

ENERGY ASSESSMENT FOR A NEW URBAN SETTLEMENT

Marco Masoero – marco.masoero@polito.it

Chiara Silvi – chiara.silvi@polito.it

Politecnico di Torino, Dipartimento di Energetica

Corso Duca degli Abruzzi 24 – 10129 Torino – Italia

Abstract. *The paper concerns the definition of guidelines in the design of a new urban settlement, based on system energy utilization and building environmental impacts and sustainability improvement. The study refers to a 160000 m² area sited on the outskirts of Carmagnola, a city close to Torino, where the municipality decided to locate about 1260000 m³ of commercial buildings: offices, shopping centres, a trade fair area, a cattle market, a multi-hall cinema, hotels, restaurants, industrial sheds. A district heating system, to which most of the buildings will be connected, is under construction as well. The study is aimed at enhancing energy efficiency in building and HVAC systems. The first step consists in the definition of the new buildings, in order to predict the required energy for heating and cooling under design conditions and under seasonal conditions, for system sizing and energy consumption estimates. In a second phase a listing of all feasible design solutions, both on the envelope and on HVAC system is provided. The last phase consists in comparisons of the alternatives, in order to assess a feasibility analysis. Finally a case study is considered, carrying out a more detailed energy analysis of a shopping centre.*

Keywords: *Energy efficiency, Sustainable design, Building envelope, HVAC systems, Feasibility analysis.*

1. INTRODUCTION

The municipality of Carmagnola, a 25000 inhabitants town sited in Piedmont (North-West Italy) 20 km South of Turin, has recently adopted a “*Program for urban improvement and sustainable development*” (*PRUSST Eurokarma 2000*), within a state-funded national project aimed at promoting the reuse of urban and suburban degraded areas. The program, which concerns public and private interventions aimed at improving the infrastructures in the industrial, commerce and services sectors, has been selected and funded as a pilot initiative to demonstrate and implement environmentally sustainable design solutions.

This paper presents the results of a study aimed at identifying suitable design concepts for the building envelope and building services, and to provide guidelines for developing feasibility analyses of the solutions proposed by the real estate developers involved in the program. Finally a case study, including a more detailed energy analysis of a shopping centre, is presented.

2. THE NEW SETTLEMENT

The area in which the new settlement will be built is located on the outskirts of Carmagnola, near the Torino-Savona motorway, and has a total surface of 160000 m². Table

1 identifies the buildings that are part of the new settlement, their destination, surface area and height. The buildings are divided into two groups: items 1-10 refer to interventions that have already been approved by the municipality and that are definitely going to be built in the near future (Phase I), while items 11-13 are part of a planned future expansion of the settlement, whose characteristics are not yet completely defined (Phase II). Other industrial buildings adjacent to the area under investigation are presently under construction, but they have not been considered in this study since their design has already been fully decided.

Table 1. Description of the new settlement

n°	Building	Sector	Surface (m ²)	Height (m) max/med
phase I: Already approved buildings				
1	Trade fair centre	Services/Commercial	10000	18/15
2	Cattle market	Commercial	2800	9/7
3	Multi-hall cinema	Services/Commercial	7000	15/7
4	Hotel - Congress centre	Services	1000	5-30/16,8
5	Office building "Coldiretti"	Services	1300	7-30/12,9
6	Multi-function buildings	Services/Commercial	5000	13-30/10,5
7	Retail buildings (non food)	Commercial	20000	9/5
8	Multi – function buildings (shops, restaurants, offices)	Services/Commercial	2500	9/5
9	Retail building (car show-room)	Services/Commercial	2500	9/5
10	Industrial sheds	Industrial	10000	9/7
phase II: Planned new buildings				
11	Retail buildings (non food)	Commercial	40000	9/5
12	Retail buildings (food)	Commercial	10000	9/5
13	Industrial sheds	Industrial	52000	9/7
Total			164100	

The trade fair district, named "the Square", is the core of the new settlement: a wide open green area, surrounded by the cattle market, the multi-hall cinema and some retail units. In the trade fair centre, exhibitions will be held, concerning typical products of the local economy, which is largely based on farming, i.e. wine, food, agricultural and zootechnical products. The adjacent cattle market represents an important presence in the territory. The multi-hall cinema, the hotel – congress centre and some commercial buildings will complete the facilities of the new settlement. In particular, the hotel and the "Coldiretti" (farmers federation) offices are multi-storey buildings, overhanging the Square.

