FEASIBILITY STUDY OF A COLD IRONING SYSTEM AND DISTRICT HEATING IN PORT AREA

Daniele Colarossi[1], Paolo Principi[1]
[1]Department of Industrial Engineering and Mathematical Sciences, Università Politecnica delle Marche, Via Brecce Bianche, Ancona, Italy
Phone +39 071 2204773, e-mail: d.colarossi@pm.univpm.it

Abstract – Among the possibilities for the reduction of pollution in port areas, cold ironing satisfies the electrical power demand of ships while they are at berth replacing on board diesel generators. Through cold ironing ships can shut down their auxiliary engines. In this paper, a feasibility study for the port of Ancona is proposed, considering only the ferry docks. A methodology of analysis of the electrical loads required by the ships while they're at berth is presented. The power is provided by a cogeneration plant powered by natural gas which allows to produce electrical energy at a lower price than what would be obtained from the grid. The energy demand is linked to the presence of ships in port which means it varies greatly over time, hence a Compressed Air Energy Storage system is installed. The heat waste recovered from the cogenerator is used in a ring district heating network. Finally, the economical aspect has been evaluated to prove the feasibility of the whole system. The results show that a 1.5 MW and 2 MW cogenerator covers 83.05 % and 92.5 % of the electrical need of ships respectively, and 61 % and 74 % of the thermal need of buildings over the analysed period. Both scenarios prove to be economically feasible.

Introduction

Over the years the continuous increase in maritime traffic of goods and people, both by ferries and cruises (which have the highest growth rate), highlights the problem of environmental pollution in port areas, especially when the port is in the proximity of urban areas. According to IMO (International Maritime Organization), maritime traffic contributes to CO_2 global emissions for approximately 2.2 % (2014) [1]. It is estimated that the naval transport sector generates about a billion tons of CO_2, expected to become, according to forecasts, 1.6 billion tons in 2050 [2]. In addition, ships contribute to NO_x, SO_x and PM emissions in varying degrees depending on the type of engines and fuel used by the ships.

This paper presents the cold ironing system [3] for the port of Ancona, as a solution for the reduction of environmental pollution in port area. Thanks to on-shore power, the energy demand of berthed ships is satisfied and they can shut down their on-board diesel generators. The energy is provided by a cogenerator, where the thermal energy produced is recovered to air-condition a series of buildings (reducing the usage of the traditional boilers) and to ensure an additional benefit on the environmental impact.

FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)
Daniele Colarossi, Paolo Principi, *Feasibility study of a cold ironing system and district heating in port area,* pp. 666-675, DOI 10.36253/978-88-5518-147-1.66

Materials and methods

The objective of the study is to illustrate the benefits of on-site energy production in terms of pollution reduction. It is worth noting that if the energy from the grid does not come from an efficient and renewable source, the result is simply a displacement of the polluting source from the ships to the centralized production site. Cogeneration provides highly efficient energy and it ensures energy saving. Although the power plant is in the port area, it is small and the pollutant emissions are easily controllable. Another advantage is that transmission losses are avoided along the network. The high cost of electrical energy from grid in Italy is also part of why on-site energy production is favourable over a grid-connected configuration.

The system consists of a cogeneration plant, where electricity and heat are produced. The electrical energy is used to power the ships at berth, while the thermal energy is exploited to air-condition a series of buildings through a heating district network. This allows the overall efficiency of the plant to be significantly increased and consequently lowers the cost of energy production. Selling energy distributed to those buildings comprises another source of economic gain for the return on the investment costs for the project. The cogenerator is flanked by the CAES (Compressed Air Energy Storage) since the electrical demand is highly variable, because it is linked to the presence of ships anchored in port. The plant scheme is depicted as in figure 1.

