TECHNICAL ATTACHMENT

ZUCCATO ENERGIA

PRODUCT SHEET
561-KWe, Skid-mounted,
Low Temperature Organic Rankine Cycle (LT-ORC)
Power Generation Module

ZE-500-LT

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PLANT TECHNOLOGY DESCRIPTION

IN SHORT

Low-Temperature Organic Rankine Cycle (LT-ORC) Technology

Emission-free closed loop operation

A low-boiling-point working fluid is evaporated and expanded by heat

Working fluid expansion spins an high-speed turbine

The spinning turbine drives directly a generator

The working fluid is cooled down, condenses back into a liquid and is pumped back into the loop

The structure of the proposed plant is based on the so-called low-temperature organic Rankine cycle (LT-ORC), and may be summed up by the diagram in Figure 1.

A heat source [1] heats, through a hot water loop and a primary heat exchanger, also known as evaporator [2], a special working fluid placed into a closed ORC circuit.

This totally biodegradable and non-toxic organic working fluid, boils in the evaporator at a temperature far lower than that of water, becoming a high-pressure dry gas the expansion of which spins the impeller of a specifically designed and sized turbine [3].

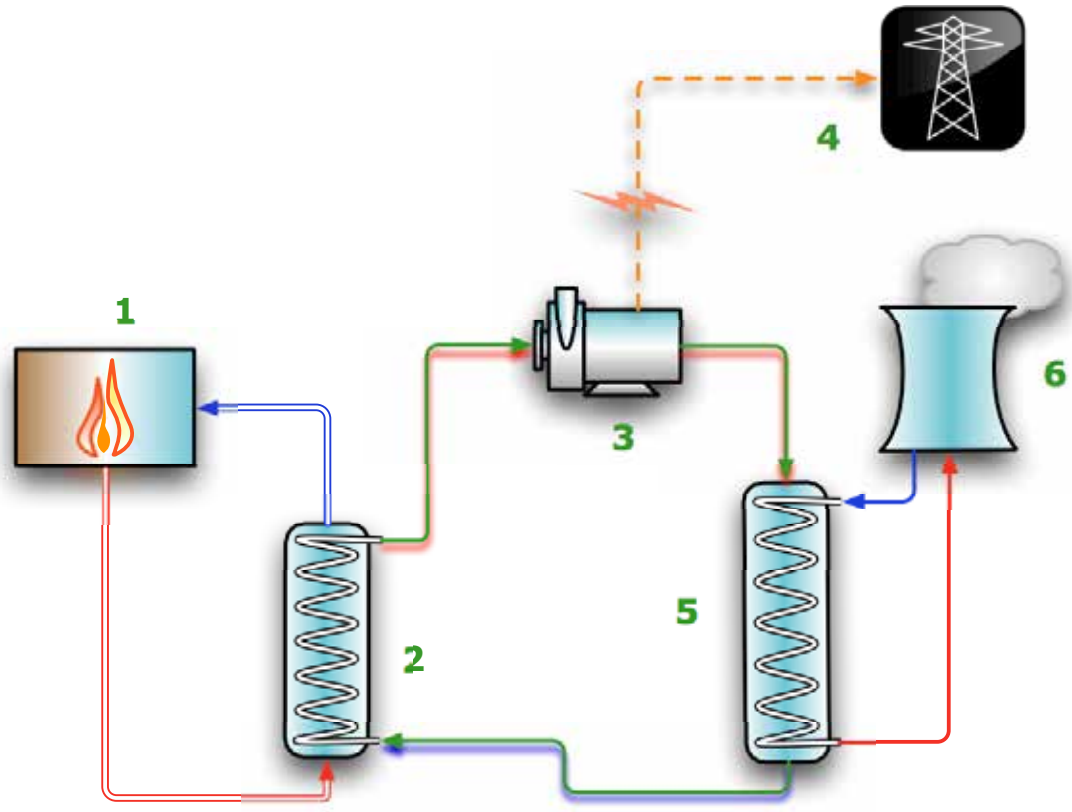
The high-speed rotation (9000÷10.000 Rpm) of the turbine shaft spins the rotor of a direct-drive generator connected to it, thus producing electric power [4] which, after getting its phase and voltage synchronized by an inverter, may be self-consumed or released to the national grid.

