Performance evaluation of a small-scale polygeneration plant including a desiccant cooling system and an innovative natural gas ICE

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He worked as a fellow tenure at CRF from September 2001 till May 2002.
After a consultancy experience of 4 years in KPMG, an international firm of business advisory services, he is presently fellow researcher in the Energetics Department at Politecnico di Torino in the field of design and construction of microgeneration system for civil and industrial infrastructures.

Politecnico di Torino
Dipartimento di Energetica

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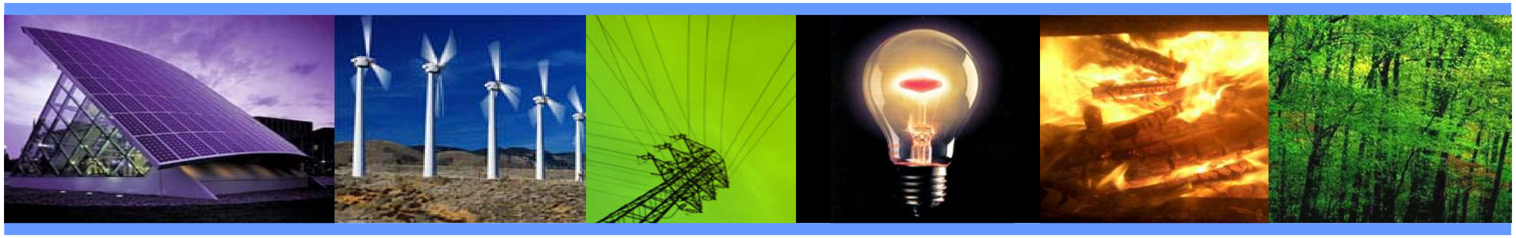


Torino, 25th of May 2007

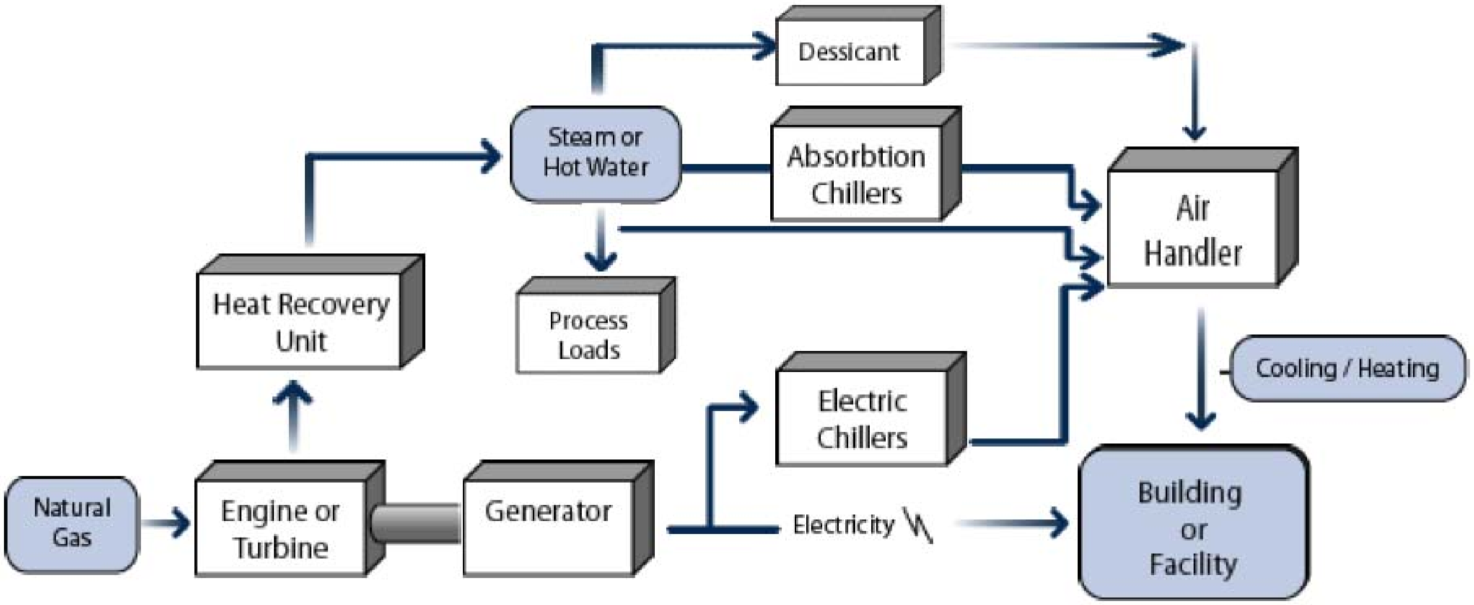
Combined Heat, Cooling and Power: the concept

- Combined Heat, Cooling and Power applications
  - Integrated System
  - Located at or near a building facility
  - Provide a portion of the electrical load

- Utilization of the Thermal Energy:
  - Heating
  - Cooling
  - Dehumidification
  - Process heat