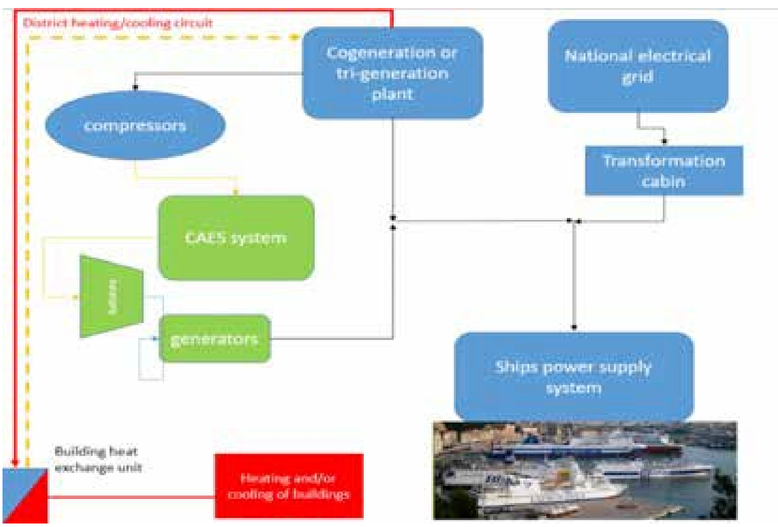
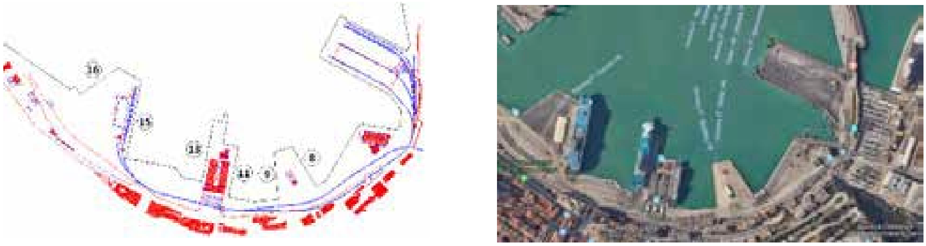


Figure 1 - Block diagram of the proposed system.

The energy analysis, upon the indication of the Central Adriatic Ports Authority, only concerns the ferry docks. Ferry ships have a fairly regular call frequency, and they do not require high power, as is the case of cruise ships. The ferry docks are number 8-9-11-13-15-16, as depicted in figure 2.



(a) (b)

Figure 2 - Area under study of the port of Ancona: CAD (a) and satellite view (b).

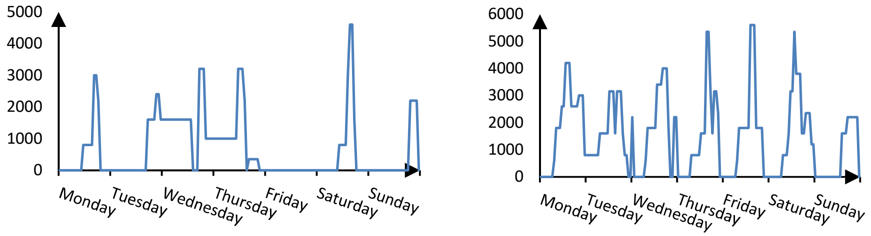
Table 1 - List of ferry ships in the port of Ancona and associated power.

	N° generators	**Power each [kW]**	**Average power [kW]**	
			Summer	Winter
Ship 1	3	2100	1600	1600
Ship 2	3	1400	1550	1000
Ship 3	3	1400	1550	1000
Ship 4	3	1900	2200	2200
Ship 5	3	3800	2200	2200
Ship 6	4	850	1200	1200
Ship 7	3	1360	800	800
Ship 8	2	960	500	350
Ship 9	4	783	600	600
Ship 10	3	945	800	800

To evaluate the power and the other electrical characteristics requested by each ship at berth, a series of meetings and on-ship inspections were held with the shipping companies and the Port Authority. In table 1 the collected data have been summarized (the names of the ships or shipping companies present in port have not been reported, but the ships have been numbered).

The analysis was carried out over a one-year period, from 01-08-2018 to 31-07-2019. The simultaneous presence of ships in port was necessary to determine the trend of the required electric power. The data were collected from the PMIS portal (Port Management Information System), that contains all the times of stay of each ship on the quay, tabulated according to the day and time of arrival and departure and the number of the quay. The sum of the powers required by the ships present at any given time determines the electrical needs to be met. The analysis was made considering the typical week for each month on an hourly basis. Here only the extreme cases are reported, namely January and July (figure 3).

