COMBINED HEAT AND POWER AND HEAT PUMP FOR RESIDENTIAL USE. SYSTEM DESIGN FOR MINIMUM CO2 EMISSIONS AND BEST ECONOMY.

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Abstract A simulation method was developed to design the best configuration of a heat-pump and combined heat and power system (HP-CHP) for district heating. It was found that the addition of an auxiliary boiler and heat storage capacity has the potential for a 25% CO2 emission reduction compared to a standard gas-fired boiler situation with the important advantage of CO2-neutral decentralised power production . Several possibilities are proposed to finance the additional investment.

Keywords District heating, CHP, heat pump, decentralised power production

INTRODUCTION

Current trends in urban power supply are for combined heat and power (CHP) systems allowing to take maximum benefit of both the heat and electricity generated at local level and to avoid the huge thermal energy losses of centralised plants. Such systems are usually installed at district level or for a group of buildings using in most cases a gas turbine for power generation. On the other hand, heat pumps (HP) for residential heating have gained a strong acceptance in many countries due to their reliability, fuel economy and lower CO2 output. Therefore the coupling of both systems, where the power requirement of the heat pump is supplied by the CHP seemed an attractive option for a distributed district heating network.

Such a heating concept has been proposed for heating of a group of buildings in the canton of Geneva where the energy policy aims at the optimisation of the energy supply at district level, during the planning phase of the construction projects. The so called "Périmètre d'aménagement

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concerté" (concerted installation perimeter) and "Plan Localisé de Quartier » (localised district plan) are planning tools used by the authorities to reduce the overall building energy consumption.

To help in the dimensioning of such a system, it is necessary to define the respective sizes of the heat-pump, CHP and auxiliary boiler so that both the kWh cost is minimum and the CO2 emissions are optimized. For this a computer program was developed and tested in a number of configurations. The program can be used for old or new buildings, taking into account the available natural heat sources and the climate conditions.

This project was the basis for two diploma works in 2003 and 2004 at the Geneva Institute of Technology and for a master thesis in 2006 at the Lausanne Federal Institute of Technology.

OVERALL PROCESS

The association of a combined heat and power system and of a heat pump (HP-CHP system) makes it possible to benefit from the advantages of each system taken individually. Indeed, the installation of CHP in urban environment, therefore decentralized compared to the large power stations, provides several advantages:

- it discharges the power lines and at the same time decreases the distribution losses.
- It increases the overall efficiency considerably compared to a centralised power station.

By associating a heat pump to a CHP system, it is possible to produce heat in a more ecological way compared to a traditional boiler. The interest is clearly illustrated in Figure 1. From 67 units of primary energy, the system covers the 100 units of request for heat. The efficiency of such a system is thus 149%. By comparison, the replacement of such a system by a boiler would require about 110 units of primary energy to satisfy the same requirements in heat. Therefore such a system has the potential to reduce the primary energy consumption and thus the production of CO_2.by about 40%

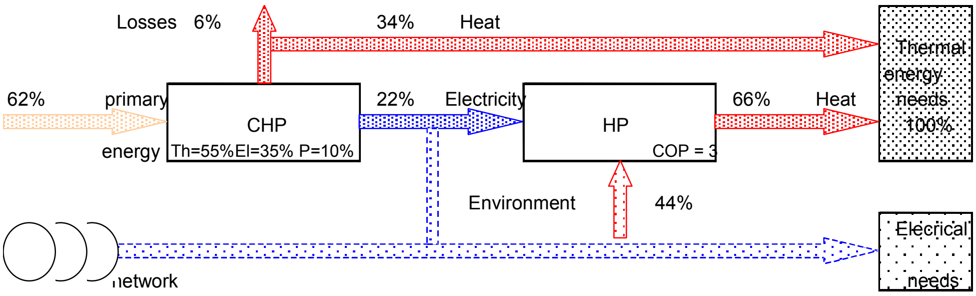

Figure 1 – Energy flow diagram of a HP-CHP system

Moreover, using heat storage to supply heat during peak hours, the HP could be disconnected and surplus electricity could be sold to the network. The overall economy of the process can thus be enhanced.