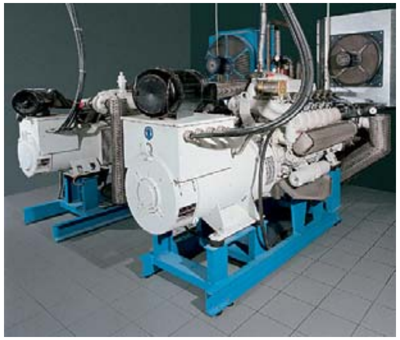
System designation	Size range	Applications
Mega	50 – 100+ MWel	• Very Large Industrial Plants • Usually Multiple Smaller Units • Custom Engineered Systems
Large	10's of MWel	• Industrial & Large Commercial Plants • Usually Multiple Smaller Units • Custom Engineered Systems
Mid	100's kWel – several MWel	• Commercial & Light Industrial Plants • Single to Multiple Units • Potential Packaged Units
Small-scale	<100's kWel	• Small Commercial & Residential • Appliance Like

Typical small and medium scale trigeneration system functional layout

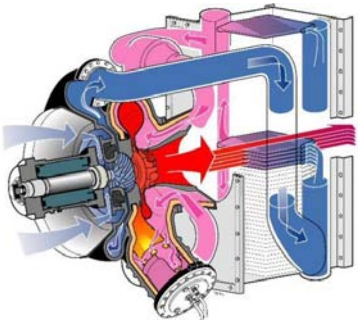


Cogeneration and trigeneration allow a fuel economy of 15 – 30 % (with respect to separate production)

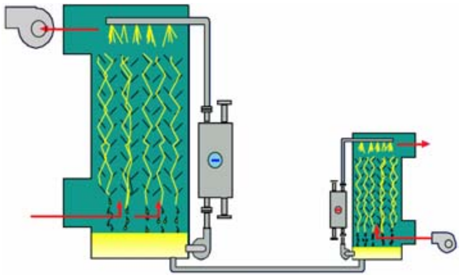
Small-scale CHCP technologies

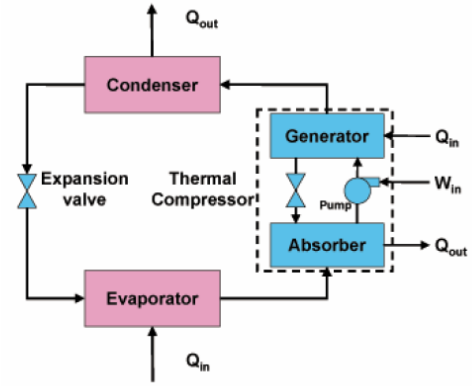


- Electric generation equipment
  - Reciprocating engines
  - Microturbines



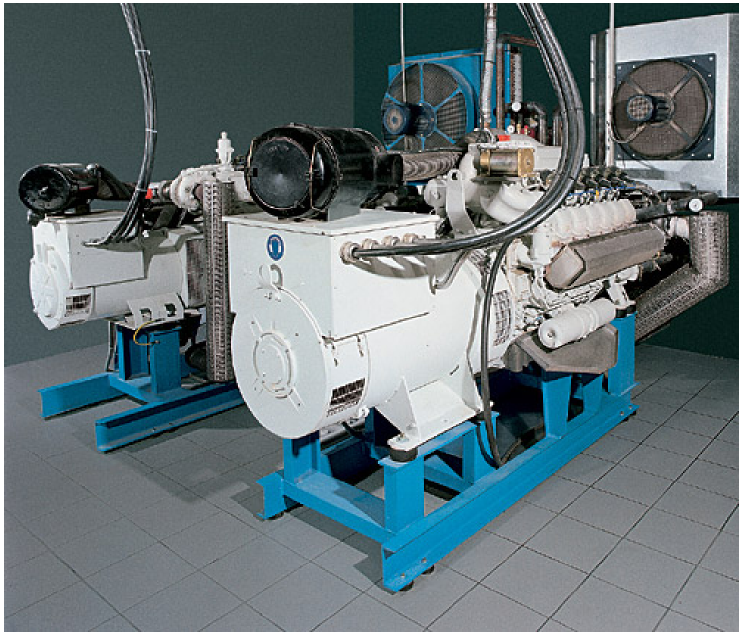
- Heat recovery
  - Hot water
  - steam
- Thermally Activated Technologies (TAT)
  - Absorption Chillers
  - Desiccant dehumidification





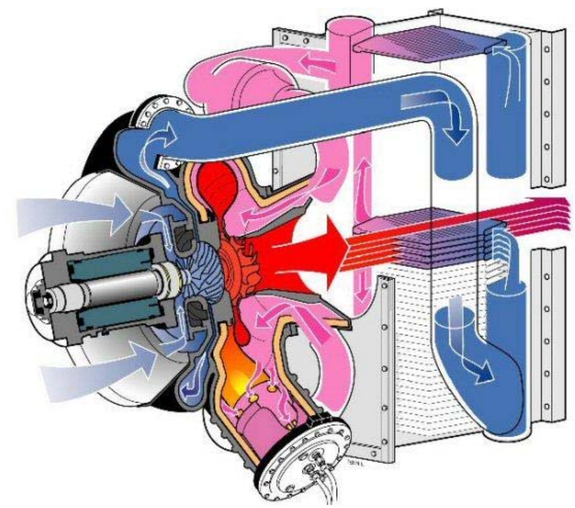
Reciprocating engines

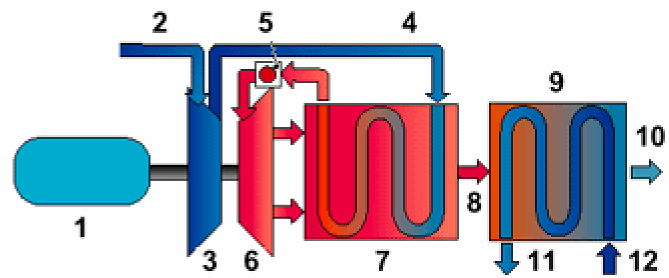
- Fastest selling, least expensive and most commonly used CHP prime movers
- Heat usually recovered as hot water at 85 - 90°C or low pressure steam (100 - 120°C)
- Electrical efficiency range: 30% - 35%
- Type of engines:
  - Spark ignited: natural gas
  - compression ignition: diesel
- Good part load operation



