A new tool simulating the optimal design of the building-plant system

ODESSE (Optimal DESign for Smart Energy) is a software platform for the dynamic simulation of the whole building-plant system. It allows to calculate the energy consumption for heating, cooling and electrical uses by means of a thermo-physical description of the building envelope and of the connected plants at given hourly climatic conditions (temperature, solar radiation, humidity).
In particular, this paper describes a mathematical model of a small-scale internal combustion engine cogenerator based on the experimental performance of the engine, that is one of the implemented plant layout available for the ODESSE user. The model enables to evaluate the energetic and economic performance of a cogeneration plant: the primary energy savings are calculated and the economic profitability of the plant operation is assessed with reference to the Italian energy market

■ *Marco Badami, Armando Portoraro, Ilaria Bertini, Francesco Ceravolo, Biagio Di Pietra, Giovanni Puglisi*

Un nuovo strumento per simulare il progetto ottimale del sistema edificio-impianto

ODESSE è una piattaforma software per la simulazione dinamica dell'intero edificio impianto. Permette di calcolare il consumo energetico per riscaldamento, raffrescamento ed energia elettrica tramite la descrizione termofisica dell'involucro dell'edificio e degli impianti a date condizioni climatiche orarie (temperatura, radiazione solare, umidità).
In particolare, viene descritto un modello matematico di un impianto di cogenerazione basato su un motore a combustione interna, che è uno dei modelli di impianto disponibili per l'utente di ODESSE. Il modello permette di valutare la performance energetica ed economica dell'impianto, calcolando il risparmio di energia primaria e la redditività dell'impianto riferita al mercato energetico italiano

■ **Marco Badami, Armando Portoraro**
Politecnico di Torino, Energy Department
■ **Ilaria Bertini, Francesco Ceravolo, Biagio Di Pietra, Giovanni Puglisi**
ENEA, Technical Unit for Energy Efficiency

The ODESSE platform

The promotion of efficient technologies for air conditioning of buildings is a crucial element to meet the national and European targets to reduce energy consumption and CO_2 emissions. The spread in the market is often hampered by the lack of tools available to professionals, to simplify the design of efficient technologies which is generally complex and not yet well known.
To this end, we completed the development of the ODESSE (Optimal Design for Smart Energy) software by integrating it with a number of preconfigured layout systems. These are characterized by a complex energy mix and technologically advanced solutions, giving the user the possibility to make the simulation of the building-plant system real. This research has been carried out within the framework of "R&D activities of general interest for the National Electric System", funded by the Italian Ministry of Economic Development.
In particular, ODESSE simulates the performance of building-HVAC system in real condition of work, with real fares, taxes and rules and enables to estimate the technical and economic feasibility of the energetic retrofit of the whole system. The energy balance used to describe the building model takes into account: the heat gain due to solar radiation on glass and opaque surfaces; the heat gain due to people, artificial lighting and electrical equipment; the heat loss through the envelope and for ventilation, thermal or cooling power supplied by the existing plants [1].
The whole heat distribution system is composed of three parts: distribution, supply (radiators, fan coils, radiant heating panels, etc.) and control system.
In particular, the following facility layouts were developed and integrated:

- traditional system with electric heat pump and boiler (traditional and condensing);
- co-trigeneration system with internal combustion engine of small size and microturbine;
- desiccant cooling system, integrated with traditional internal combustion engine for the regeneration of the enthalpy wheel;
- hybrid system, providing for the integration of renewable technologies with traditional power generation from photovoltaic, thermal solar collector generation, integrated with electric heat pumps and gas boiler backup for domestic hot water;
- solar cooling system with cooling units for lithium bromide absorber and solar washers.

For each preconfigured layout a control system has been developed that determines the ignition off and adjustment of the main plant components following the logic that normally characterizes the real plant.
Hence, ODESSE is a candidate to be not only a software for the rapid evaluation of innovative energy mix, but also a tool to spread technical engineering