PROGRAM

The dimensioning of such a system is not easy and depends on many factors such as the type and performance of the elements, the climate conditions, the fluid source temperatures etc.

The goal of the program is to determine the size of each element of the system according to two objectives: the minima CO2 emissions and/or the minimum heating kwh cost. The decision maker can then select his solution amongst a certain number of configurations.

The calculation program was implemented on a Matlab® platform and input and output data are provided in excel format. The size of the program is approximately 100 KB. Its structure is shown in Figure 2.

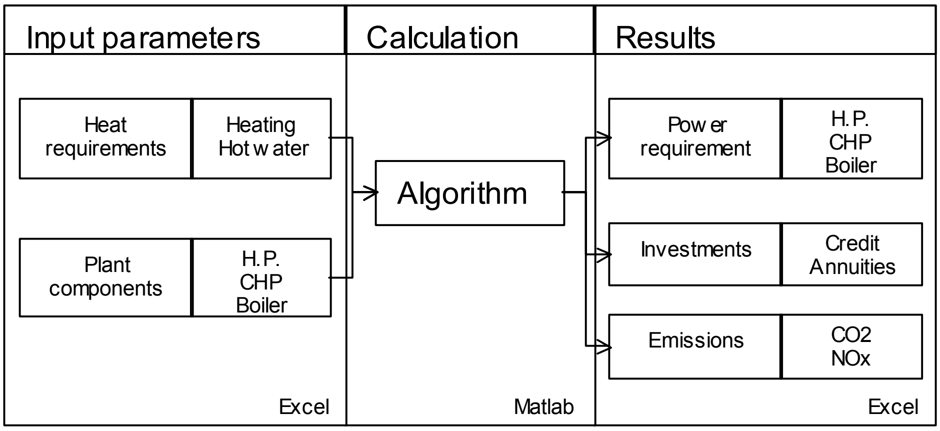

Figure 2 – Program structure

The building blocks of the program logic are shown in Figure 3.