Downstream the turbine, the working fluid - still in gas phase - is conveyed to another heat exchanger, called a condenser (5), where excess heat is released and the fluid condenses back into a liquid which is collected in a tank, ready to be pumped back to tyhe primary heat exchanger, thus closing the loop.

Excess heat released in the condenser is a thermal energy source which may be used for other purposes such as preheating or dessiccating biomass fuel (thus increasing its heating value), building heating, hot water production and so on.

In case that is not possible, residual heat may be dissipated by using a compact cooling tower [6]

Figure 1 - Plant diagram



INNOVATIVE TECHNOLOGY

Independently designed and manufactured using the most advanced technologies in finite elements and fluid-dynamics analysis (CFD/CFX), Zuccato Energia's turbogenerators are designed from scratch to operate in a low-temperature organic Rankine cycle which uses a special working fluid that offers better performances and several advances over traditional steam turbines:

- **Low operational temperature** that allows tapping very low-grade heat sources;
- **High condensation temperature** which may allow the use of simple air-cooled condensers;
- Totally dry working fluid, which means no turbine blade erosion, giving the system **high reliability** and **reduced maintenance costs** as well as **fewer controls**;
- **Lower pressures** (20 bar max), for safer operation, less bureaucratic hassles and lower costs;
- **No atmospheric emissions** (closed circuit operation);

What's more, the organic working fluid used is 100% ozone-friendly, non-toxic and biodegradable.

The ZE turbogenerators - **custom designed from scratch** to be installed in small plants (<1MWe)- implement several performance-enhancing engineering solutions such as:

- **Direct turbine-to-alternator coupling**, to eliminate the attrition losses inherent in gearboxes;
- **Use of ceramic bearings** to prolong operational life and allow very high-rpm operation;
- **Custom-designed and sized inverters** for optimal energy conversion performance.

Our innovative technology has already been **widely field-tested with success** in many plants installed worldwide, from biomass-fueled power plants, to syngas- and biogas- fueled genset systems, from boiler rooms of cinemas and hotels to thermoelectric power stations and district heating systems.

HIGH POWER, HIGH EFFICIENCY

The ZE-500-LT is the **largest power generation module** offered by Zuccato Energia, designed to operate in conjunction with boilers in **power generation applications** but equally well suitable for **industrial heat recovery systems** where large enough quantities of medium-temperature (≥160°C) waste heat are available. If required, this modular unit is also capable to be **coupled with other similar or smaller units** to take advantage of all available thermal power.

The use of **shell-and tube heat exchangers** for the cold side instead of the usual brazed plate units gives the system the highest efficiency (16%) of all the Zuccato Energia range of products.

IN SHORT

May be used to tap "low-grade" heat sources

Simpler plants

No turbine blade erosion

Lower pressure, higher safety

No atmospheric emissions

High reliability

State-of-the-art technology

Automated, operatorless systems

Remotely monitorable and controllable

IN SHORT

Widely tested technology

Dozens of installations already in operation

Some plants have been operating non-stop since 2012 (except scheduled maintenance)

Primary energy production from biomass-fueled boilers

Heat recovery from exhaust gases and cooling jackets

Heat recovery from engines, gasifiers, turbines

FIELD TESTED TECHNOLOGY

Zuccato Energia ORC systems have been in use for years in several installations, both for primary power generation and waste heat recovery : the following photos show just a few of them.