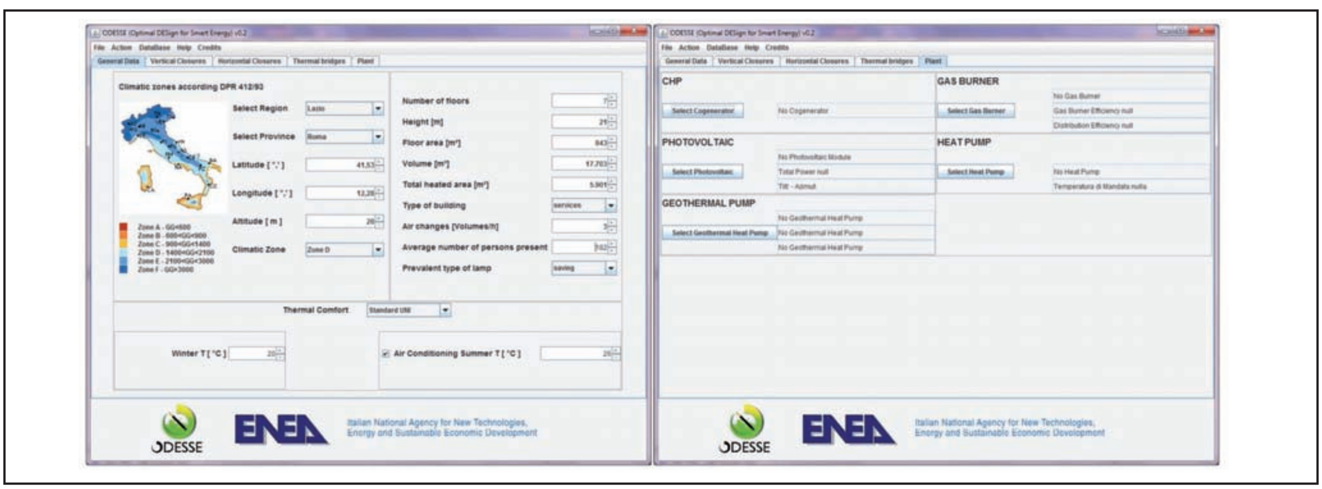

FIGURE 1 ODESSE user interface: Climatic Zone and general Building data

solutions that do not find any supplier in the market yet and therefore require an experienced professional able to put them into a system (e.g., solar cooling, the DEC is in configuration and in the solar hybrid configuration, combined cooling, heating and power systems, etc.). The ODESSE user interface is implemented in Java according to criteria of intuitiveness to permit even an unexperienced user of dynamic simulation to use it. The user can enter information regarding physical, structural and geometrical building data, location and climatic zone (heating season and cooling season) internal gains profile, heating and cooling system (Figure 1).
The tool is available for free download in the ENEA official Website (www.enea.it).

Description of the Combined Heat and Power model

In order to show the results of the application of the ODESSE tool to a real case study, it has been chosen to describe the CHP layout.

Main input model	Main output model
On-off time scheduling of the plant	Natural gas consumption of the CHP plant and gas burner backup on seasonal base
Thermal load profile of the simulated building	Electrical and thermal energy generated by the CHP plant on seasonal base
DHW hourly profiles	Thermal energy generated by the backup gas burner on seasonal base
Electrical non-HVAC profiles of the simulated building	Hourly average electrical and thermal power generated by the CHP plant
Hourly average temperature of the building	Hourly temperature of the cooling water of the engine downstream from the water / water heat exchanger
Hourly average outside temperature	Hourly average temperature of the hot water provided to the building (to the thermal supply system), downstream from the thermal storage
Temperature of the hot water coming from the thermal storage	Hourly average inside temperature of the simulated building
	CO_2 emissions by internal combustion engine

TABLE 1 Main input and output CHP model

The CHP system model has been implemented on the Matlab/Simulink platform. The model has been developed by means of experimental maps adimensionalised in order to be able to work properly, in the small-scale range, with different types of combined heat and power plants.

In particular, the CHP user interface allows the control strategy (electrical or thermal load following) to be chosen and to change the most important parameters and performance characteristics that are usually given in the producers' datasheets:

- electrical rated power of the combined heat and power plant;
- percentage of the rated power of the combined heat and power below which the engine switches to stand-by mode;
- maximum temperature of the engine cooling water;
- mass flow of the engine cooling water;
- efficiency of the water/water and of the gas/water heat exchangers.

In order to evaluate realistic electrical non-HVAC load profiles for the buildings to be simulated, a typical electricity demand load profiles for multi-family houses [3] and for office buildings are considered. Realistic electrical load profiles can also be entered directly into the model by the user.
Performances of the installation are calculated by means of the Primary Energy Savings index, the electrical and thermal efficiencies and CO_2 emissions; the proficiency of the plant operation is assessed with profits and costs evaluations on the reference energy market (subsidies acknowledged by the Italian legislation are also taken into account). Finally, the EBITDA (Earnings Before Interest, Taxes, Depreciation and Amortization) value offered by plant operation in the period of the simulation is also calculated.
In Figure 2 a screen shot of the main CHP interface of the tool is reported.