Behind the Square, the retail facilities with their parking areas will rise: these buildings are connected by a grid of foot paths covered by metal structure canopies. Next to the cattle market, in the West part of the area, a multi-function complex will be located, including office spaces, retail facilities and restaurants; the third tower building will rise in this block. From this area a fly-over is accessible, that, together with another structure close to the cinema, allows to cross the railway and connects the new quarter to the city. The area also includes, in its North-East part, some multi-function buildings and a car retail show room, and the industrial buildings on the South side.

3. THE PROPOSED SOLUTIONS

Within the *Eurokarma 2000* program a feasibility study has been carried out in order to evaluate the energy and environmental benefits of a new cogeneration plant based on gas-fired internal combustion engines. The favourable conclusions of the study have led to the decision to build the cogeneration plant that will feed a hot water (temperature < 100°C) district heating (DH) system. For the new settlement, the connection to the DH network will be mandatory. (The only exception is the multi-hall cinema, where individual reversible heat pump rooftop units with direct expansion coils will be installed). As far as the service period of the plant is concerned, two alternatives have been considered: in summer it is possible to take advantage of the DH system for producing cold water by means of absorption chillers as an alternative to conventional electrically-driven vapour-compression chillers (Table 2). The final choice will depend upon the analysis of several aspects: resources consumption, environmental impact, importance of investments, applicable energy rates, control strategy.

Table 2. Supply periods of DH system and refrigeration methods

Options	Service period of the DH system	Refrigeration energy production
A	Year-round	absorption chillers
B	Heating season only	electrically-driven vapour-compression chillers

3.1 Thermal and electrical loads

The winter and summer thermal loads prediction is of paramount importance for the HVAC system sizing and for energy consumption evaluation. At the present stage of the study, only a general description of the buildings is available: thus the loads have been calculated on the base of building volumes, destinations and available parametric data for heating / cooling loads and electric power, obtained from technical journals, manuals and unpublished reports. No reliable data were available for refrigeration loads of the cattle market and industrial sheds (the latter strongly depending on the activity carried out). In Table 3, for each building (item numbers refer to Table 1), the following data are provided:

- V = volume
- Φ_{TV} = volumetric heat load
- Φ_T = total heat load
- Q_T = annual heat consumption
- Φ_{FV} = volumetric refrigeration load
- Φ_F = total refrigeration load
- P_{AppV} = apparent volumetric electric load
- P_A = total electric load ($\cos\phi = 0,85$)

Table 3. Thermal and electric loads

n°	V (m ³)	Φ_{TV} (W/m ³)	Φ_T (kW)	Q_T (MWh/yr)	Φ_{FV} (W/m ³)	Φ_F (kW)	P_{AppV} (VA/m ³)	P_A (kW)
1	150000	17,4	2610	1305	25	3750	10	1275
2	19600	17,4	341,04	170,52				
3	49000	17,4	852,6	999,6	21	1029	17	708
4	16800	21	352,8	638,4	21	353	38	543
5	16800	21	352,8	638,4	21	353	28	400
6	52500	21	1102,5	1995	21	1103	28	1250
7	100000	17,4	1740	2040	25	2500	22	1870
8	12500	17,4	217,5	255	25	313	22	234
9	12500	17,4	217,5	255	25	313	22	234
10	70000	17,4	1218	1428				
11	40000	17,4	3480	4080	25	5000	22	3740
12	10000	17,4	870	1020	25	1250	17	723
13	52000	17,4	6333,6	7425,6				
tot	164100		19688	22252		15962		10975

3.2 Design concepts for the building envelope and HVAC system

In order to define the guidelines to be used in the feasibility analyses, buildings have been classified into six main destination categories. A list of applicable design concepts for the building envelope and building services (particularly for the HVAC system) is summarized in Table 4.