Microturbines

- Small turbines with recuperation
- Capacity range: 25 kW to 400 kW
- Electrical Efficiency Range: 25% to 30%
- Thermal (Recoverable) Energy:
  - exhaust gases
- Advantages:
  - Compact Size
  - Low Emissions
  - Fuel Flexibility
  - Modular
  - Lower Maintenance
  - Quicker Start
- Disadvantages:
  - Moderate Conversion Efficiencies
  - Poor Part Load Operation
  - Requires High Pressure Gas or Gas Compressor

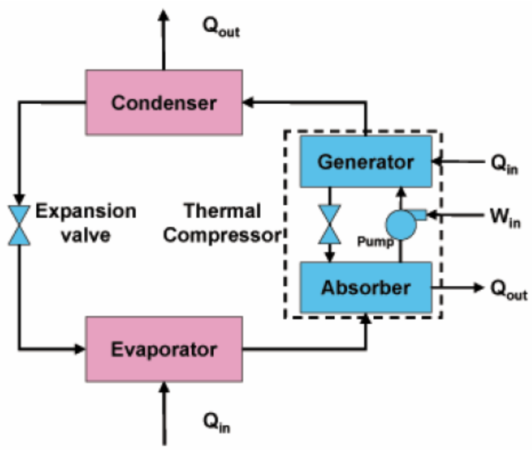




1. Generator
2. Air inlet
3. Compressor
4. Air to recuperator
5. Combustion chamber
6. Turbine
7. Recuperator
8. Exhaust gases
9. Heat exchanger
10. Exhaust gas outlet
11. Hot water outlet
12. Water inlet

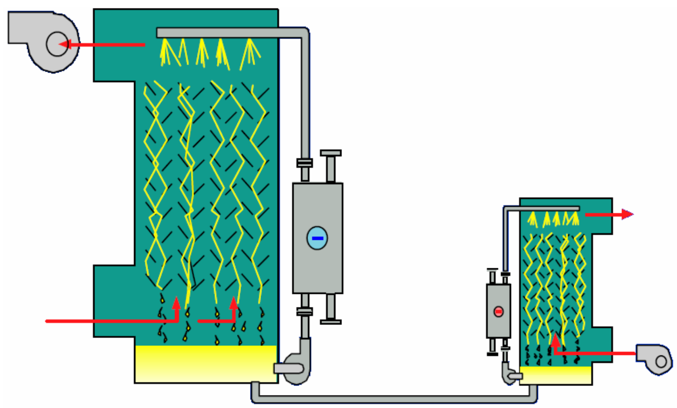
Thermally Activated Technologies

- Absorption Chillers



- Direct Combustion or Waste Heat Fired
- Water as the Refrigerant and Lithium Bromide as the absorbent
- Ammonia as the refrigerant and water as the absorbent

- Liquid Desiccant



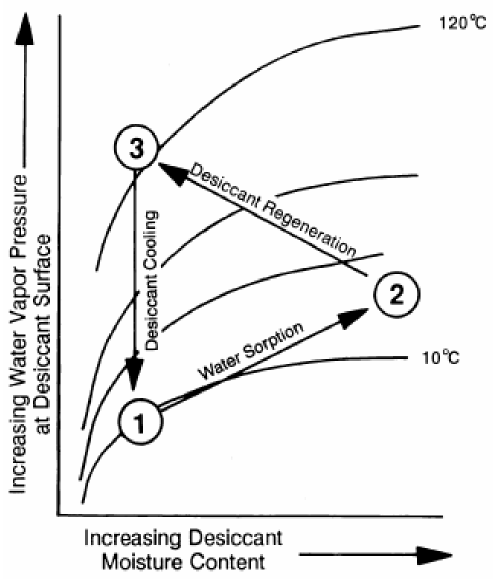
- Remove bacteria, pollutants and viruses
- Operates with low reactivation temperatures
- Can connect many process air sections with a single regeneration section
- Humidity control - vary solution concentration ; temperature control - vary solution temperature

The liquid desiccant cooling system

- Air dehumidification is obtained through the sorption of the humidity by a LiCl-water solution

