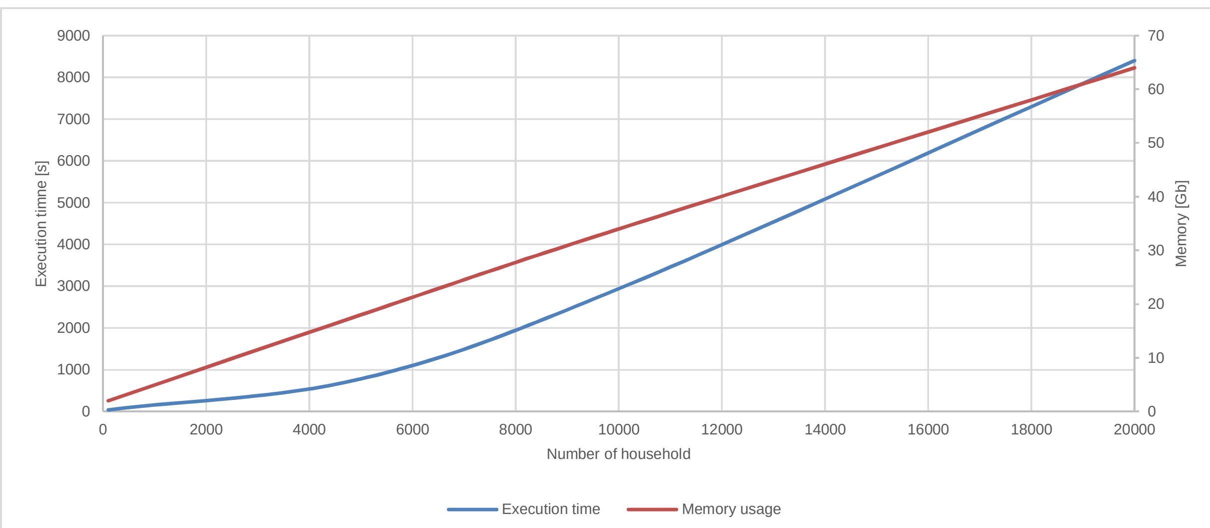

Figure 6: Time simulation and memory usage depending on number of simulated households

4 Examples and first results

4.1 Effect of simple control on 500 households

The scenario used to generate the results (detailed later) are based on Swiss data. Building properties (surface, year of construction, year of renovation, etc.) are based on the Swiss Statistics Office[2] and the weather information is based on 8 cities in Valais is provided by bSol. In the given scenarii only relatively small households (<= $100m^2$) are used.

The first result presents the consumption of 500 households for 1 day. Figure 7 presents the global consumption of the households and Figure 8 presents the same consumption without the heating systems (heat pumps and water heaters).

These figures show that the heating systems represent the largest part of the electrical consumption of households, and validate that controlling the heating systems is crucial to reduce the impact of residential area on the electrical grid.

The second result presents two run of the same simulation with two different global controllers. Figure 9 and Figure 10 show respectively the power with no global controller and the power with an external controller that turns off all the heating systems from 8:00 to 10:00.

Table 2 summarises the results of the second scenario. The most important information in Table 2 is the variation of temperature. The minimal temperature goes from 18.81°C to 17.91°C in the coldest household and the mean temperature goes from 19.97°C to 19.56°C.

These values give an average decrease in temperature of 0.20°C per hour which is not significant for a human. More research needs to be done in order to determine when the temperature drop has an impact on the user’s comfort.

[2] http://www.bfs.admin.ch/bfs/portal/en/index.html

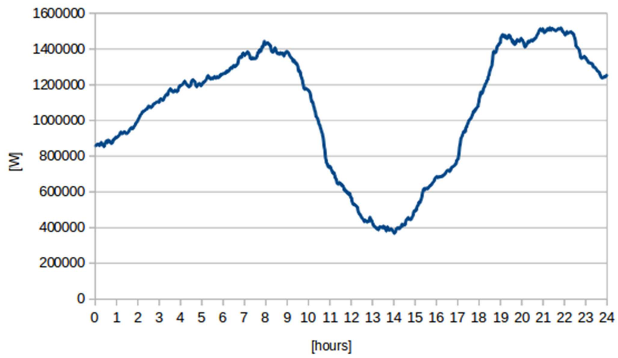

Figure 7: Global consumption of 500 households (including heating systems)