Table 4. – Building destinations, envelope and HVAC design concepts

<ul style="list-style-type: none"> ♦ Building destinations: - Trade fair centre - Hotel-congress facility - Multi-hall cinema - Shopping centres - Industrial sheds - Office buildings
<ul style="list-style-type: none"> ♦ Building envelope design concepts: - Building orientation; role of vegetation as a bioclimatic regulator - Thermal and acoustic properties of the building envelope components - Control of solar heat gains and daylighting: high performance glazings, shading devices, light wells - Passive, active, and hybrid solar systems (thermal and photovoltaic systems): solar walls; photovoltaic roofs / sunshades, ventilated double envelopes, atrium buildings, green roofs - Recyclable and eco – compatible materials
<ul style="list-style-type: none"> ♦ Building services design concepts: - Heat producing equipment: cogeneration and district heating; high efficiency boilers, heat pumps - Refrigeration equipment: absorption and vapour compression chillers, heat recovery, cooling energy storage - Heat pump systems: water loop; heat pump with combustion engine - Low-temperature water systems: roof / wall / floor radiant panels, chilled beams, etc. - All-air systems and optimal ventilation strategies: heat recovery, free cooling, chemical dehumidification, natural and hybrid ventilation - High efficiency lighting systems - Rain water recovery

3.3 Guidelines for feasibility analysis

With reference to Tables 1 and 4, in this section the proposed design solutions for each building type are presented and summarized in tables with a short explanation.

The trade fair centre. This centre includes the main triangular shaped exhibition pavilion (Table 1, n° 1), and two industrial-like reinforced concrete buildings (Table 1, n° 2) hosting the cattle and agricultural markets. The features of the exhibition pavilion (high volume, typically intermittent utilization profiles) are well suited for an atrium building, exploiting renewable energy resources for climatization and daylighting.

Table 5 – Trade fair centre

Building envelope	<i>Exhibition pavilion</i> Light glass and metal covering (atrium building) Solar shading devices			<i>Cattle market</i> Green roofing	
Renewable resources	Motor driven openings for nat.ventilation	Photovoltaic panels on the roof	Solar walls on south facing façade	Rain water recovery for service use	Light wells
HVAC system	All air with fabric air supply ducts	Free-cooling	Ground water for room refrigeration and chemical dehumidification	Ventilation air pre-cooling underground ducts	Air-water systems w/ ceiling panels or fan-coil s
Heat product.	District heating				
Refrigeration equipment	Hot water absorption chillers		Compression chillers with heat recovery for service hot water and air reheat		

The multi – hall cinema. This type of facilities (Table 1, n° 3) utilise standard constructive solutions for the building envelope (in which sound insulation is the main requirement) and HVAC system (reversible heat pump rooftop units with demand-controlled, based on occupancy, variable air change rate).

Table 6 – Multi–hall cinema

Building envelope				
Renewable resources	Photovoltaic panels on roof			
HVAC system	Rooftop reversible heat pump units with direct expansion coils and heat recovery on exhaust air	Displacement air supply (under seat diffusers)	Air change controlled by CO ₂ sensors	Free cooling
Heat product.				
Refrigeration equipment				

The Hotel – Congress centre. The hotel (Table 1, n° 4) is a rectangular plan high rise (eight floors) building, adjacent to the trapezoidal shaped congress centre. Given the high surface of the external envelope surface, with South facing main orientation, thermal insulation and solar gain control are of paramount importance for the hotel, while indoor heat gains and ventilation loads mostly determine the heating and cooling loads of the congress centre. Both facilities are well suited for implementing HVAC energy saving strategies.

Table 7 – Hotel – Congress Centre

Building envelope	Thermal insulation	Solar shading devices		
Renewable resources	Rain water recovery for service use			
HVAC system	<i>Hotel</i> Air and water (fan-coils)	<i>Congress facility</i> Air and water (cold beams or radiant ceiling)	Ground water for space air conditioning and chemical dehumidification	Free-cooling
Heat product.	District heating			
Refrigeration equipment	Hot water absorption chillers	Compression chillers with heat recovery for service hot water and air reheat		

The high-rise office buildings. Two high-rise, eight floor office buildings with square plan are foreseen in the project (Table 1, n° 5-6). Design issues are similar to the ones already discussed for the hotel, i.e. envelope thermal insulation, solar gain control, optimal ventilation strategies, etc.

Table 8 – High-rise Office buildings

Building envelope	Double-envelope façade		Thermal insulation + sun screens	
Renewable resources	Rain water recovery for service use			
HVAC system	Air and water (cold beams or radiant ceiling)	Ground water for room refrigeration and chemical dehumidification		Free-cooling (primary air)
Heat product.	District heating			
Refrigeration equipment	Hot water absorption chillers	Compression chillers with heat recovery for service hot water and air reheat		Cooling energy storage

The shopping centre. Two types of retail facilities are present: “Type A” refers to industrial-like single storey buildings (Table 1, n° 7-8-9-11-12), typically hosting specialised non-food retail points, while “Type B” indicates multi storey buildings, including shops and restaurants at the street level and office spaces at the upper floors.