Sommalombardo (Varese, italy) - ORC Power generation from biomass (sawmill residues)

Portogruaro (Venice) - Heat recovery from cooling jackets & exhaust gases of biogas-fueled gensets

Città della Pieve (Perugia, Italy) - ORC power generation from biomass (pruning residues)

Mestre (Venice, Italy) - Heat recovery from biomass boiler and hot air turbines

Rovato (Brescia, Italy) - ORC Power generation from biomass (end-of-life shipping pallets)

Benneckestein (Germany) - Heat recovery from cooling jackets & exhausts of biogas-fueled gensets

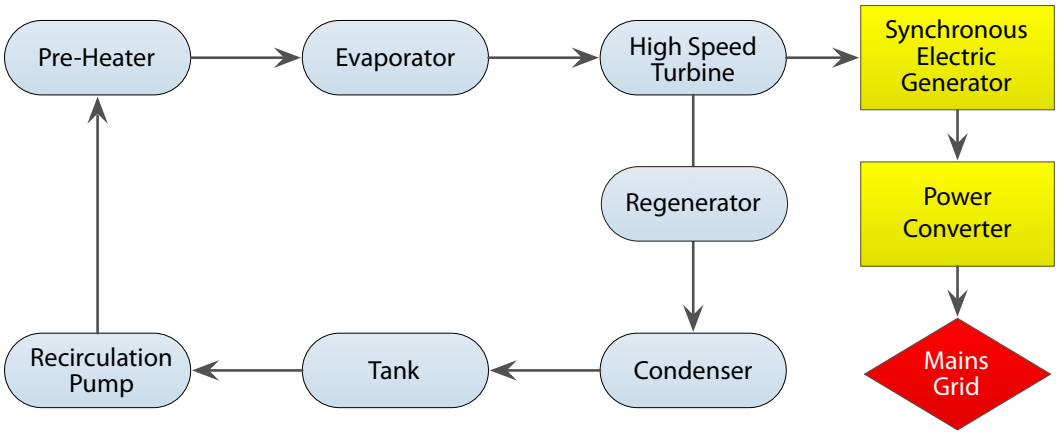
Castrovillari (Cosenza,Italy) - ORC Power generation from biomass (pruned tree branches)

Borgoforte (Mantua, Italy) - Heat recovery from cooling jackets & exhausts of biogas-fueled gensets

For a more up-to-date and far more exhaustive list of our references, please consult the "References" section of our website, **www.zuccatoenergia.it.**

ORC CIRCUIT COMPONENTS

Besides the aforementioned working fluid, the power generation module is made of various elements, shown in the following diagram.



- **Pre-Heater**: preheats working fluid using the overheated water of the diathermic loop which feeds the ORC power generation module, increasing efficiency;
- **Evaporator**: uses 160°C heat from the overheated water diathermic loop feeding the ORC power generation module to vaporize the working fluid (i.e. change its state from liquid to gas, increasing its pressure);
- **Turbine:** propelled by working fluid expansion, its ultralight impeller reaches very high rotational speed (9-10.000 rpm) drawing along the generator rotor assembly;
- **Synchronous Electric Generator** : spinning at high speed thanks to its direct connection with the turbine, it produces electric power.
- **Inverter** : makes all specifications (phase, frequency and voltage) of the electric current output by the generator suitable for interfacing with the national power grid;
- **Regenerator** : recovers part of the heat of the working fluid downstream of the turbine and uses it to preheat the working fluid entering the preheater, to further increase efficiency;
- **Condenser** : reduces the temperature of the working fluid gas downstream of the turbine, to make it go back to its originary liquid state;
- **Storage tank** to keep the condensed working fluid in liquid form;
- **Recirculation pump** to pump the fluid back in the ORC loop;

PROCESS DATA

These are the estimated process data for the plant:

PREHEATER + EVAPORATOR	VALUE	U.M.
Total thermal power input	3 500	[kWth]
Overheated water input temperature	= > 160	[°C]
Overheated water output temperature	145	[°C]
Max overheated water inflow	54.03	[kg/s]
Electric power output from turbogenerator	561	[kWe]

CONDENSER	VALORE	U.M.
Thermal power dissipation	2 909	[kWth]
Water output temperature	38	[°C]
Water input temperature	28	[°C]
Condenser circuit flowrate	69.41	[kg/s]

WORKING FLUID

IN SHORT

Exclusive working fluid

Low boiling point, high condensation point

Closed circuit = no contamination

No turbine blade erosion

Safe for man and environment

The organic working fluid, with its low boiling point, is the special component that allowed Zuccato Energia to create this type of plants.