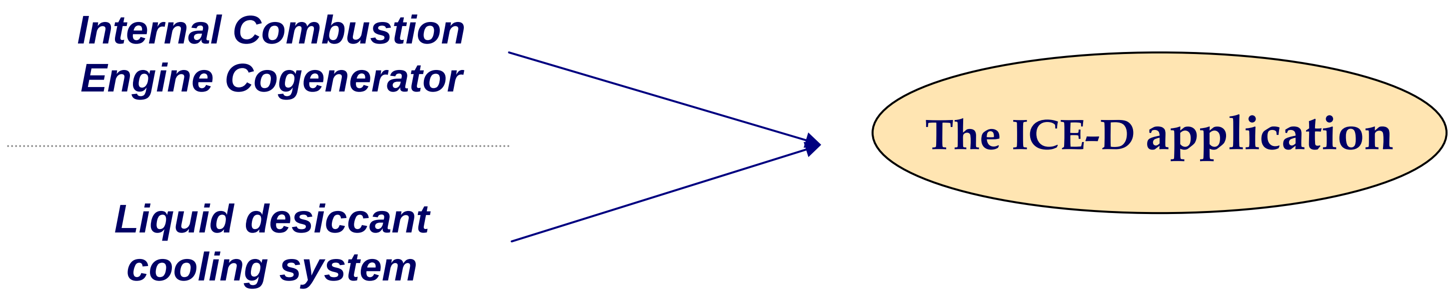
- This capacity to absorb moisture is due to the difference between the water vapour pressure at desiccant surface and that of the surrounding air: when the vapour pressure at the desiccant surface is lower than that of the air, the desiccant attracts moisture. Vice versa, the desiccant releases moisture (regeneration process)

- The liquid desiccant system operates in three phases:
  1. **conditioning phase**: air is dehumidified through air contact with the LiCl-water solution in a porous matrix; humidity sorption always generates an amount of sensible heat equal to the latent heat of the water vapour taken up by the desiccant, so that the desiccant is warmed
  2. **regeneration phase**: hot water from the heat recovery unit of the ICE heats the desiccant solution so that its water vapour pressure becomes higher than that of the outside air. Outside air is passed through the desiccant, and water evaporates into the air from the desiccant solution, thus concentrating the solution
  3. **desiccant cooling phase**: all the thermal energy acquired by the desiccant substance during the conditioning and the regeneration phases must be dissipated, so that a cooling tower is needed