Table 9 – Shopping centres – Type A

Building envelope	Green roofing			
Renewable resources	Photovoltaic panels on roof		Light wells for daylight transport	
HVAC system	<i>Commercial</i> All air system + air-jet barriers	Free-cooling	Ground water for space cooling and chemical dehumidification	<i>Multi-function</i> Air and water systems (cold beam or radiant ceilings)
Heat product.	Distr. Heating	Heat recovery from food refrigeration units		
Refrigeration equipment	Hot water absorption chillers	Compression chillers with heat recovery for service hot water and air reheat		Cooling energy storage

Table 10 – Shopping centres – Type B

Building envelope			
Renewable resources			
HVAC system	Air and water (fan-coils) + air-jet barriers		Free-cooling (primary air)
Heat product.	District heating		
Refrigeration equipment	Hot water absorption chillers	Compression chillers with heat recovery for service hot water and air reheat	

The industrial buildings. Industrial buildings (Table 1, n° 10-13) include sheds and office spaces; they consist of single- or two-storey prefabricated reinforced concrete structures, to which solar energy concepts may be applied. Low temperature HVAC systems are well suited for such buildings.

Table 11 – Industrial buildings

Building envelope	Covering with transparent elements for daylighting and motor driven openings for natural ventilation		Solar walls Green roofing	
Renewable resources			Photovoltaic panels on roof	
HVAC system	<i>Shed</i> Low temperature water (radiant ceiling or fan-coil units)	<i>Offices</i> Air and water (fan- coils, radiant)	Free-cooling (primary air)	
Heat product.	District heating			
Refrigeration equipment	Hot water absorption chillers		Compression chillers with heat recovery for service hot water and air reheat	

4. THE CASE STUDY: REFRIGERATION OF A SHOPPING CENTRE

In this section a comparison is carried out, between the two alternatives for cooling energy production, as mentioned in section 3, Table 2. The adoption of absorption chillers, coupled with year-round service for the DH system, is technically possible with water supplied at 85 – 90 °C as an alternative to electrically-driven vapour compression chillers.

The cost analysis is developed for the two options, taking into account the annual refrigeration production costs and the capital costs for the equipment.

4.1 Refrigeration use characteristics

The selected building destination is a “Type A” shopping centre (n° 7 in Tables 1 and 3), for which typical load profile data are available. A 5000 m² surface, 5 m medium height retail building was selected, with a design cooling load of 625 kW (see Table 3). The following reference daily refrigeration load profiles were used: Monday, midweek, Saturday or opening holiday, for the months of June, July – August, May – September. For middle seasons and for the hot hours of the day, or for severe crowding conditions in winter, the HVAC equipment is supposed to operate in free – cooling mode.

4.2 Equipment characteristics

The analysis of load profiles indicates that typical hourly refrigeration load variations are on the order of 100 kW. Hence, the two selected options, which are illustrated in the following paragraphs, both allow a stepwise power output regulation well matched with such load variation. The characteristics, operation and cost data of the equipments were provided by the manufacturers, who also supplied the partial load efficiency profiles.

A. Absorption chillers

The equipment is a single effect water condensed water – lithium bromide chiller. A modular equipment was selected, consisting of six units running in parallel, with a cascade regulation strategy, each unit being a 105 kW ON-OFF apparatus. A plate heat exchanger connecting to the DH network supplies hot water and an evaporative tower is necessary for condensing water refrigeration.

B. Electrically – driven chillers

The equipment is a compact 625 kW air cooled chiller, using R-134a as the refrigerant fluid. The apparatus, equipped with two independent twin-screw compressors, allows to achieve a high efficiency at partial loads thanks to the control strategy that permits to modulate the output power in six steps, from 21% to 100% of nominal load. No condensation heat recovery is considered for this building destination (see 3.3): in fact service hot water demand is negligible and outside - recirculated air flow-rate ratio is small for this application.

4.3 Energy rates

In order to evaluate the costs related to the two options it is necessary to point out that different kind of primary energy sources are involved, with different formulations and rate profiles. In both cases a 20% VAT has to be added to the total cost.