The high-tech solutions Zuccato Energia has been able to develop and propose are as a matter of fact due to its existence.

The working fluid employed by Zuccato Energia has the following excellent characteristics:

- Wide working range which allows to exploit previously unexploitable heat sources;
- High condensing temperature which allows the use of standard cooling towers;
- Totally dry when in gas form, which means no turbine blade cavitation nor erosion;
- Low operational pressures (20 bar) equals better safety, less bureaucratic problems, lower costs;
- Totally ozone-friendly, organic, non toxic, 100% biodegradable and non-flammable in liquid form. As such, it is totally environmentally compatible and any accidental leaks are neither harmful or dangerous;
- Closed loop operation means refills are rarely required, if any;
- What's more, there's no steam nor water consumption so the plant is far more economical to operate as well as simpler and more compact than steam-based systems.

The fluid inside the plant undergoes several phase changes and treatments; the process specifications are resumed in the following table:

WORKING FLUID	
Operational range	60-165°C
Condensation temperature	~33°C
Working pressure	max. 20 bar
Vector fluid	Water
Input temperature	145 °C
Input pressure	16,08 bar

TURBOGENERATOR SPECIFICATIONS

The following tables show the main technical specification of the ZE-500-LT power generation module turbine and its attached generator and inverter

TURBINE	
Type	Single-stage radial inflow turbine w/fixed nozzles, directly coupled to generator shaft
Input Temperature	145°C
Output temperature	~ 100°C
Stage pressure	PS 16 (tested to 24 bar)
Turbine body	Machined steel
Impeller	Aluminium alloy
Speed control	Feedback loop on generator current output
Seals and gaskets	Labyrinth seal on impeller back Axial labyrinth seal at generator interface (optional). Outside seal: Gaskets, O-rings

GENERATOR	
Type	Synchronous, permanent magnet
Power Output	561 kWe
Rotational Speed	9 500 Rpm (9 ...10 kRpm)
Rectifier	Built-in
Synchronizer	Includes
Output voltage	503- 577 VAC @ 500Hz
Cooling	Water jacket
Cooling requirements	15 kW_T
Cooling fluid	Water /glycol
Cooling fluid input temperature	< 40°C
Cooling fluid volumetric flow	30 l/min
Additional cooling (optional)	Working fluid injection
Pressure seal	2,5 bar (gas seal)

INVERTER	
Type	IGBT- mains synchronized
Output power	550 kWe
Output voltage	400 V + 5% Tol.
Output frequency	50 Hz +0,5% Tol.
Cooling	Water-cooled
Max operational environmental temperature	40°C
Braking chopper	Built-in, resistor-type

IN SHORT

Custom designed low-temperature, high-speed radial turbine

Built-in alternator, mounted directly on the turbine shaft

Custom-designed, integrated inverter

SYSTEM COMPONENTS

HEAT EXCHANGERS

IN SHORT

Compact & efficient brazed plate evaporator and preheater heat exchangers

Sturdy shell-&-tube regenerator and condenser heat exchangers

Ample reservoir of working fluid

High-efficiency recirculation pumps

The **hot-side heat exchangers** used in this ORC module are of the **brazed plate** type - a compact and efficient solution for heat exchange, made by brazing several quality corrugated steel plates together, taking care first to turn the fishbone-shaped corrugations on each plate 180° from the adjacent plate to ensure turbulent flow. Keeping in mind that the fluid-passing sections are very small, the heat exchange-to-encumbrance ratio of these exchangers is great. Among the characteristics for this type of exchanger, these are the most important ones:

- **Small size :** they occupy up to 10% of the space other exchanger types require;
- **Low temperature differentials**: it is possible to work with minimal temperature differentials, thus increasing overall system efficiency;
- **Reduced weight:** compact construction and small internal volume make this exchanger type weight a fraction of that of traditional exchangers;
- **Low load losses:** in most cases, the load loss in a brazed plate exchanger is even lower than that of a coaxial exchanger.
- **Resistance to dirt and corrosion:** high fluid turbulence and total use of the available surface reduce deposits due to suspended solids and allow cleaning with normal detergent fluids. Corrosion problems are avoided by using specifically resistant materials in their construction.

The **cold-side exchangers** are instead of the time-tested shell-and-tube type, which besides having a lower cost than equivalent brazed plate components, has better performances and is easier to clean than brazed plate exchangers when dealing with potentially contaminated cooling water, a problem that hot-side components - working in a closed loop - do not have to face.

HEAT EXCHANGERS	
Type	Brazed plate (evaporators & preheaters) Shell & tube (regenerator and condenser)
Nominal working pressure	30 bar
Test pressure	39 bar
Bursting pressure	225 bar
Construction materials	AISI316 S/Steel & 99,9% copper
Max working temperature	195°C

CONDENSATION TANK

It is a container to keep an adequate reserve of liquid working fluid for the plant, equipped with sensors to constantly monitor fluid levels.

CONDENSATION TANK	
Construction material	Rustproofed carbon steel
Capacity	500 litres
Connectors	PN25
Level sensor	Built-in

WORKING FLUID PUMP

A couple of pumps is used to send the condensed, liquid working fluid back into the ORC loop. The hydraulic part is kept in place between the upper cap and the pump body by tie rods.

WORKING FLUID PUMPS	
Motor	Closed short-circuited cage type with external ventilation
Energy Efficiency	Efficiency class 1
Degree of protection	IP55
Insulation	Class F (T_{MAX}=155°C);
Certification standard	EN 60034-1;

CONTROL PANEL

The control panel hosts all control, supervision, automation and communication electronics for the power generation module. It contains :

- Process management electronics;
- Temperature control electronics;
- Pressure control electronics;
- Alarm management systems;
- Mains connection management systems;
- Inverter circuitry for produced energy power factor correction;
- Mains interface panel with low-voltage protection circuitry.

The control panel also include telecontrol and telediagnostic systems that allow constant monitoring of the plant perfornmances as well as real-time remote control for intervention in case of malfunctions.

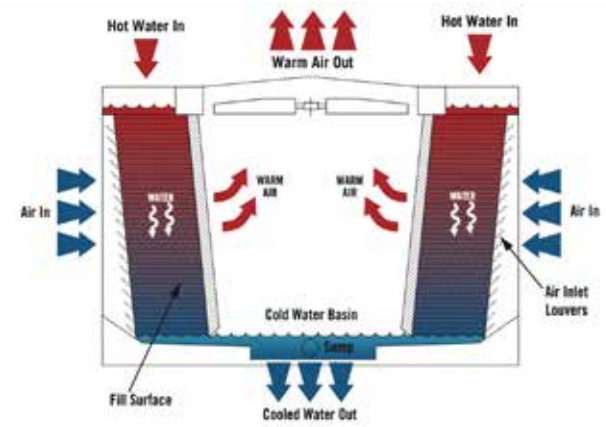
Said connections take place trough a built-in 3G / GPRS / EDGE cellular modemn router and allow access through any Internet-savvy device (PC or tablet).