Since the ships that are part of the analysis are scheduled ferries that connect the port of Ancona with those of Croatia and Greece, the winter months are characterized by a low frequency of calls which determines a low average load of energy required, while the summer months are characterized by a higher frequency of calls with traffic-due shorter stays mainly concentrated during the day.



(a) (b)

Figure 3 - Trend of electrical energy demand (kWh) of ships at berth during January (a), July (b).

Table 2 - Thermal energy demand [kW] of buildings in winter and summer.

	Buildings	Winter	Summer
1	Non-commissioned officers club	338	-
2	Finance police HQ Tommaso Mariani	238	-
3	Former Fincantieri administrative offices	132	145
4	Port Authorities	469	480
5	Current maritime station	632	599
6	Port Authorities 2	168	-
7	Border police	247	350
8	Coast Guard	214	-
9	Administrative court	427	436
10	ITN Elia	612	-
11	INAIL	351	417
12	Fincantieri canteen	565	-
13	Finance police HQ Carlo Grassi	150	176
14	New Port Authority headquarters	877	945
		5474	**3604**

As regards the thermal analysis of buildings, the thermal loads in summer and the heat losses in winter through the building envelope were evaluated. For the calculation of the overall heat transfer coefficient of the walls, roofs, floors and glazed surfaces, typical stratifications, based on the year of construction, for each building have been assumed. The results of thermal analyses carried out on the buildings to be air conditioned are summarized in table 2.

These values are useful for sizing the equipment, such as central heating boilers, chillers and auxiliary devices. To carry out an analysis of real consumptions, it was necessary to define the "average monthly day" according to the climate data on an hourly basis, taken from the CNR (Italian National Research Council) databases [4] for winter months and also the relative humidity and solar radiation for the summer months. Furthermore, for a better completeness it was decided to differentiate between the working days and the holidays. In the latter, the buildings used as offices, remain closed and are therefore not involved in air conditioning.

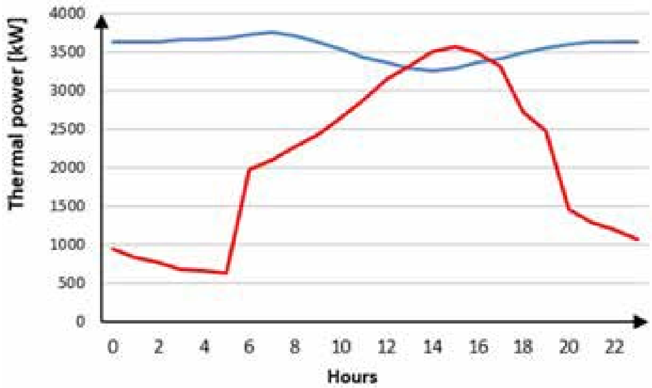


Figure 4 - Trend of thermal demand of buildings for a typical weekday in January (blue) and July (red).

Figure 4 depicts the trend of a winter month (January in blue) and of a summer month (July in red). For the winter months it is enough to consider the outside temperature. The minimum of the trend occurs during the hottest hours of the day. In a summer month, the temperature values for calculating the heat transmitted through the building envelope and the incident solar radiation on the surfaces (both opaque and transparent) are reported in the Italian standard. The trend shows a peak of thermal power in the hours with the maximum solar radiation.

A ring district heating network [5] connects the thermal power plant to the buildings located near the port area. In figure 5 each of them is identified with a number on the map. The list also includes the new headquarters of the Port Authority to be built.

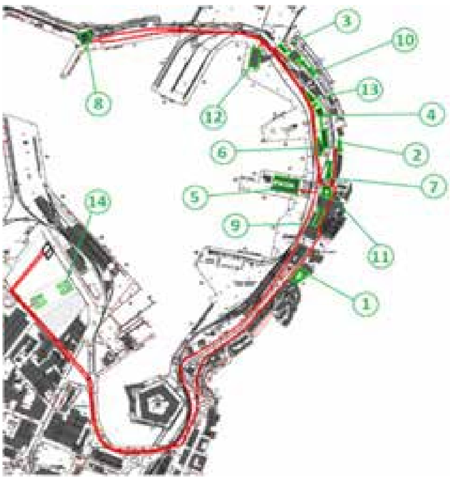


Figure 5 - Heating district network and position of buildings on the map.

