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TOWARDS SUSTAINABLE CITIES, THE BUILT ENVIRONMENT ENERGY PLAN OF HUAI ROU NEW TOWN

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Abstract

The project takes place in the framework of a process of collaboration and knowledge transfer between Italy and China.
This research is related to the energy planning of Huai Rou, a new town near Beijing that will host about 80 thousand people with more than 3,5 million of m^2 distributed by residences, commercial buildings and parking.
Huai Rou New Town represents a case study in the field of planning and realizing harmonious cities that means to plan and realize eco-settlements in which energy and material inputs are minimized and thus ~~outputs~~ emissions, while integration of different utilities and recycling are promoted in order to reduce energy and mass flows. To that end, the following measures are mainly implemented: to plan a suitable lay out for controlling solar radiation and wind effects, to design buildings with a low energy approach, to promote their mixed use, to use available local sources, i.e. renewable energies, to create a smart integration of the main utilities (waste management, energy supply, waste water treatment, transportation …).
The energy plan includes energy consumptions (cooking, domestic hot water, heating, cooling and electricity in residential and commercial buildings; electricity for car parks and public lighting; public and private transportation into the new town; transportation of biomass from the district to the plants; transportation of waste from the new town to the plants) and supply that is based on local sources (biomass, wastes, sludge, solar energy and mini-hydro).
Huai Rou New Town is an example of the concrete possibility, with today's technologies and in a context of cost-effectiveness, to design a fully renewable energy supplied, zero emission, and very small energy footprint settlement.

1. INTRODUCTION

This work started concerning the unbelievably fast process of urbanization (especially in developing countries) and the consequent building stock expansion and increasing of energy consumption.
In settlements, is mostly concentrated the world's final energy consumption, accounting for more than 70% of the total. Thus, more than two thirds of total energy consumption is needed for urban metabolism, and more than two thirds of the CO_2 emissions are due to it.
In this alarming framework, strong actions are needed for curbing the fossil energy consumption trend in cities. Taking into account the state of the art of economy and technology, it is necessary to develop a new urban design approach based on a new urban energy system, to avoid the catastrophic effects of global warming on one side, and to cope with the unavoidable constant increase of oil cost on the other.
Taking into account this approach, a new methodology has been defined and applied to the case study of a 80 thousand people Chinese town to be realized.

2. METHODOLOGY

The energy system of a city can be considered as a thermodynamic system in which high quality energy (exergy) is transformed into low quality energy [1] [2]. To design a renewable built environment means, first of all, to maximise its thermodynamic efficiency, i.e. to minimise the amount of primary, high quality, energy consumed. In low energy urban design, thus, the main aim is to minimise primary energy consumption, that presently is due for more than two thirds to residential, commercial and transport sectors. The fulfilment of this aim involves several combined actions i.e.:

- optimise the energy efficiency of the urban structure
- minimise the energy demand of buildings
- maximise the efficiency of energy supply
- maximise the share of renewable energy sources.
- minimise primary water consumption and exploit energy potential of sewage water
- minimise the volume of waste generated and going to disposal, and use the energy content of wastes
- minimise transport need and optimise transport systems
- minimise the primary energy consumption of transport means
- maximise the share of renewable energy sources in transport.

From a more practical point of view, when the methodology is defined, it is important to identify the aims that should be reached. For example, in the case of Huai Rou New Town, first aim was the reduction of the greenhouse emissions and of the ecological footprint; as maximum limit of the last was indicated the boundary of the District on which the town will depend for its energy supply, as it will be explained in the following paragraphs.

The application of the mentioned methodology to Huai Rou New Town is reported in [4].

Figure 1: Lay out of Huai Rou New Town (main areas, axes, parking and accesses) [3]

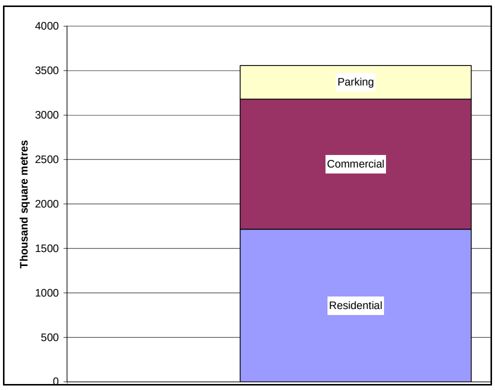


Figure 2: Areas of the building stock of Huai Rou New Town according to functions

2.1. Demand side

The combination of some strategies mentioned in the previous list, permit to control the energy demand of buildings, parking and transportation. This means to drastically reduce total energy demand taking into account the available status of technology for buildings envelope and systems and for mobility.
Energy demand in buildings has been defined according to the climate [5] and to the new European standards for heating and cooling, reachable with the current status of technology (see also table 1).