COOLING TOWER (optional)

Whenever the client has no use for the residual heat that has to be dissipated during working fluid condensation and has no cooling tower available, we have chosen to supply a third-party cooling tower with superior construction specifications, able to ensure a constant condensing temperature all year round - a fundamental requirement for a continued optimal cycle efficiency. The heat exchange battery in this tower has been designed to obtain a large heat exchange surface and to make maintenance and cleaning easy. Proper use of fiberglass and polymer components helps keeping its weight down and allows its installation almost anywhere. Optional anti-icing resistors extend its environmental capabilities to frigid zones down to -18°C , and several noise reduction options are available for use near residential areas..

COOLING TOWER	
Type	Axial fan
Dimensions (L x W x H)	2,58 x 5,50 x h 3,65 m
Dissipation performance (nominal / maximum)	3000 / 3273 kWT
Shipping / Working weight	4079 / 8421 Kg
Wet bulb / Dry bulb temperature	22 °C / 30.6 °C
Required /maximum water flowrate	71,7 /78.2 l/min
Maximum water reintegration flowrate (P=1...4.5bar)	1.79 -1.9 l/s
Maximum noise level @15 m / 100% fan speed	67 dBA (without optional silencer)
Frame/tank material	Hot-galvanized steel
Axial fan power consumption(@ 100% RPM)	30 kW (56.2A@400VAC 50Hz)
Anti-icing resistors (optional; protection up to -18°C)	2 x 8kW

A similar tower in a residential area with full noise reduction options applied



IN SHORT

Fully automated control system

No human presence required

Touch-screen synoptic control panel

Remote control via mobile internet interface

Inverter and mains interface panels included

Optional high-efficiency evaporative cooling tower

IN SHORT

Standard version mounted on 2 skids for indoor installation + separate control panels

Skid dimensions:
Hot side (main) skid
5.0 x 2.8 x h 3.2 m
Cold side skid:
5.2 x 3.3x h 4.6 m

Dry Weights :
7 t (hot side)
11.5 t (cold side)
3 t (control panels)

Paneled version available

Containerized, weatherproof version for outdoor installation available

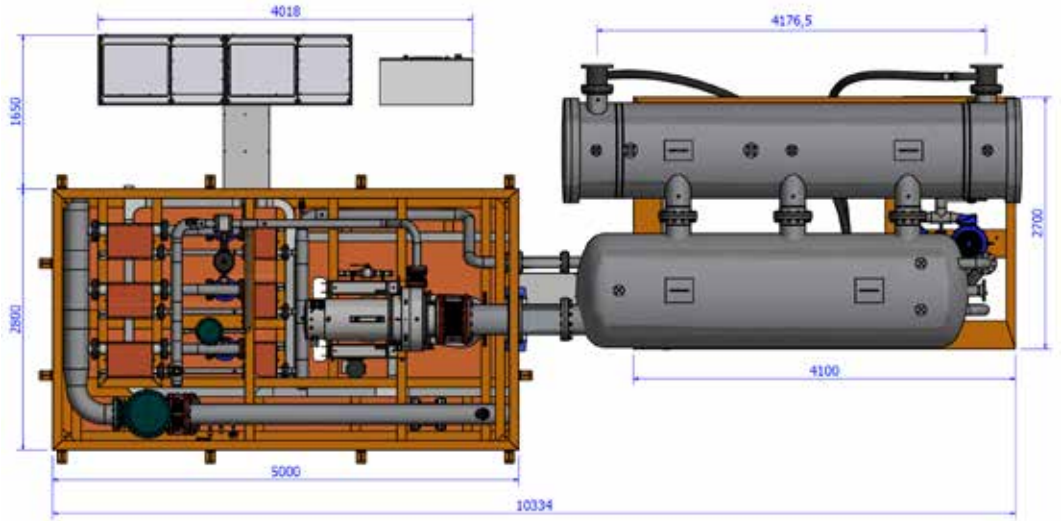
Custom skid designs available upon request