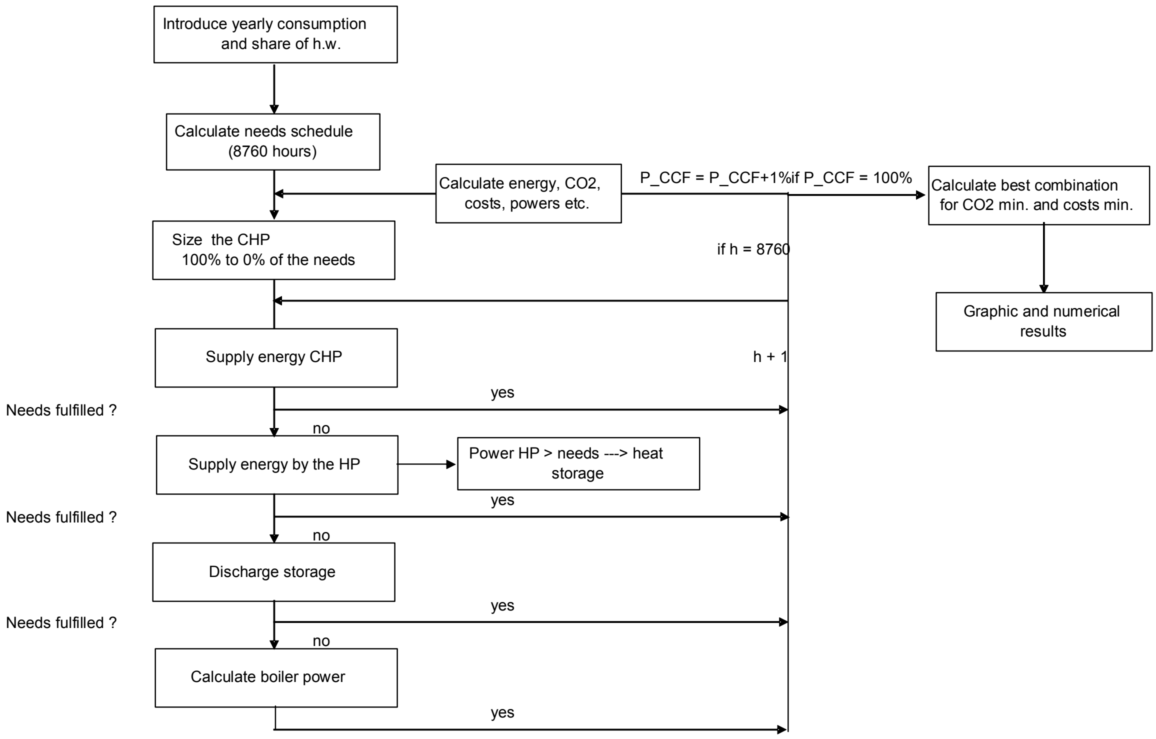

Figure 3 – Program logic

RESULTS

In order to demonstrate the usefulness of the computer program, a typical building case was chosen and the program was used to define the respective sizes of the various process variants, the energy cost and the CO2 emissions.

The Building Example

The example chosen for comparison of the various scenarios is that of a group of residential buildings with an annual consumption of 2000 MWh including a hot water consumption of 30%.

The yeraly consumption profile is shown in Figure 4 and it provides the hourly distribution of heating power requirement for this building.

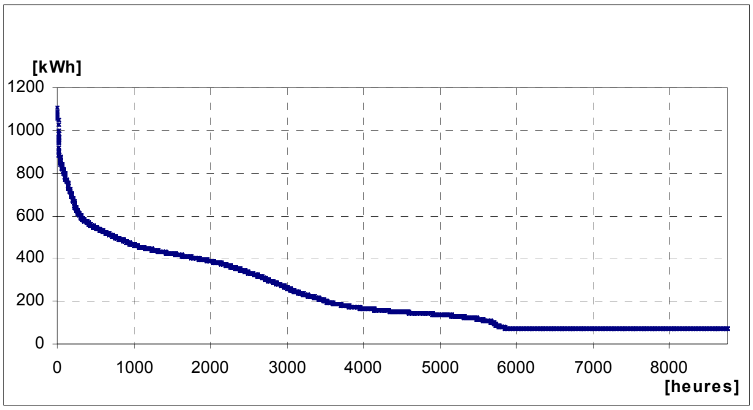

Figure 4 - Yearly distribution of energy needs

The distribution profile will be used to size the heating plant as a function of the maximum heating requirement.

The various cases

Three different cases were compared:

Case 1 is the reference case with a conventional boiler system. Its annual CO2 production is 530 tons.

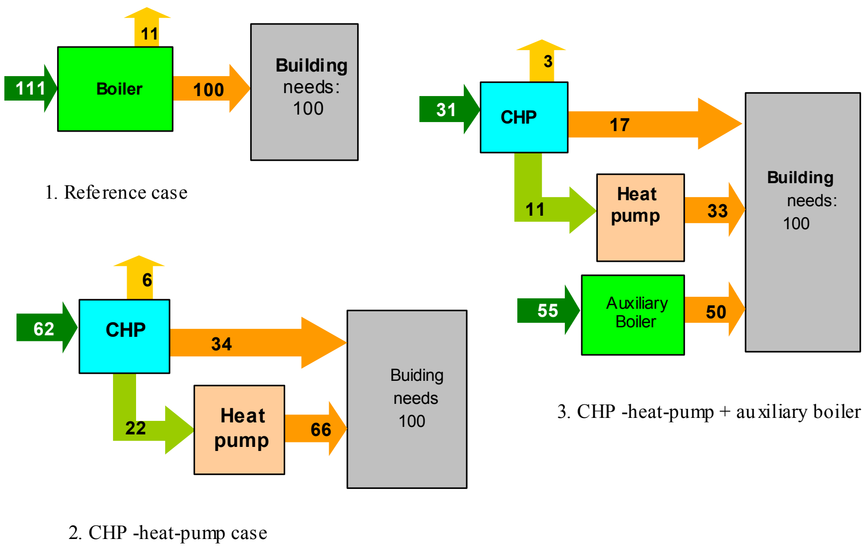

Figure 5 – Comparison of the three scenarios

For the CHP-HP combination, there were two possible operation modes:

1) The mode "absolute" where the CHP operates continuously with full load (100%) and the heat pump is modulating to fulfil the complement of heat required (see Figure 6). This option produces 730 tons of CO2 per annum, i.e. approximately 200 tons more than the boiler alone.