Table 1: Specific energy demand in buildings (gross average values)

	kWh/m^2y	kWh/m^2y	kWh/m^2y	kWh/m^2y
	Heating	Cooling	Lighting	Equipment/ Appliances
Residential	30	30	3	15
Commercial	25	60	15	20

In Huai Rou New Town, also the private transportation demand has been reduced due to the adoption of sustainable strategies as: urban planning towards compact mixed use and short distance zones, the availability of "comfortable" (mitigated due to the integration of systems for a partial heating or cooling and with protections from rain and sun) pedestrian and bicycles paths, an effective public transportation in which vehicles are fuelled by carbon neutral electricity and biofuels, and an effective car sharing scheme.
In short, Huai Rou New Town has been planned assuming:
- compactness, mixed use structure for reducing energy demand for transportation
- priority to pedestrians and cyclists
- good network of public transport (hybrid and all electric buses, tram)
- advanced mobility like plug-in hybrid cars.

Due to this approach, the use of private cars is significantly reduced (6,000 km/year instead of the average 12,000 in present European cities, 80% of which for urban mobility). Public and private mobility is fuelled by local sources; transport system is based on biofuels replacing fossil fuels and electricity produced either from PV systems or biomass powered generators, according to Table 2. Private cars for urban use are assumed to be electric and plug-in hybrid the ones for extra-urban use; it is also assumed that 50% of families owns an electric car and that a car sharing system is available and used [6] [7] [8].

Table 2: Vehicles and fuels for transports in Huai Rou New Town

Type of vehicle	Renewable energy source used
Lorries	Biofuels
Buses	Biofuels
Trams	Electricity from CHP units
Vans	Electricity from PV
Cars (urban use)	Electricity from PV
Cars (extra urban use)	Biofuels

On the basis of the mentioned assumptions, the resulting energy demand pattern by sector and by final uses are plotted in Figure 3 and 4 (gross values).

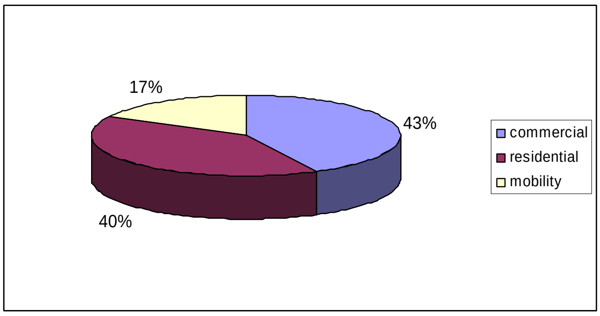


Figure 3: Energy demand by sector

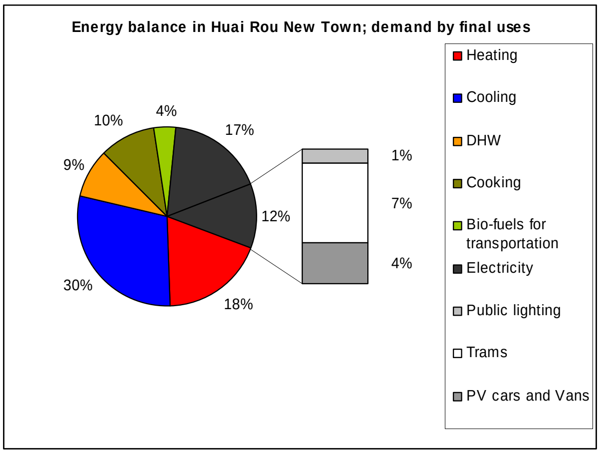


Figure 4: Energy demand by final uses

2.2. Supply side

Once the energy demand has been minimized, with appropriate urban and buildings design, the time comes to evaluate the use of the most energy efficient technologies for providing heating and cooling, hot water production, lighting, etc.