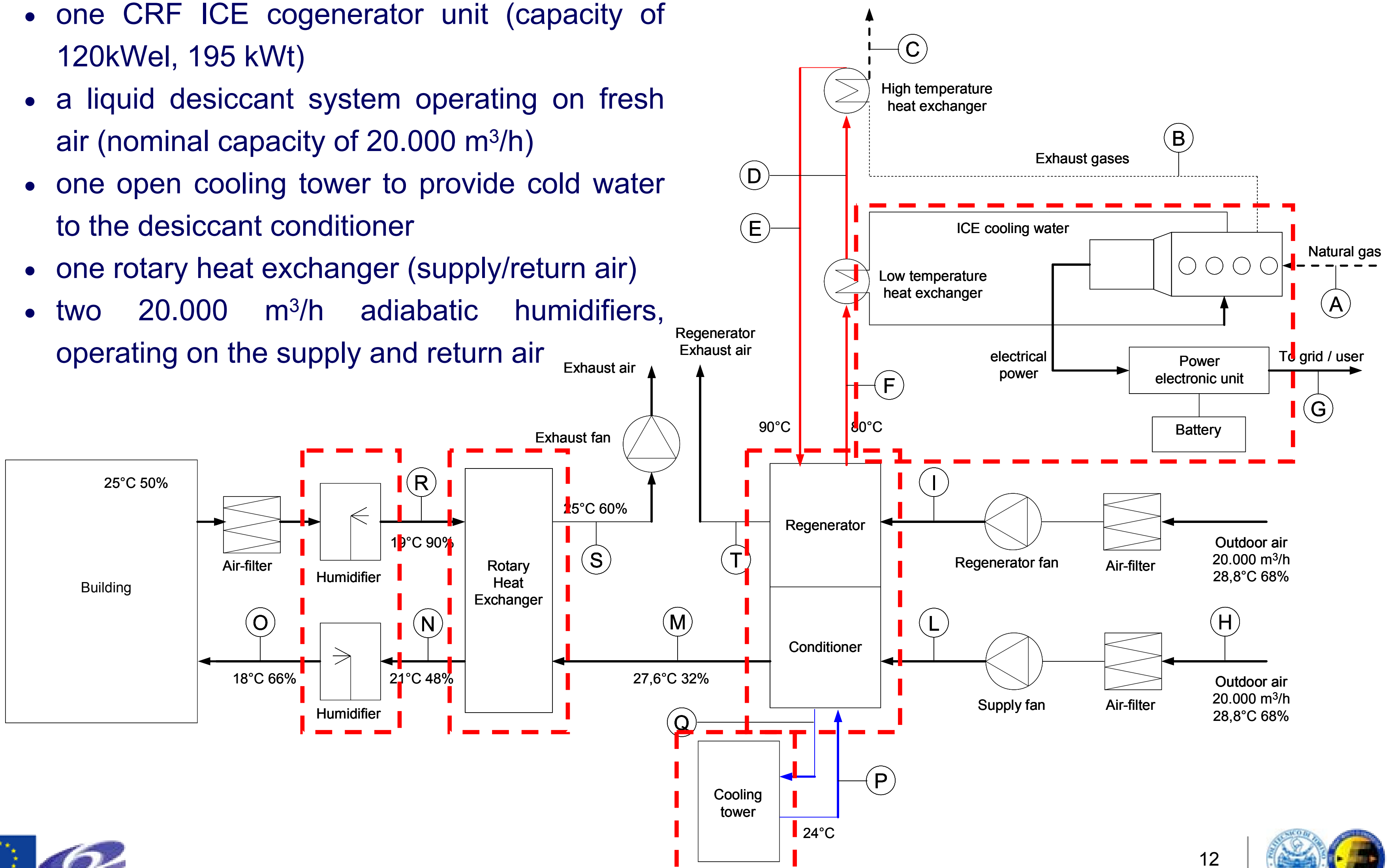
The ICE-D application

- The application falls within HEGEL, the acronym of an R&D project funded in the EU 6th Framework Program, whose objective is to develop, demonstrate and compare high efficiency applications of micro-trigeneration for the civil and industrial sectors
- The ICE-D application consist of a natural gas ICE coupled to a liquid desiccant (LiCl-water) cooling system
- From some preliminary researches conducted on this topic it seems that this system architecture has not yet been thoroughly investigated. For this reason a similar trigeneration plant was included in the investigation objectives of the 6th European Framework Program and is going to be installed and tested at the Politecnico di Torino



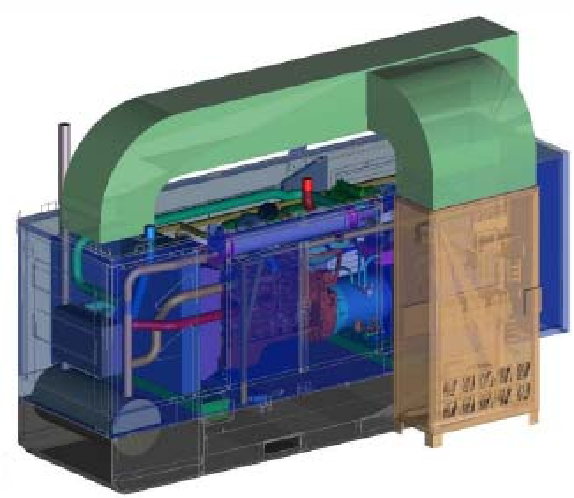
The plant layout

- The concept layout of the system consist of:
  - one CRF ICE cogenerator unit (capacity of 120kWel, 195 kWt)
  - a liquid desiccant system operating on fresh air (nominal capacity of 20.000 m³/h)
  - one open cooling tower to provide cold water to the desiccant conditioner
  - one rotary heat exchanger (supply/return air)
  - two 20.000 m³/h adiabatic humidifiers, operating on the supply and return air



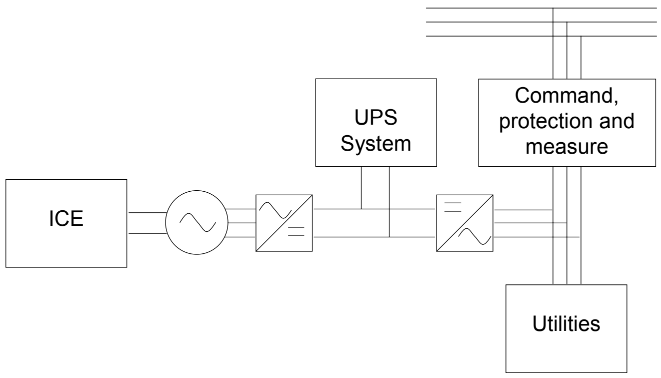
The ICE cogenerator

- The cogenerator (120 kWel, 195 kWt) was developed and set up by FIAT Centre of Research in Turin, Italy
- The heat is recovered from the ICE cooling water and from the exhaust gases, through two heat exchangers and a secondary hot water loop
- The innovations of the system concern both the technology and the provided services:
  - high part load efficiency
  - low pollutant emissions (lower than an equivalent boiler)
  - built-in UPS system, which assures power continuity without the need of external devices
  - high efficiency and high flexibility, even during stand-alone applications (i.e. not connected to any external grid)

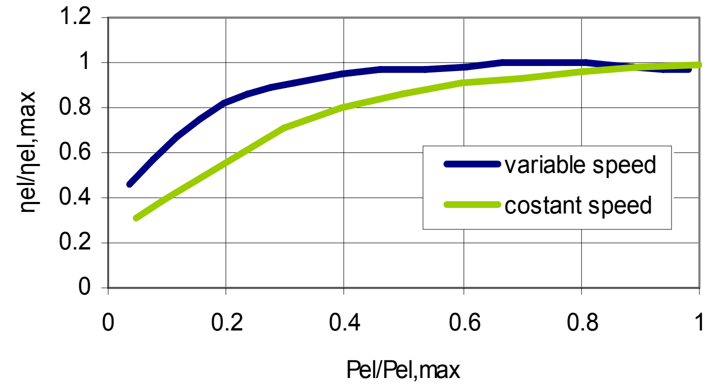


The ICE cogenerator (2)

- The power electronic unit, made up of an AC/DC-DC/AC converter, allows the engine to operate at variable speed, while delivering 50 Hz AC to the grid