The main performance indices calculated by the tool are specified in detail here below:

- average electrical (η_{el}) and thermal (η_{th}) efficiency of the cogenerator on seasonal base
- primary Energy Savings (PES) achieved thanks to the plant operation on seasonal base

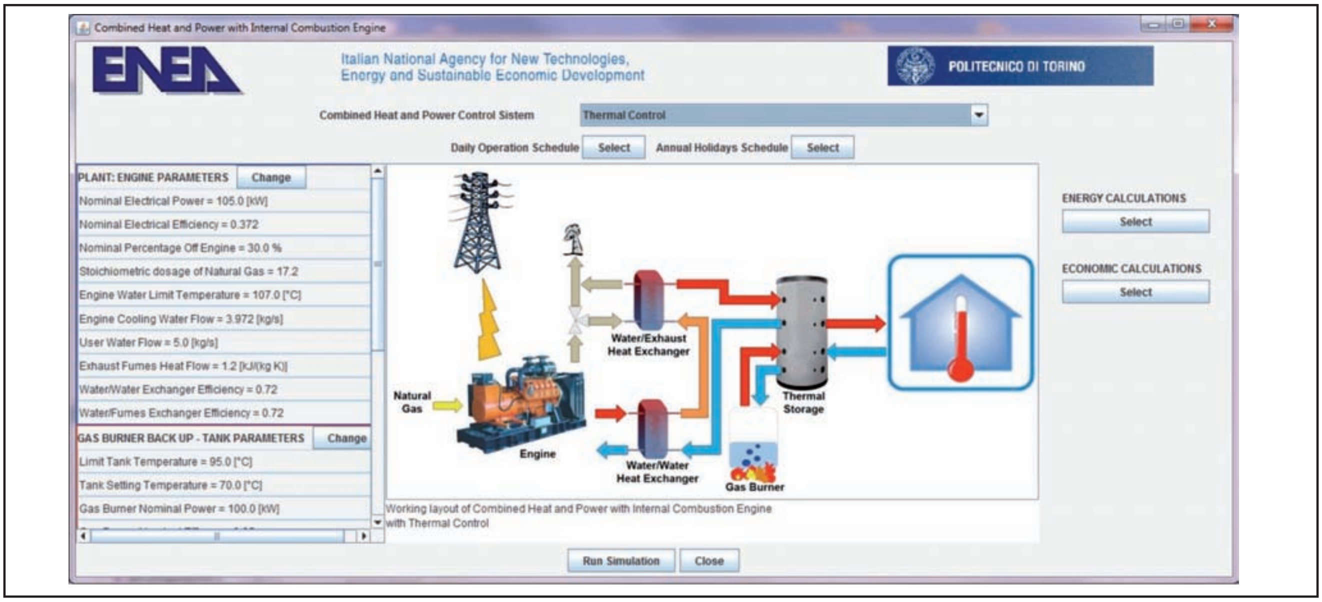

FIGURE 2 ODESSE user interface: CHP configuration plant and component parameters

- total costs and total revenues obtained from plant operation on seasonal base
- total hours of operation per year of CHP plant.

The tool also performs the calculation of total costs and total revenues obtained from plant operation on seasonal base. In particular, the considered revenues at the time of the simulation are the following:

- the avoided cost of the electrical energy generated by the plant and self-consumed by the building;
- the avoided cost of the surplus production of electrical energy, which can be sold to the grid;
- the avoided cost of the thermal energy recovered from the prime mover and exploited in winter for heating the building.

The costs are the following instead:

- maintenance costs
- fuel cost
- general, administration and operational costs.

The calculation of the economic profitability (Earnings before interest, taxes, depreciation and amortization, EBITDA) at the time of the simulation is therefore possible, by evaluating the difference between the revenues and costs, as expressed below:

EBITDA = Total revenues – total costs

Performance Indices calculation

Average electrical η_{el} and thermal η_{th} efficiency of the combined heat and power plant on seasonal base can be calculated, by means of Equations (1) and (2):

$$\eta_{el} \quad \frac{E_{el}}{E_{fuel}} \qquad (1)$$

$$\eta_{th} \quad \frac{E_{th}}{E_{fuel}} \qquad (2)$$

In order to evaluate the energetic performance of a CHP plant, the EU Commission introduced the PES (Primary Energy Savings) indicator, defined as in Equation (3):

$$\eta_{el} \quad \frac{E_{fuel}}{\frac{E_{el}}{\eta_{el,s}} + \frac{E_{th}}{\eta_{ths}}} \qquad (3)$$

Where:
E_{fuel} is the total fuel energy input at the time of the simulation;
E_{el} is the total net electricity generation;
E_{th} is the total thermal energy recovered from the prime mover, at the same time.
$\eta_{th,s}$ and $h_{el,s}$ are the thermal and electrical efficiency values for the separate generation.