Within this framework, and considering the context of the case of study, only two technologies seem to be more consistent with the second law of thermodynamics for supplying the final services required in buildings to assure our well being: combined heat and power (CHP) and heat pumps.

CHP or co-generation plants are most efficient energy supply systems, when their waste heat is used not only for heating but also for cooling by means of devices such as the absorption chiller, that use low temperature heat to produce chilled water (tri-generation).

Cogeneration and tri-generation by absorption chillers have been integrated in the energy supplying strategies of Huai Rou New Town.

Further, as the energy consumption is minimised with appropriate technological systems, renewable energy can have a significant role in the energy balance of an urban settlement. According to available data, it is possible to single out the available local energy sources into Huai Rou district: biomass from forest, biomass from agriculture, biomass from farms, solar, hydro, wind, waste, sludge from waste water treatments. Among these, the most largely available renewable source is wood biomass. Another important available renewable is solar radiation. As mentioned before, the appropriate orientation of buildings favours the use of solar thermal and photovoltaic energy, for both heating and cooling. Technologies such as evacuated solar thermal collectors coupled with combi-systems, absorption chillers and desiccant cooling units can reduce significantly the need for fossil fuel.

Table 5: Self-sufficient Huai Rou New Town, energy demand satisfaction by local renewable sources

Sources/demands	Electricity	Heating	Cooling	Domestic hot water	Fuels (*)
Biomass	x	x	x	x	x
Waste (2)	x	x	x	x	
Sludge from waste water (2)	x	x	x	x	x
Solar radiation	x			x	
Wind (1)	?				
Hydro	x				

(1) To be investigated in the future.
(2) Treated in a CHP plant; cooling is provided both by compression chillers (electricity) and by absorption chillers (heat).
(*) For cooking and transportation

The supply for all energy final uses has been identified for both residential and commercial building designed for Huai Rou New Town. Electricity generation has been assumed completely renewable by using sources like waste, sludge, biomass, hydro and sun (see figure 5). These electricity is given to the grid and used for lighting and equipment in buildings and parking, for public lighting and for public transportation.

Plants fuelled by waste, biomass and sludge cogenerate also heat that is used for space heating, domestic hot water supply and, in summer, for space cooling due to absorption chillers. In general, CHP plants are based on gas (Bryton) cycle (against Rankine Cycle); to that end, pyrolysis-gasification of biomass and waste and anaerobic digestion of sludge are foreseen. Further, a feasible integration of solar systems is foreseen on the roofs of some residential (solar collector for supplying, globally, the 50% of the heat demand needed for domestic hot water; and PV systems connected to the grid) and commercial buildings (PV systems connected to the grid).

In residential buildings, space heating and space cooling are provided to the final users due to district networks; domestic hot water is provided both by district heating and by solar thermal collectors (50% and 50%, respectively). Heat is generated by biomass fuelled CHP plants, as mentioned before (figure 6).

In addition to common residential buildings, in Huai Rou, there will be also villas (high quality buildings). In villas, heating and cooling are provided by high performance Ground Source Heat Pumps, powered with the electricity produced by their PV roofs. Also the electric demand is met with the production of their PV roofs (figure 4). The electricity exchanges with the electric grid permit to guaranty a safe electricity availability during all the year; PV integrated systems have been designed with the aim to have a positive electric balance within a year, taking into account climatic data (during a year, only for villas, electricity sold to the grid is more than electricity bought from the grid).

In commercial buildings (figure 7), domestic hot water and space heating are provided to the final users due to district networks. Heat is generated by CHP plants, fuelled by biomass, syngas from biomass and waste and biogas from anaerobic digestion of sludge, as mentioned before. Space cooling is provided both by compression and absorption chillers: the first ones are feed by electricity from the grid, the second ones are able to transform heat generated by the CHP plants.

The PV installations on the roofs of residential and commercial buildings are able also to empower private or shared electric cars and vans.