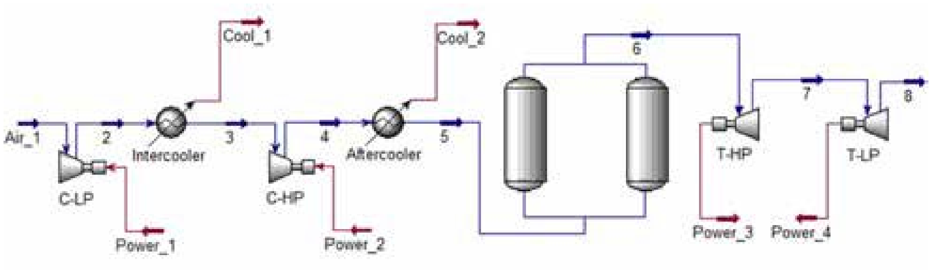


Figure 6 - Plant layout of a CAES system.

The CAES system [6-8] stores energy when the required amount is less than the produced one. Then it is expended when the potential of the cogenerator is insufficient to satisfy the energy demand, namely when more ships are present in port. The CAES system is composed of three parts, charging via compressors (single or multiple), storage in tanks and discharging into turbines, as depicted in figure 6.

The sizing of a CAES system is based on the choice of a set parameter, in the present case study the tank charging time. It has been evaluated considering the average of the times in which there is no demand for energy due to the absence of ships in port. This time can to be used to charge the tanks.

Results and discussion

In the present work, the annual average of the electrical load that was calculated, as shown in figure 7, nears 1394 kW.

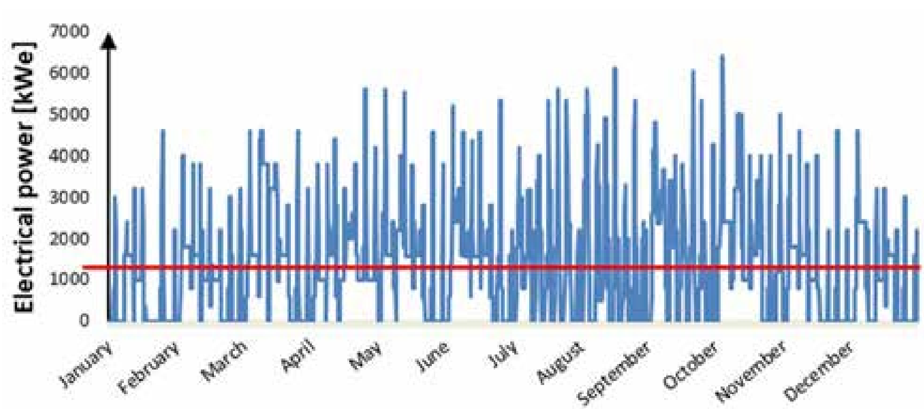
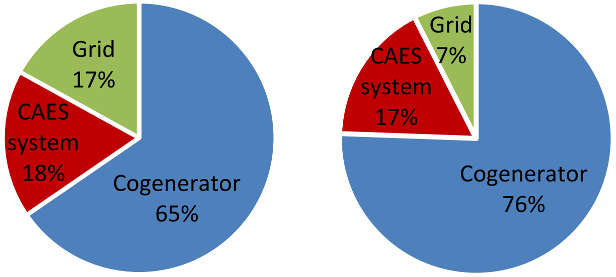


Figure 7 - Annual trend of electrical energy required by ships at berth. The red line indicates the average over the year analysed.

The idea is to create a constant production of energy and to balance the moments of non-demand of energy with the moments of maximum demand, leaving the task of "load tracking" to the storage system. Two different scenarios are hypothesized. The first simulation led to the evaluation of a 1560 kW cogenerator to stay as close as possible to the average annual load. For the second simulation instead, a 2 MW power plant was chosen, with the aim of increasing the autonomy of the system and supply a greater amount of thermal energy to the buildings (table 3). The results are shown in the two pie charts of figure 8.

Table 3 - Simulations carried out.