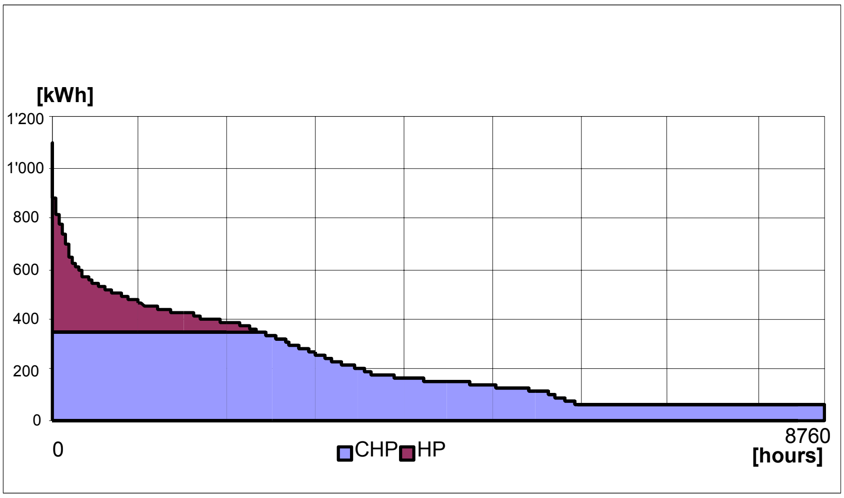

Figure 6 – Respective contributions of the HP and CHP in the full load CHP case

2) The mode "proportional" where the CHP is modulating its power proportionally so that the heat pump makes maximum use of the electricity produced by the CHP. This option would generate only 268 tonnes of CO2 per year (see Figure 7). However, this case is unrealistic since it does not take the minimum allowable load of the CHP and is relatively more expensive because one has to design it for 100% heating demand.

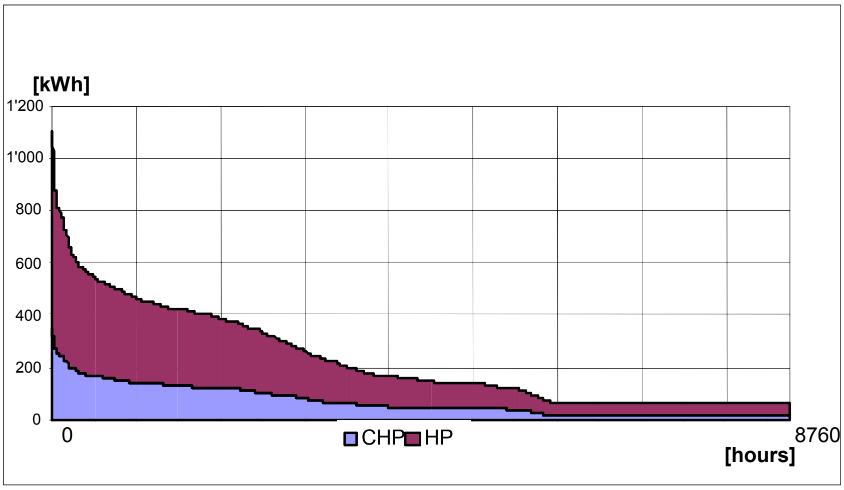

Figure 7 – Respective contributions of the HP and CHP in the proportional case

It is therefore essential to integrate an auxiliary boiler to reduce the power of the CHP-HP as in the following case 3.

For such a combination, there is an optimum thermal power of the CCF which can produce minimal CO2 emissions as illustrated in Figure 8.