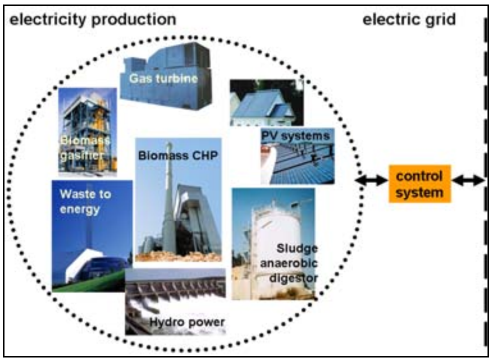
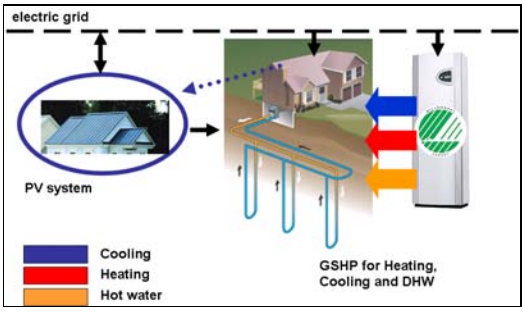


Figure 5: Mix for electricity generation



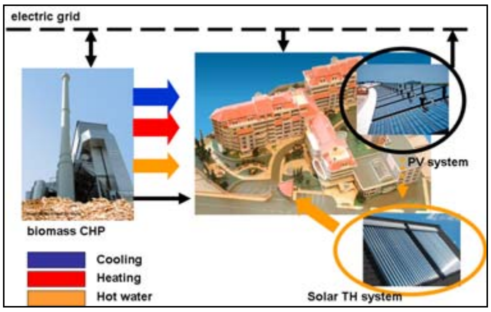


Figure 6: Energy supply for villas (left) and other residential buildings (right)

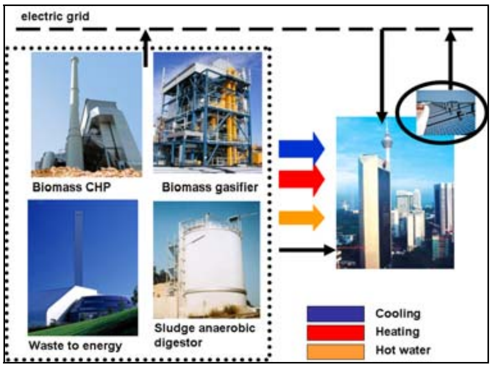


Figure 7: Energy supply for commercial buildings

The approach, based on the Distributed Energy Resources concept, besides being energy efficient, it has also a practical value, since it is possible develop the town construction zone by zone, thanks to the modular nature of the urban subsystems. This is the only way to design cities capable to develop relying only on renewable energy sources.