	Power [kW]	Thermal efficiency [%]	Electrical efficiency [%]	Overall efficiency [%]
Scenario A	1560	43.8	43.2	87
Scenario B	2000	43.2	43.7	86.9



(a) (b)

Figure 8 - Coverage of electricity needs for the 1560 kW scenario (a) and the 2000 kW scenario (b).

As shown in figure 8, the first scenario (1560 kW) provides less autonomy than the second one (2000 kW). With a larger power plant it is necessary to withdraw from the network only 7 % of the energy required by the ships, and it rises to 17 % with a smaller sized cogenerator. In both cases there are quotas of energy transferred and purchased from the grid, due to the dynamic nature of the request. It can be noted that the percentage satisfied by the CAES system is not influenced by the size of the cogenerator. Overall scenario (b) allows greater energy autonomy, in fact it is self-sufficient for electricity supply for three months a year, while scenario (a) is self-sufficient only for one month.

The results from a thermal point of view are analysed by looking at the percentage covered by the thermal energy requirement of the buildings. The trend is variable and reaches a minimum value in January, where the energy request is higher than the other months. Overall, the 2 MW plant covers almost 15 % more, as it recovers a greater amount of thermal energy. The results in detail over the whole year are shown in figure 9.

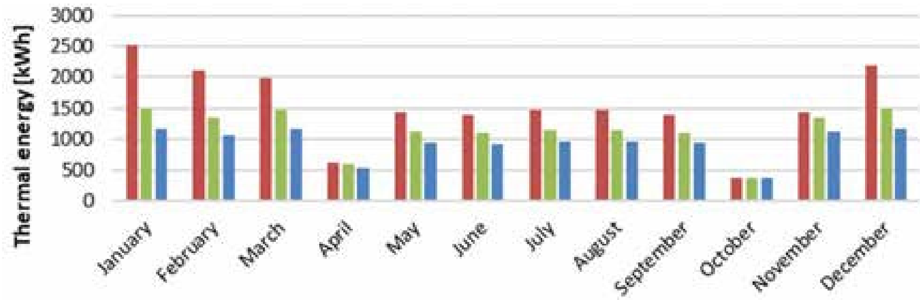


Figure 9 - Coverage of thermal demand. Red indicates the thermal energy demand, green the energy provided by scenario (b), while blue indicates scenario (a).

The index used to evaluate the energy saving is the PES (Primary Energy Saving). It is calculated as follows:

$$PES = 1 - \frac{1}{\frac{\eta_{th,CHP}}{\eta_{th,s}} + \frac{\eta_{el,CHP}}{\eta_{el,s}}} \qquad 1$$

Where $\eta_{th,CHP}$ is the thermal efficiency of the cogenerator, defined as ratio between the useful heat and the fuel supply used to produce the sum of useful heat output and electricity from cogeneration, $\eta_{th,s}$ is the reference thermal efficiency of separate production, $\eta_{el,CHP}$ defined as "annual electricity from cogeneration" divided by the fuel input used to produce the sum of useful heat output and electricity from cogeneration and $\eta_{el,s}$ is the reference electrical efficiency of separate production. From the calculation it emerges that the scenario (a) returns a PES value of 17.89 while 17.5 for that (b). The first solution is better by a slight margin, since it is the configuration that determines a greater PES minimizing the waste of energy.

For the economic analysis the NPV (Net Present Value), the IRR (Internal Rate of Return) and the PB (Pay-back) were chosen as evaluation indices. The results of the considered indices are summarized in Table 4. The best investment is therefore the one associated with scenario (b) because it produces a lower PB with a higher associated NPV and IRR. It yields a higher revenue from the sale of thermal energy and the greater revenue from the incentives linked to the increased sale of electricity to the grid.

Finally, savings are analysed from the shipowners' point of view transitioning from diesel generators to on-shore supply. The costs of generating electricity from diesel engines were compared with consumption [9] and the cost of energy from the cold ironing system. The total savings over the year are around 850 thousand euros, or about 59 % of current costs. Figure 10 shows the trend of the two costs during the period analysed.

Table 4 - Economic results.