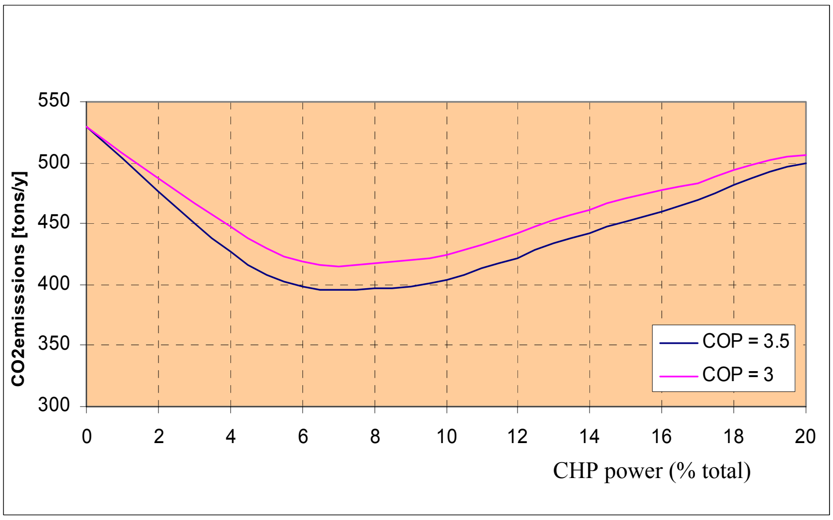

Figure 8 – CO2 emissions as a function of the CHP power

In the example taken, the optimum was with a CHP maximum heating power of 7% of the total, with respective minimum loads of 50% for the CHP and 20% for the heat pump (see Figure 9) .

The CO_2 emissions amount to 400 tons/year i.e. a 25% reduction compared to the reference case with the additional potential of excess electricity production that can be sold to the grid.

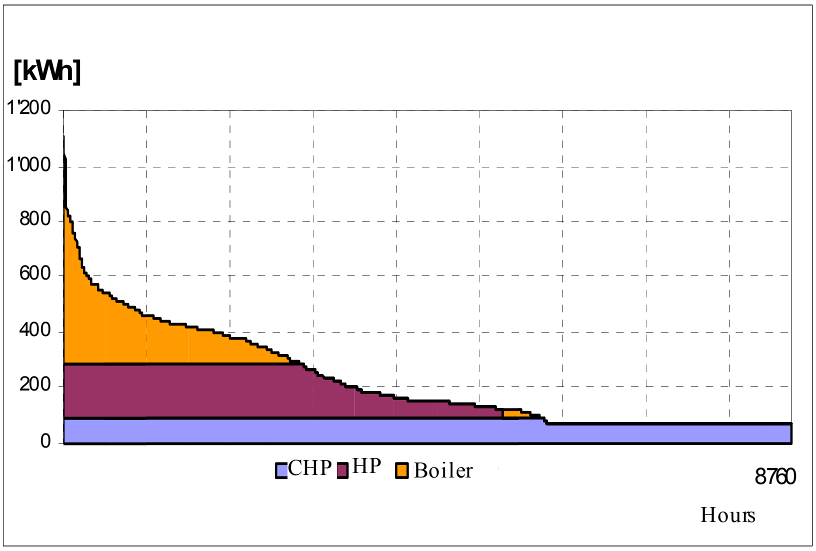

Figure 9 – Respective contributions of the HP and CHP in case 3.

The minimum cost will be determined by the choice of each subsystem power in so far as the CO2 emissions are in an acceptable proportion from the ecological point of view. The ecological limit can be defined, for example, by a window as shown in Figure 10.