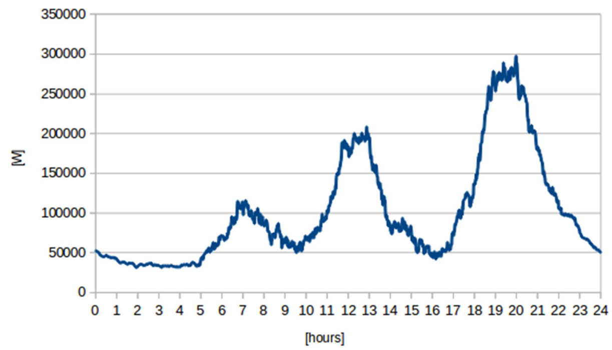

Figure 8: Global consumption of 500 households (without heating systems)

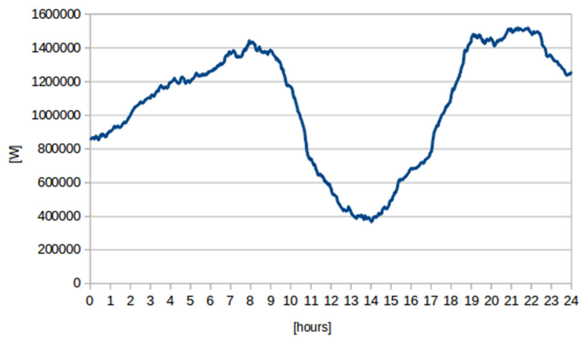

Figure 9: Global consumption of 500 households (only local controller)

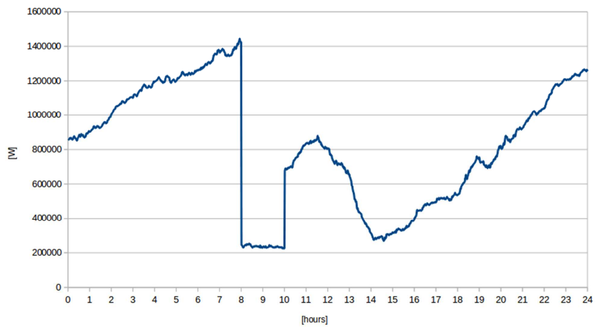

Figure 10: Global consumption of 500 households with a global controller cutting of heating systems between 8:00 and 10:00

Table 2: Summary of the data during the cut from 8:00 to 10:00

	No controller	Cut controller	Difference
Minimal temperature	18.81°C	17.91°C	0.90°C
Mean temperature	19.97°C	19°56C	0.41°C
Minimal power	1’166’795 kW	222’465 kW	944’330 kW
Maximal power	1’436’322 kW	253’607 kW	1’182’715 kW
Mean power	1’331’595 kW	235’839 kW	1’095’756 kW

4.2 Results of 500’000 simulated households.

To simulate such a large number of households a very large cluster is necessary. As the HES-SO doesn’t have a cluster as large as necessary, we have to run several times a set of 20’000 households. The aggregated data are presented in Figure 11, Figure 12, Figure 13 and Figure 14.

The peak of the boiler consumption (Figure 13) at the beginning of the simulation is a border effect. The initialisation of boiler status (on/off) is based on a random value thus 50% of the boilers are turned on, which is not a valid value.

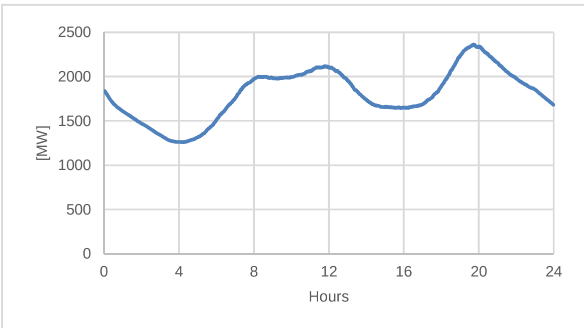

Figure 11: Global consumption of 500'000 households (only local control)

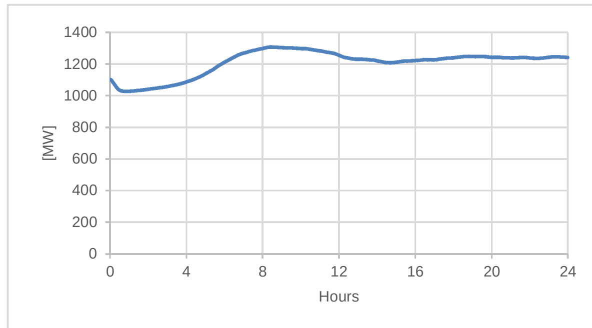

Figure 12: Consumption of heating systems (heat pumps or electric heaters) of 500'000 households (only local control)