According to the Decision of the European Commission 2007/74/CE of 21 December, 2006, they are fixed $h_{th,s}$= 0.9 and $h_{el,s}$ = 0.454

Average electricity and natural gas costs		*PES parameter*	
Tax free natural	0.4 €/Sm^3	Electric grid efficiency	0.30
Natural gas	0.61 €/Sm^3	Traditional gas boiler efficiency	0.88
Grid electricity for F1 rate	0.166 €/kWh		
Grid electricity for F3 rate	0.142 €/kWh		
Grid electricity for F3 rate	0.109 €/kWh		

TABLE 2 PES parameters and reference costs

Results

Studies concerning the energy simulation of the CHP plant for tipical office buildings in the city of Rome with different control strategies have been carried out. The structure of the buildings has been designed with average features typical of buildings of the 70s in reinforced concrete and with double glass windows.
Below, the results of a specific case study are reported. Such example refers to an office building of 6000 m^2, characterised by a thermal demand of around 500 MWh and an electrical demand of around 140 MWh.
The CHP system is a grid-connected internal combustion engine of 105 kWe, adopting a net metering rule with the power company: the energy generated in excess is delivered back into the grid and used as a credit for periods when not enough energy is generated to meet electric needs.
The results in terms of energy and economic analysis for different control strategy of CHP system (thermal and electrical following) are given in Table 3.
The decision to install or not to install a cogeneration plant is not only related to energy consideration (PES>0); in fact, as it can be seen from the tables below, in both cases (thermal and electric following) the PES index is positive and similar, so that the two strategies might seem equivalent whereas, for the case study, the Annual Economic Profitability (EBITDA) is about 13.500 € for thermal following and less than 1000 € for electric following; considering a total cost of the plant of about 200.000 €, payback time analysis makes not feasible a CHP installation with electrical following strategy.

Thermal following control		**Electrical following control strategy**	
Total thermal energy generated by CHP	189.26 MWh	Total thermal energy generated by CHP	31.40 MWh
Total electric energy generated by CHP	141.38 MWh	Total electric energy generated by CHP	21.70 MWh
Total thermal energy generated by gas burner backup	323.00 MWh	Total thermal energy generated by gas burner backup	419.40 MWh
Average annual PES (primary energy saving)	0.44	Average annual PES (primary energy saving)	0.42
Hours of CHP operation per year	1347 hours	Hours of CHP operation per year	652 hours
Profit from power generation by CHP system	20942€	Profit from power generation by CHP system	3187€
Profit from thermal generation by CHP system	14874.5€	Profit from thermal generation by CHP system	2468.4€
Total costs of gas consumed by CHP system	19481.31€	Total costs of gas consumed by CHP system	3283€
Total annual cost of O&M for CHP system	2714.6€	Total annual cost of O&M for CHP system	1315€
Total costs of gas consumed by Auxiliary gas burner	22767€	Total costs of gas consumed by Auxiliary gas burner	29560.11€
EBITDA	13485€	EBITDA	990€

TABLE 3 Energy and economical analysis for different control strategy

Conclusion

The core of the work was the development of a new tool with user interface for the simulation of a building-plant system and ODESSE software has proven to be useful for this task.
Its user friendly interface has been designed to give the possibility to simulate different types of air conditioning plants with easy and fast input (traditional system, CCHP - combined cooling, heat and power -, solar-cooling, etc.) for multi-family houses or office buildings. The user interface contains default performance indices of each component but gives the

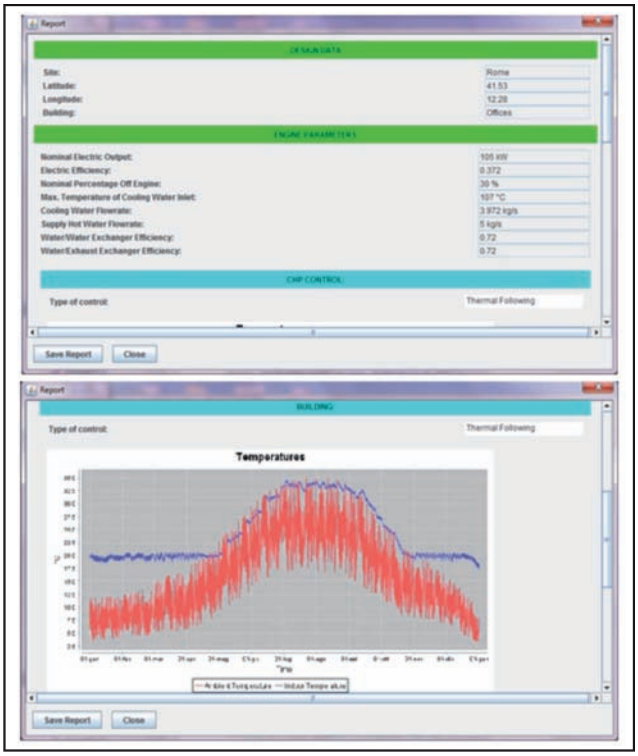

FIGURE 3 Example of a technical simulation report

user the opportunity to change these figures with other ones related to market available equipment.

The results of the application of ODESSE tool to a typical office building connected to a CHP system are shown below. Main performance indices as well as hourly diagrams are provided in a detailed output report.

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