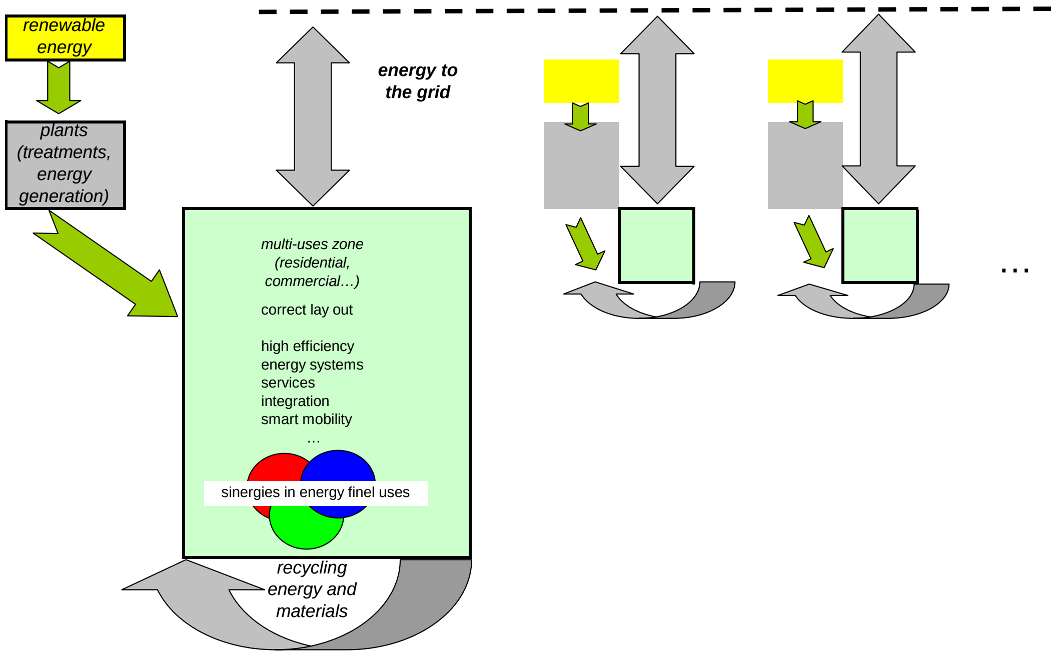


Figure 8: Scheme of the implementation of energy plan of Huai Rou New Town

The global view of the energy sources by which Huai Rou would be fuelled is plotted in figure 9, in which, due to the lack of data, wind energy contribution was assumed to be zero. It is possible to observe the very important role of biomass, assumed to cover more than 80% of the total. This is strictly dependent on the characteristics of Huai Rou District, in which biomass from forests and agriculture is easily and plentifully available. Data show that about 117,600 ha of territory are covered by forest, while about 53,826 ha of territory are covered by agricultural crops and plants. A first calculation of the biomass availability has been carried out with a conservative approach, not considering the possibility to convert these fields to short rotation forestry or other biomass to energy crops. Further, considering that the morphology of the district and the availability of roads could influence the phases of harvesting, collection, transportation and pre-treatments of the biomass, only the 75% of the total amount of hectares has been taken into account.
The calculation of biomass productivity (tons/ha y) is very difficult because no data are available; therefore, reasonable estimations were done on the basis of some Italian similar experiences and taking the same value of productivity for forests and other cultivation (very conservative approach, because in this case, a higher value could be assumed).
Other difficulties were met in defining biomass density and LHV because these parameters depend on biomass type, origin, location, way of collection and transportation, time and site of storage etc.
Also in this case, a rough estimation has been done and the same LHV and density have been assumed for all the biomass collected.
Several pre-treatments are preview in order to transform biomass in a fuel ready to be converted in other kinds of energy. In short, from the field to the plant there are: felling, cutting, harvesting, drying, chipping and other further reductions of the biomass size as chips, chunks or pellets production. Their combination depends on biomass typology, conditions of the fields etc.
All these phases are very important for supplying the plant and they need suitable machines and equipments.
Energy consumptions related to these phases are relevant and have to be taken into account.
Biomass could be treated in different bio-chemical or thermal treatments to be converted in heat and power. The most common is the thermal treatment of combustion, but, especially for small and medium sizes, also pyrolysis and gasification are applicable.

After that, energy recovery section could be designed in different way depending of the quality of energy demand (heat, heat and power) and on the size. In the present work, only technologies suitable for size between 10 and 50 MW_{el} have been considered. For these sizes, heat generation, electricity generation of both are possible.
As mentioned above, biomass conversion technologies needed for Huai Rou new town are:

1. CHP plants; see reference plants
2. biomass combustion for district heating and cooling
3. fuels productions (biogas for cooking and transportation; bio-ethanol and bio-diesel for transportation.

All the phases of the process of biomass treatments and utilization should be well planned and integrated, while, the size and the number of the plants for biomass to energy should be combined with urban planning.

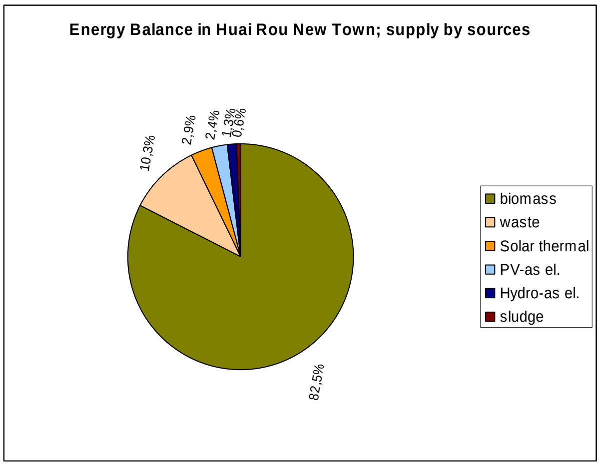


Figure 9: Energy supply by sources

From the analysis of energy plan of Huai Rou, it is possible to state that:

- Energy generation is totally carbon neutral
- All the sources come from Huai Rou Region
- Not the total available renewable energy potential of Huai Rou Region is exploited but a part of it remain for next generations (or other uses, or new settlements).