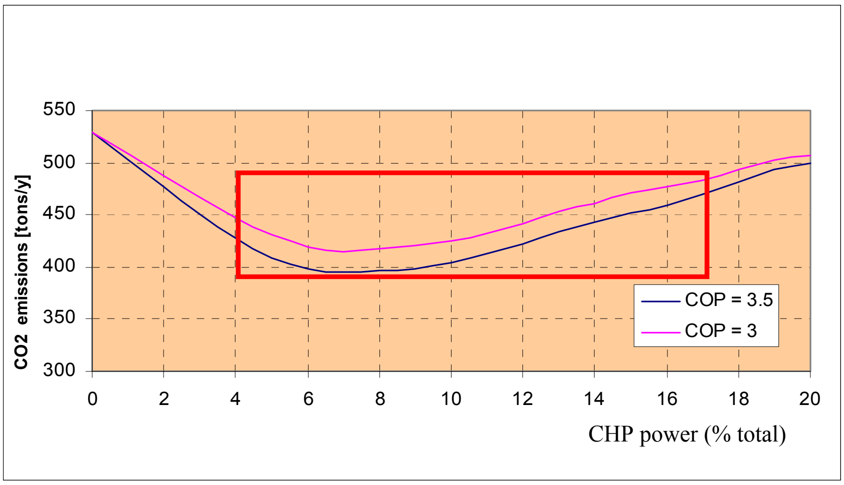

Figure 10 – Working window for the dimensioning of the elements

By taking the right limit of the window, the HP-CHP power is minimum (4%) and the boiler will produce the greatest heat quantity. It is the opposite on the left limit with a HP-CHP power of 17%

ADVANTAGES

The advantage of the last case lies in the fact that it becomes possible to produce CO_2 neutral power during peak hours if one can store the excess heat during off-peak hours.

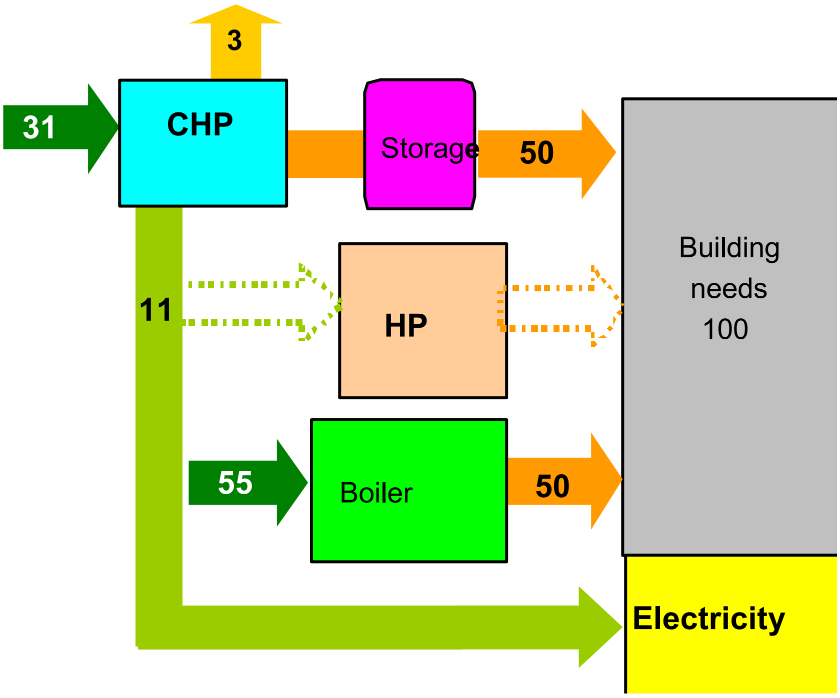

Figure 11 – Integration of heat storage tank for the production of CO2 neutral electricity

It is thus easy to size the CHP within the defined window limits so that its electric output can compensate for the peak hour grid power requirements. During this time the heat pump is stopped and the heating needs are fulfilled by the heat storage. This is demonstrated on Figure 11 and 12.