A. Thermal energy from DH network for absorption chillers supply

The actual energy rates that the operators of the plant facilities will be asked to pay are not available at present; thus attainable data were used, related to an existing DH plant of similar characteristics. It is a binomial tariff, formed by two terms, the first one depending on the plant size (675,00 € per year per m³/h of DH water flow rate), the second on energy consumption (3.1047 €cent/kWh). In this calculation, only the second term was taken into account, being an “added cost”, while the first one is a fixed cost, independent from the annual load profile.

B. Electric energy for vapour-compression chillers supply

The local utility is supposed to supply electricity at medium-voltage. Many terms participate in making up the final rate value. In this study the only considered terms concern the refrigeration equipment. It is necessary to take into account the annual and daily load

profiles, as four different rates are applied per consumed kWh, depending on the day of the year and the hour of the day, electricity being more costly in high-demand critical hours. (The values of the applied electricity rates are not given in this paper, since they derive from the application of a rather involved calculation scheme, that would require a lengthy explanation).

4.4 Annual energy consumptions

On the basis of thermal and electric loads and equipments characteristics (see 4.1 and 4.2) the annual energy consumptions were calculated, as represented in Table 12.

Table 12 – Calculated annual energy consumption

MONTH	DAY TYPE	A. Absorption chillers		B. Electric chillers	
		day consumption (kWh)	month consumption (kWh)	day consumption (kWh)	month consumption (kWh)
June	Monday	10050	297450	2187	64265
	Midweek	12000		2592	
	Saturday	13050		2809	
July and August	Monday	13050	470400	2317	102221
	Midweek	11250		2416	
	Saturday	11850		2622	
May and September	Monday	5250	356850	1062	72958
	Midweek	6600		1370	
	Saturday	7200		1408	
TOTAL ANNUAL CONSUMPTION			1124700		239444

4.5 Cost analysis

On the basis of the previous calculations, the evaluation of the annual “energy bills” and refrigeration equipment costs is possible. As mentioned in 4.2, the adoption of absorption chillers requires an evaporative tower too, whose installation implies a more complex hydronic system. The related costs have to be taken into account: for this purpose, a 10% was added to the calculated value. The final annual costs are presented in Table 13.

Table 13. Calculated annual costs

	A. Absorption chillers	B. Electric chillers
Energy bill	41.902 €	58.051 €
Equipment cost	229.000 €	121.730 €
TOTAL COST	270.902 €	179.781 €

Finally, the Present Worth Analysis was used, in order to assess the convenience of the two options. The applied discount rate was assumed to be 10%. The equipment costs only affect the first year, over a ten year economic life. From up-to-date cost analysis, the calculated final costs are:

A. Absorption chillers
884.905 €

B. Electric chillers
712.206 €

Compared to the results in Table 13, option A still results more costly, but the capital cost is less important after the considered period. In any case, the electric chiller option proves to be more favourable.

5. CONCLUSIONS

EUROKARMA 2000 is a pilot program aimed at defining and testing on a real case a procedure for identifying and evaluating the feasibility of environmentally sustainable design concepts in the industrial, commerce and services sectors.

The relevance of this experience derives from a number of factors: firstly, the size of the area and the variety of building destinations that are present in the intervention plan; secondly, the context in which this plan is situated, i.e. the reuse of degraded urban areas, a very common problem in a region like Piedmont which is undergoing profound changes in its economic structure, following the outplacement of heavy industrial activities (on which the local economy was largely based in the past), that have constantly taken place in the past 25 years; thirdly, the strategic importance of the commercial sector in the overall energy use scenario of Italy.

REFERENCES

- Alemanno, N., Vezza, S., 2002, Le prospettive di sviluppo della cogenerazione con teleriscaldamento in Provincia di Torino, Tesi di Laurea in Ingegneria Gestionale, Politecnico di Torino.
- EGEA S.p.a., 2004, Studio di fattibilità per un impianto di cogenerazione associato a teleriscaldamento (unpublished).
- Grumman, D. L. (Ed.), 2003, ASHRAE Green Guide, ASHRAE, Atlanta.
- Madeddu, M., 2003, Analisi economico-energetico di un impianto di cogenerazione per un centro commerciale di piccola taglia, Tesi di Laurea in Ingegneria Elettrica, Politecnico di Torino.
- Monte, A., 2003, Elementi di impianti industriali, Cortina, Torino.
- Wulfinghoff, D. R., 1999, Energy Efficiency Manual, Energy Institute Press, Wheaton.