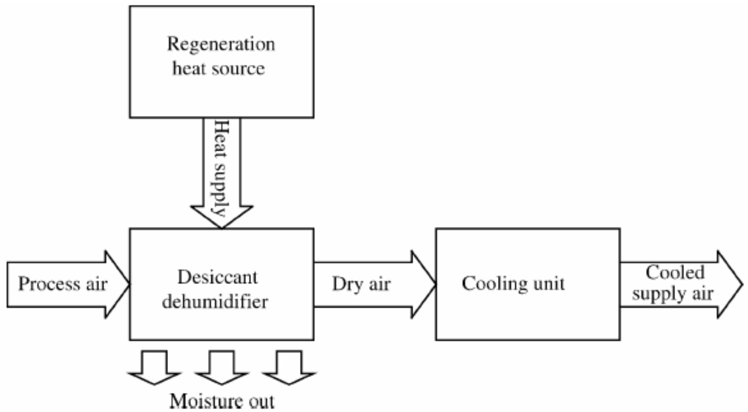
- The power electronics unit allows the engine to operate at part load conditions by varying the rotating speed; this strategy allows the engine to achieve higher part load efficiency than conventional cogenerators

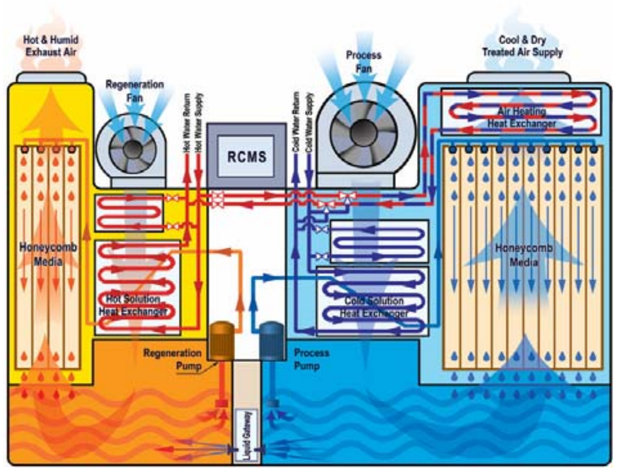


CHP unit technical features	
Engine type	Otto 4T
Displacement	~6 litres
Emission reduction	TWC
Dry weight	4000 kg
Fuel	Natural Gas
Generator	Asynchronous water-cooled
Power electronics	AC/DC - DC/AC converter
Container dimensions (L/W/H)	3800 / 1200 / 1900 mm
Electric power	120 kW
Thermal power	195 kW
Electrical efficiency	32%
Energy utilization factor	84%