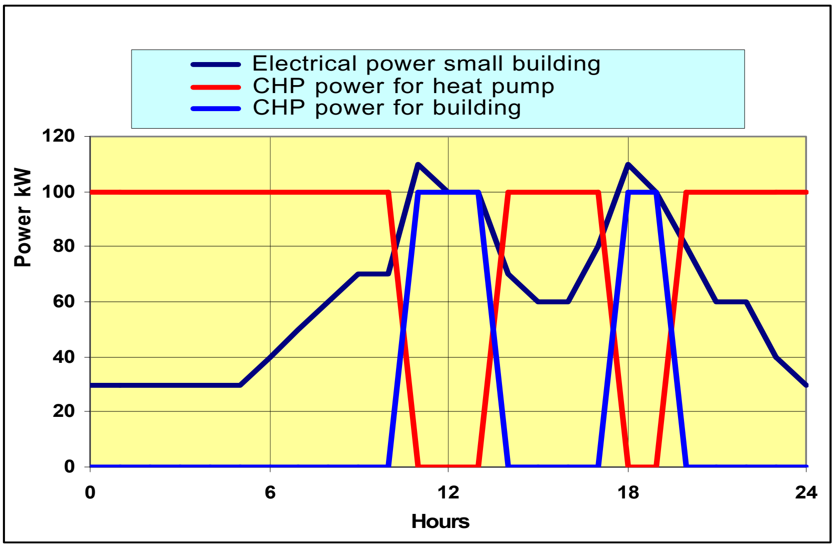

Figure 12- Use of the CHP electric output to produce CO2 neutral electric output

Therefore this method makes it possible to produce peak power and helps to avoid the saturation of the power grid . This is an elegant way to produce decentralized and CO2-neutral power by means of fossil fuels.

However this inevitably bears an additional cost which has to be compensated by financial measures such as:

- The economy of a CO2 tax or by CO2 credits
- Credit rate reductions
- Government subsidies

The program can be used to define the best scenario for the implementation of the proposed system at minimum costs.

The simulation model will be used to help decision makers to select the best strategies for new building projects according to the following scheme.

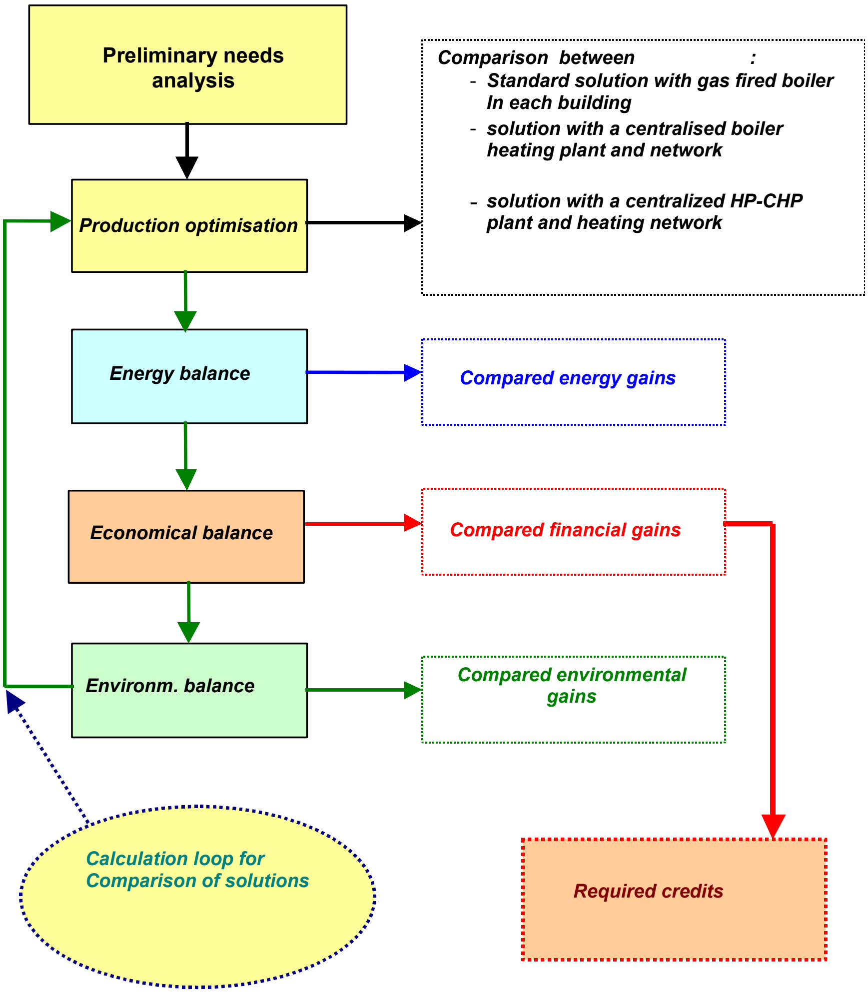

Figure 13 – Overall design methodology

CONCLUSIONS

The production of heat and power by means of a combined heat-pump and CHP can be an effective way to reduce CO2 emissions and to produce peak electricity in a decentralised and CO2 neutral way. The computer program allows to evaluate all possible scenarios with respect to the existing situation and constraints. It can be a usesul planning tool for municipalities and energy planning architects.

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