	PB	NPV	IRR
Scenario (a)	5 years, 7 months	5 640 003.24 €	13.4 %
Scenario (b)	4 years, 5 months	10 348 968.00 €	18.9 %

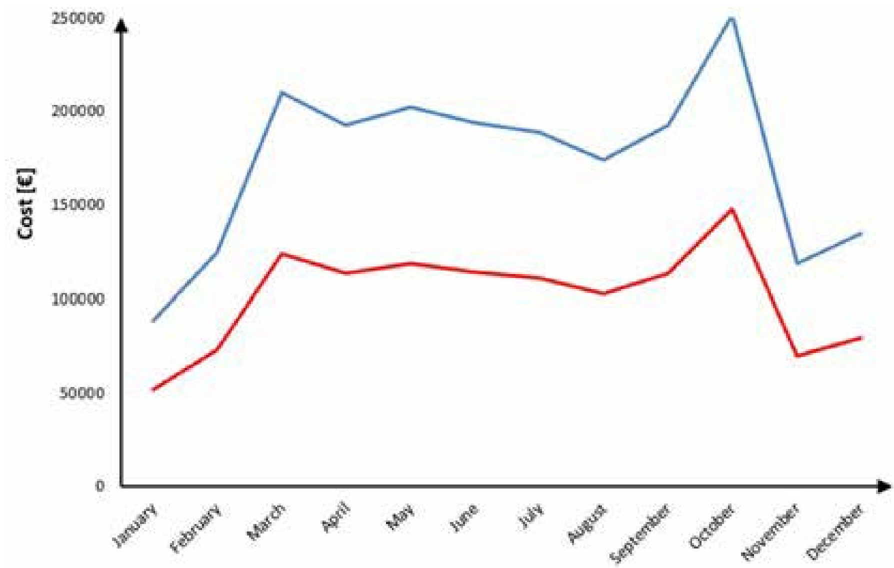


Figure 10 - Savings trend obtained from the production of electricity from cold ironing and diesel generators on board.

Conclusions

This work has proved the feasibility of a cold ironing plant in the port of Ancona and the results can be summarized as follow:

- About the energy aspect, scenario (a) (1560 kW) realises a greater PES compared to scenario (a) (2000 kW), because minimises the amount of fuel used (natural gas);
- Scenario (b) is self-sufficient for electricity supply for three months a year, while scenario (a) only for a month;
- Scenario (b) better satisfies the thermal needs of buildings (74.55 %) compared to the first scenario (61.18 %);
- Regarding the economic aspects, scenario (b) yields a greater NPV and IRR, with a lower PB.

Furthermore, the feasibility from the shipping companies' point of view has been proved.

References

[1] Agenzia europea dell'ambiente (2016) - *I trasporti aerei e marittimi*.

[2] IMO (2014) - *Third IMO GHG Study 2014*. International Maritime Organization (IMO), London. [Online] Available at: http://www.iadc.org/wp-content/uploads/2014/02/MEPC-67-6-INF3-2014-Final-Report-complete.pdf

[3] Thalis P.V. Zis (2019) - *Prospects of cold ironing as an emissions reduction option*, Transportation Research Part A 119, 82-95.
[4] CNR (1982) - *Dati climatici per la progettazione edile ed impiantistica*, Roma.
[5] Versace M. (2016) - *Analisi dinamica e valutazione delle prestazioni di una rete di teleriscaldamento*, Università di Pisa.
[6] Cárdenas B., Hoskin A., Rouse J., Garvey S. D. (2019) - *Wire-wound pressure vessels for small scale CAES*, Journal of Energy Storage 26, 100909.
[7] Rogers A., Henderson A., Wang X., Negnevitsky M., Senior Member (2006) - *Compressed Air Energy Storage: Thermodynamic and Economic Review*, Proceedings of the IEEE Power and Energy Society General Meeting, USA, National Harbor, 27-31 July 2014, pp. 1-5.
[8] Hartmann N., Vöhringer O., Kruck C., Eltrop L. (2012) - *Simulation and analysis of different adiabatic Compressed Air Energy Storage plant configurations*. Applied Energy 90, 541-548.
[9] Sciutto D., Pinceti P. (2019) - *L'elettrificazione delle banchine dei porti del Mar Ligure Occidentale*.