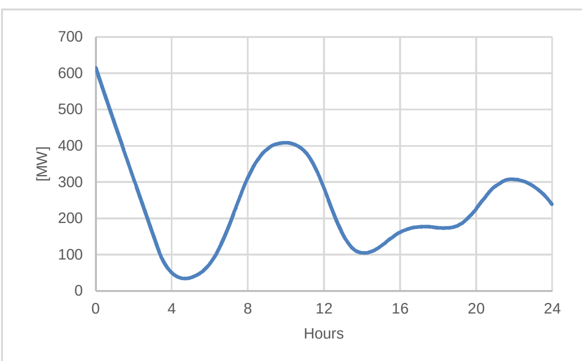

Figure 13: Boiler consumption of 500'000 households (only local control)

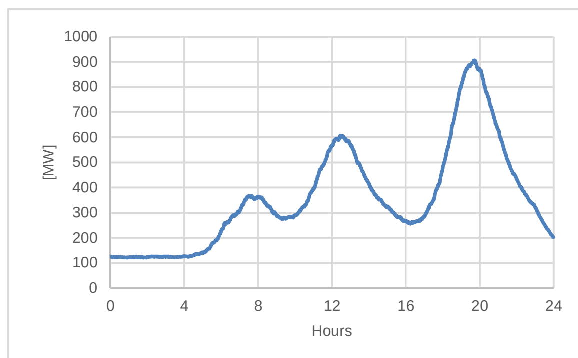

Figure 14: Uncontrollable consumption of 500'000 households

4.3 Simple control of 10’000 households

A 2-days simulation was realised with a set of 10’000 households. To run of this simulation were launched. The Figure 15 presents the results of the two runs. The blue curve presents the consumption of the 10’000 households with only a local controller. The red curve presents the consumption of the same households with a cut of heating systems (boilers and heaters) during 7 hours. These runs highlight the drawback of a long cut without planning, when the heating systems are turned on a new peak appears.

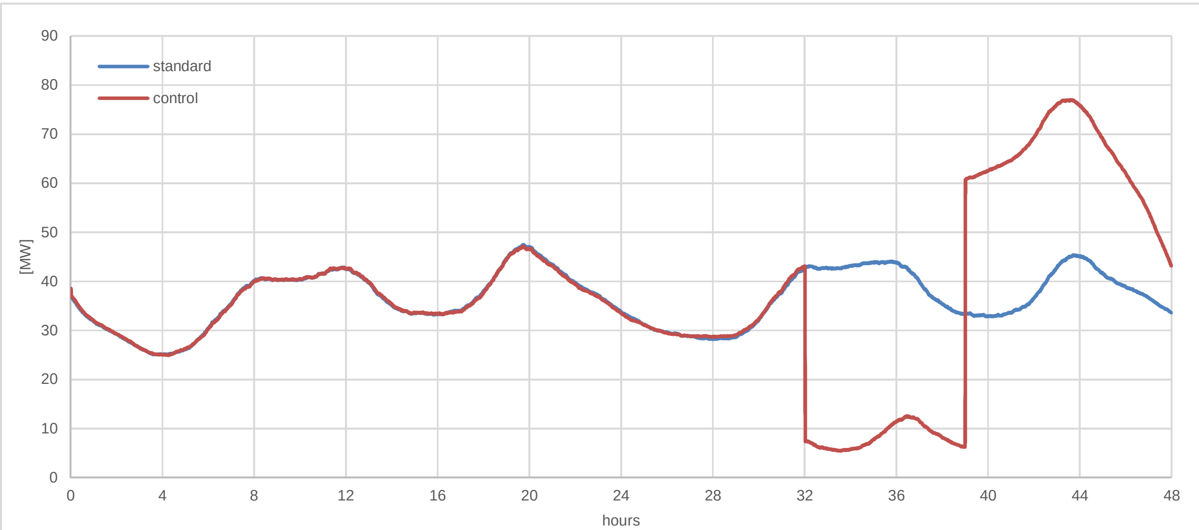

Figure 15: Comparison between standard simulation (blue) and simulation with global controller (red)

5 Conclusion

The large scale simulator developed for SEMIAH can simulate thousands of households and the separation of each part of the simulation allows a faster simulation than an all-in-one simulator.

With this simulator, the test and validation of different control strategies for DSM can be realised. These strategies can be evaluated with different parameters such as the consumption reduction, the welfare of the householders (with the internal temperature of buildings) or the voltage stability in a local grid.

The first results present the importance of the thermal devices in the energy consumption in residential buildings and the impact of heating systems on the electrical grid. A controller which wants to influence these systems has to be validated by the simulator to ensure that the temperature inside the households will not reduce the comfort of the households.

A first release of the large scale simulator is done. This release allows to simulate a large number of households depending on the underlying hardware. As a first release, improvement will continue to be made to make the simulator faster and less memory. The future releases will be updated on the links given in this report.

6 References

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