The liquid desiccant cooling system

➢ Principle and functional representation of a liquid desiccant cooling system

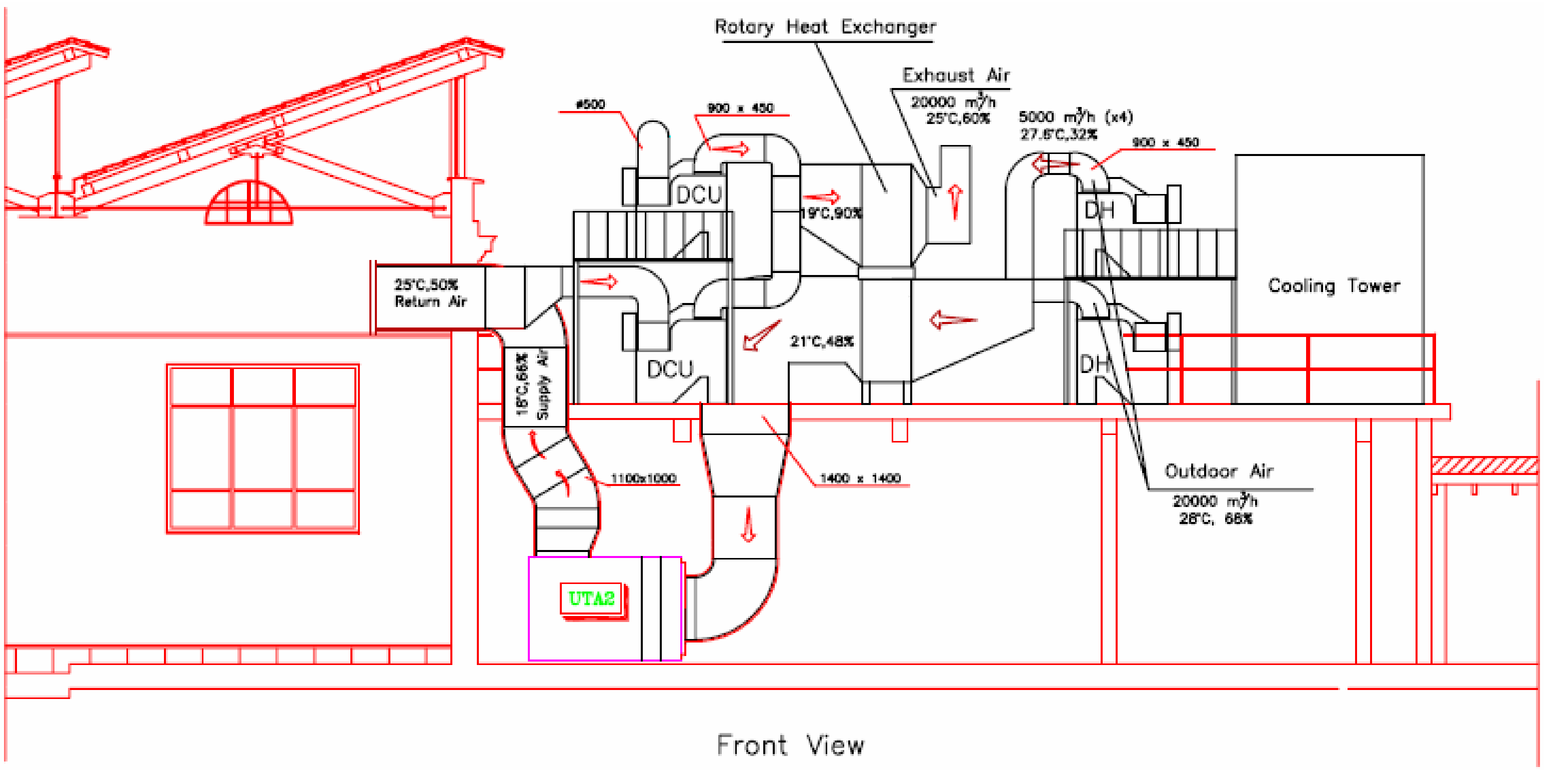




Characteristics of the desiccant cooling system	
Number of units	4
Typical air capacity (conditioner)	5000 m^3/h
Typical air capacity (regenerator)	5000 m^3/h
Typical Latent cooling capacity	~ 40 kW
Desiccant solution type	LiCl-water
Desiccant solution max concentration	55%
Desiccant solution capacity	125 lt
Typical Moisture extraction	~ 50 lt/h
Auxiliary power	4.8 kW_{el}
Net weight	540 kg
Operating weight (including LiCl)	690 kg
Dimensions (L/W/H) (mm)	2240/1420/1575

The plant layout

- The ICE-D application at the Politecnico di Torino has been conceived to supply air-conditioning to a building dedicated to educational activities (several classrooms)
- The building is currently heated in winter through an all-air system integrated with hot water heaters (heat, both for AHU and heaters, is provided by a connection to district heating). No cooling is present in summer