These considerations are represented also in figure 10, in which, for each source, 100% corresponds:

- For biomass, to the all biomass available in Huai Rou District (on the basis of the available data)
- For solar, to the all roof surfaces (buildings and parking) adequate for solar installations (PV and thermal collectors)
- For waste, to the waste produced that can be gasified for recovering heat and power
- For waste water, to the sludge produced that can be gasified for recovering fuels, heat and power
- For hydro, to the existing plants (but other plants could be implemented in the future).

All the souses are referred to the current status of Huai Rou Region.
The quantities defined “used” represent the fractions of the available/collectable sources that are actually used in the energy balance. The quantities defined “not usable” represent the fractions of the available sources that are to difficult to reach or to collect (for solar system, the roofs that could be shaded or are not well oriented; for waste, the fraction of waste separated during the collection and destined to material recycling). And, The quantities defined “not exploited” represent the fractions of the available sources that are easily available but not needed in the energy balance, so they could be used for other aims.
It should be noted that some sources have to be better investigated (hydro and wind), while biomass potential could be increased if not a conservative approach, as in the present case, but a improved approach is assumed, taking into account a different use of the existing fields and forests, with a

higher production of biomass. This eventual agricultural shift, aimed to improve biomass productivity from existing forests and fields, should be study in depth before of any actions, because it is important to select different cultivations taking into account several factors and problems, such as biodiversity, climatic conditions, landscape, human behavior etc.

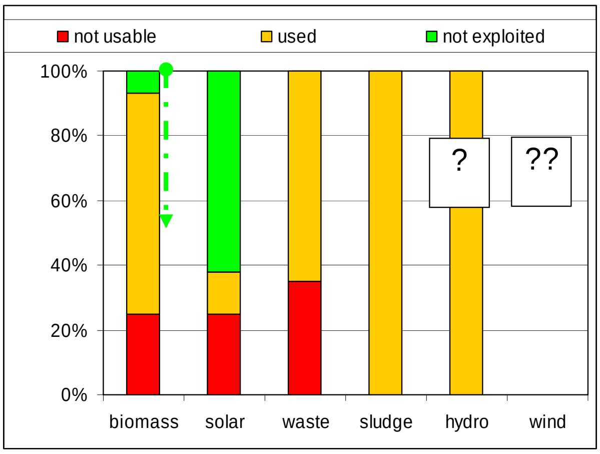


Figure 10: The sustainable and total renewable energy supply strategy of Huai Rou New Town

2.3. Matching energy demand and supply

For matching energy demand and energy supply and for giving a preliminary design of the plants, the software *Homer* has been used. In this way, also an estimation of the instantaneous demand with dynamic simulations has been found out (figure 9).

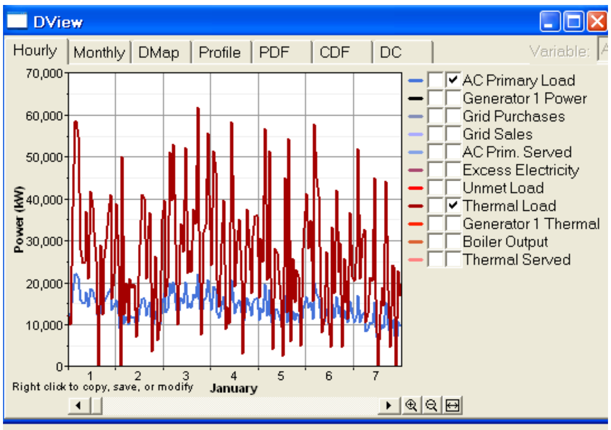


Figure 9: View of the hourly calculations by Homer (thermal and electricity demand in January); http://www.nrel.gov/homer/

The peaks of energy demand and other needs of the town (i.e. waste produced per day and waste water collected per day) have been taken into account for sizing the different plants.
Starting from the yearly energy demand, approximate estimations of the monthly, hourly and instantaneous energy demand has been carried out by dynamic simulations with *Homer* software, in order to define the size of the energy plants needed.
In this first calculation, only one biomass CHP plant has been assumed with the size of c.a. 30 MW_{el} and with conservative values of thermal and electric energy performances (one plant of c.a. 30 MW_{el}, including two or four modular lines; in alternative, more plants with smaller size).