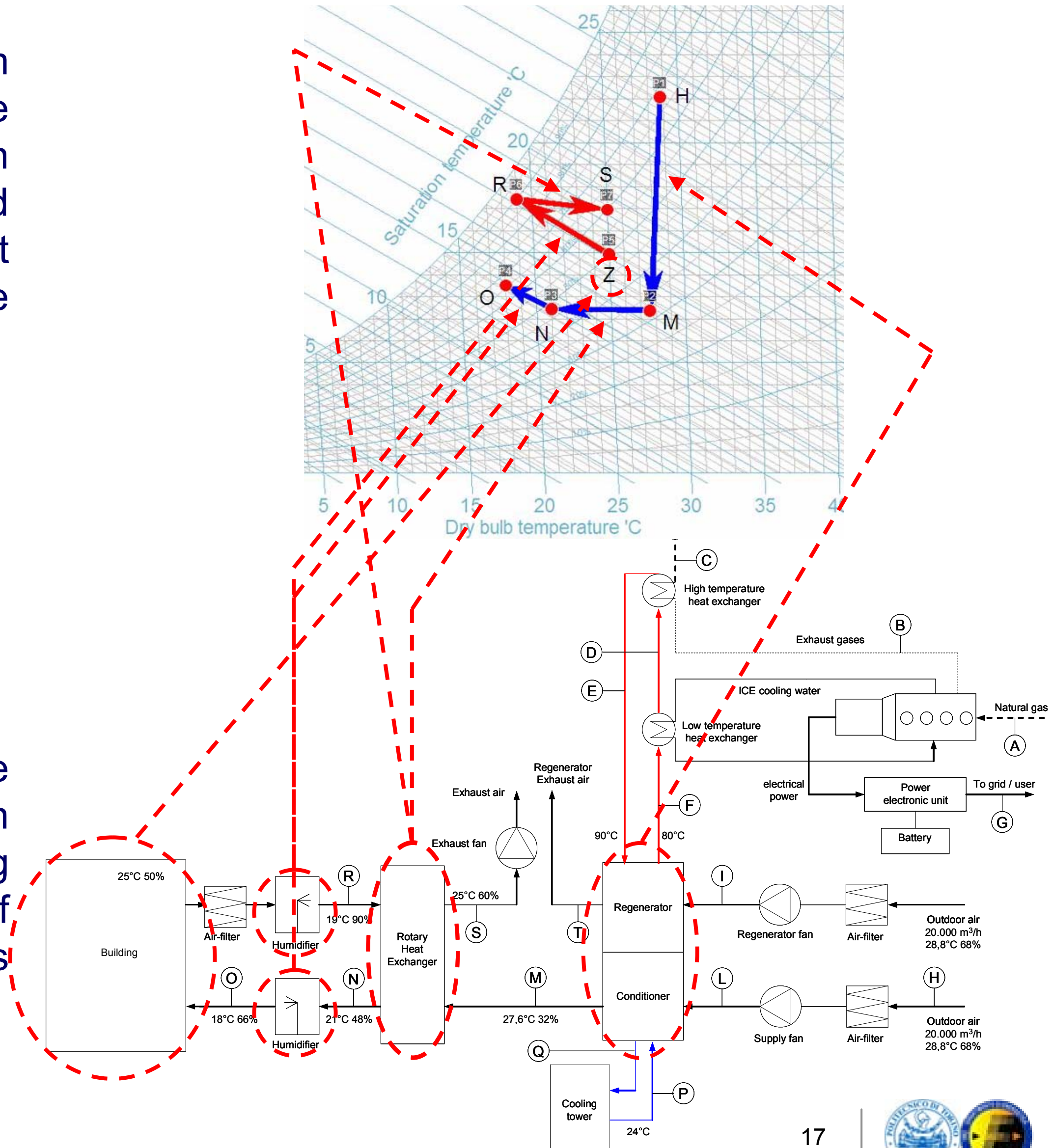


System performance

- In order to evaluate system performance, ASHRAE climate conditions for Turin has been considered as outdoor temperature and relative humidity conditions. The set point condition inside the building are the typical one for summer season

Indoor set point conditions	Design wet bulb temperature
T db = 25 °C T wb = 18 °C R.H. = 50%	T db = 28.8°C T wb = 24.2 °C R.H. = 68% X=17.2 g_v/kg_a

- A first preliminary assessment of the performances of the system has been made for the nominal operating condition, considering values of temperature and R.H. in different points of the plant supplied by the designer

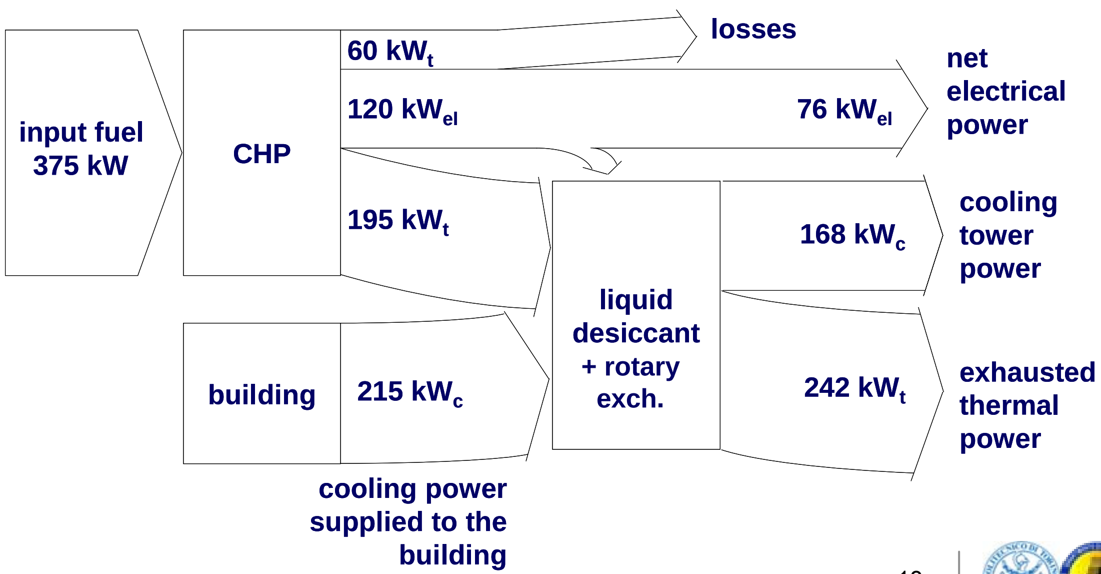


System performance (2)

- Ventilation required by the building 20.000 m^3/h
- Power introduced into the internal combustion engine by the natural gas Pfuel = 375 kW
- Thermal power provided by the CHP system Qth = 195 kWt
- Cooling power supplied by the conditioner Qc = 168 kWc
- Total cooling power supplied to the building (desiccant + rotary heat exchanger) Qc,p = 215 kWc
- Electrical power produced by the CHP unit Pel = 120 kWe. Pnet = 76 kWe

CHCP plant efficiency

(Pnet + Qc,p) / Pfuel = 0.78



System innovation

- The innovation of the application can be considered at four levels:

ICE-D

1 Reciprocating cogenerator

The CHP unit, has the distinct feature of showing a very high efficiency above all at part load conditions

2 Desiccant cooling system

Thermally Activated air Conditioner (TAC) system with a liquid desiccant solution is applied. The task of the TAC is to remove humidity from the air without the aid of any additional mechanical cooling system

3 Particular architecture of the system

Regeneration heat is recovered from the CRF CHP unit, which among its distinctive characteristics is capable of operating in "dual mode" function (in parallel to the grid or in stand-alone UPS mode)

4 Electrical connections

The plant will be connected to a local grid that is not only able to satisfy the requirements of the connected local users, but is also available for experimental activities and transient load simulations

Road map

- Ongoing activities
  - Refining of sizing and performance assessment
  - Ducting and integration of Desiccant units with cogenerator. The cogenerator will be installed in a separate building, a direct hot water connection with the desiccant units is foreseen. Also current air ducting will be modified to exploit the existing AHU and allow for integration of cooling sub-systems.

- To do activities
  - Design and setup of system controls
  - Installation of the system (foreseen within summer 2007)
  - Design and setup of the measurement system and the data acquisition devices
  - Emissions evaluation
  - Air Quality assessment
  - Operation and Maintenance costs evaluation
  - Extensive performance analysis and experimental tests (steady state and transient)

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