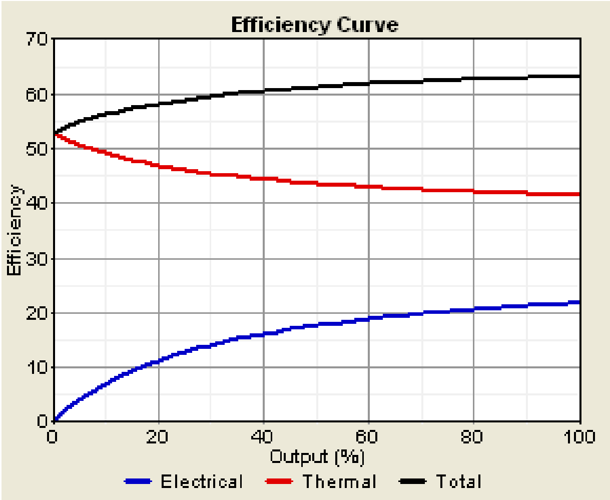


Figure 10: Electric and thermal performances assumed for the biomass CHP plant

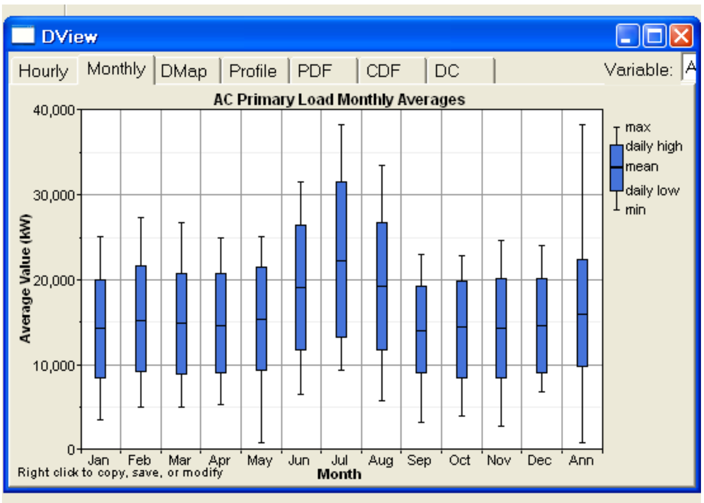


Figure 11: Electricity demand met by the biomass CHP plant (summer peak due to compression chillers for cooling)

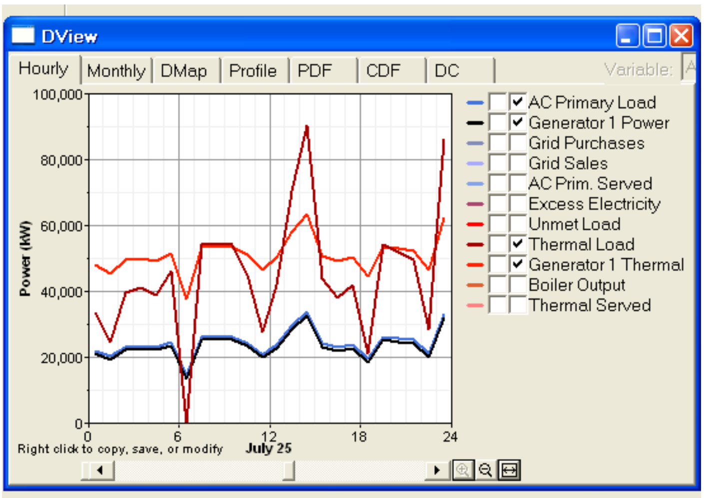


Figure 12: Operation of the biomass CHP plant in a summer day (output of *Homer* software)

3. CONCLUSIONS

The methodology applied to Huai Rou New Town demonstrates the possibility of designing a new town with the aim of reaching the full sustainability, i.e. zero fossil energy consumption, negligible CO_2 emissions and negligible ecological footprint.
Even if more detailed technical and economic evaluations are necessary, the preliminary ones show that this result is fully achievable and:

- It can be obtained with presently available technologies and already adopted – in some parts of Europe – building standards for energy conservation,
- It requires minor changes of lifestyle,
- It guarantees a high standard comfort level,
- It leaves some renewable energy potential of the district still exploitable (about 3-5% of the biomass potential - considering all the needs, including syn-gas for cooking and biofuels production -; about 60% of roof area for solar collectors; plus the cover of all the protected, mitigated paths, plus the vertical surfaces of the buildings, mostly facing south, etc.; some spare hydropower not accounted for; some presumable wind power potential).

4. REFERENCES

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