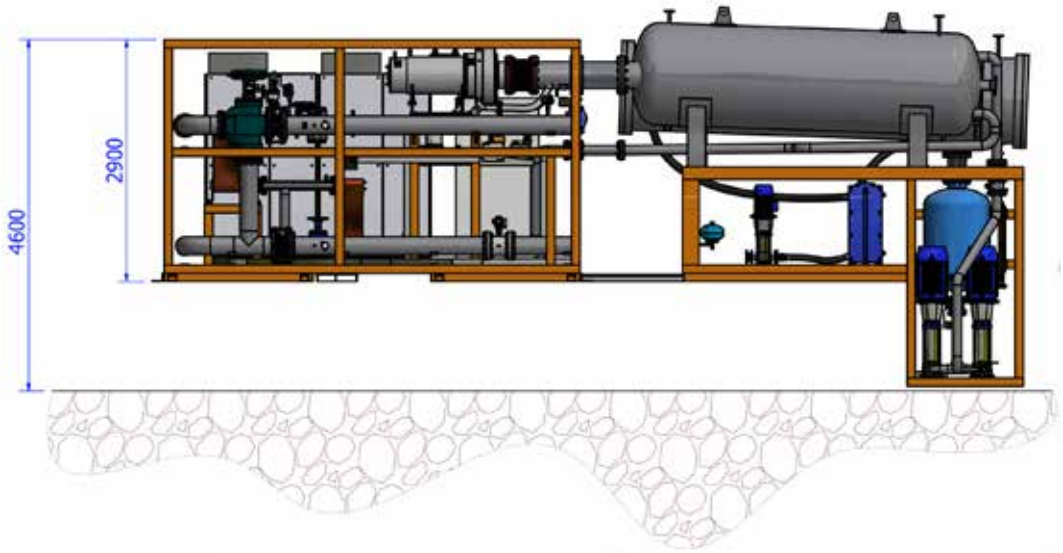
ZE-500-LT SYSTEM DIMENSIONS

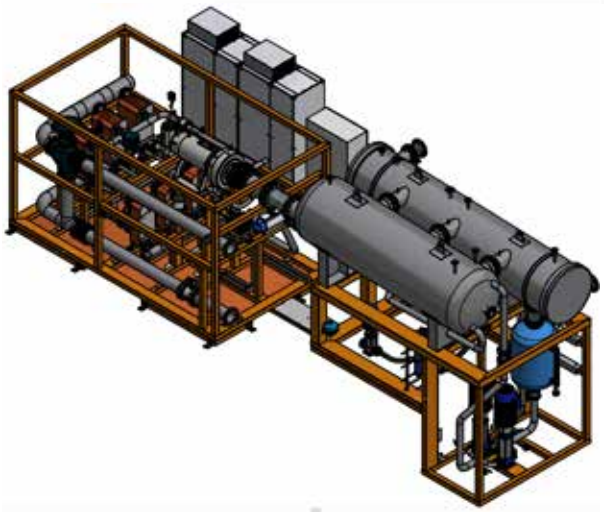
SKID

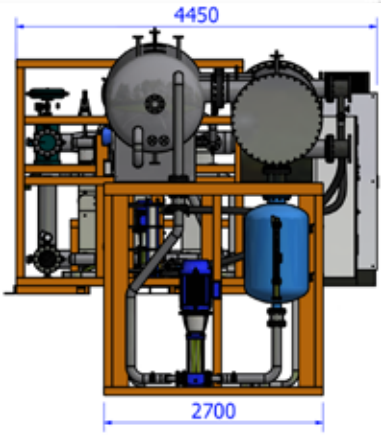
The power generation module is supplied mounted on two self-supporting, interconnected frames ("skids"), one of which houses the "hot side" components (turbine, evaporators, preheaters...) while the other houses the "cold side" - regenerator, the condenser, the working fluid tank and pump. The following drawings show the standard, "naked" version of the ZE-500-LT ORC power generation module, which weighs about 10 tons an is designed for indoor installation.

Paneled and containerized/weatherproof versions for outdoor installation are also available.







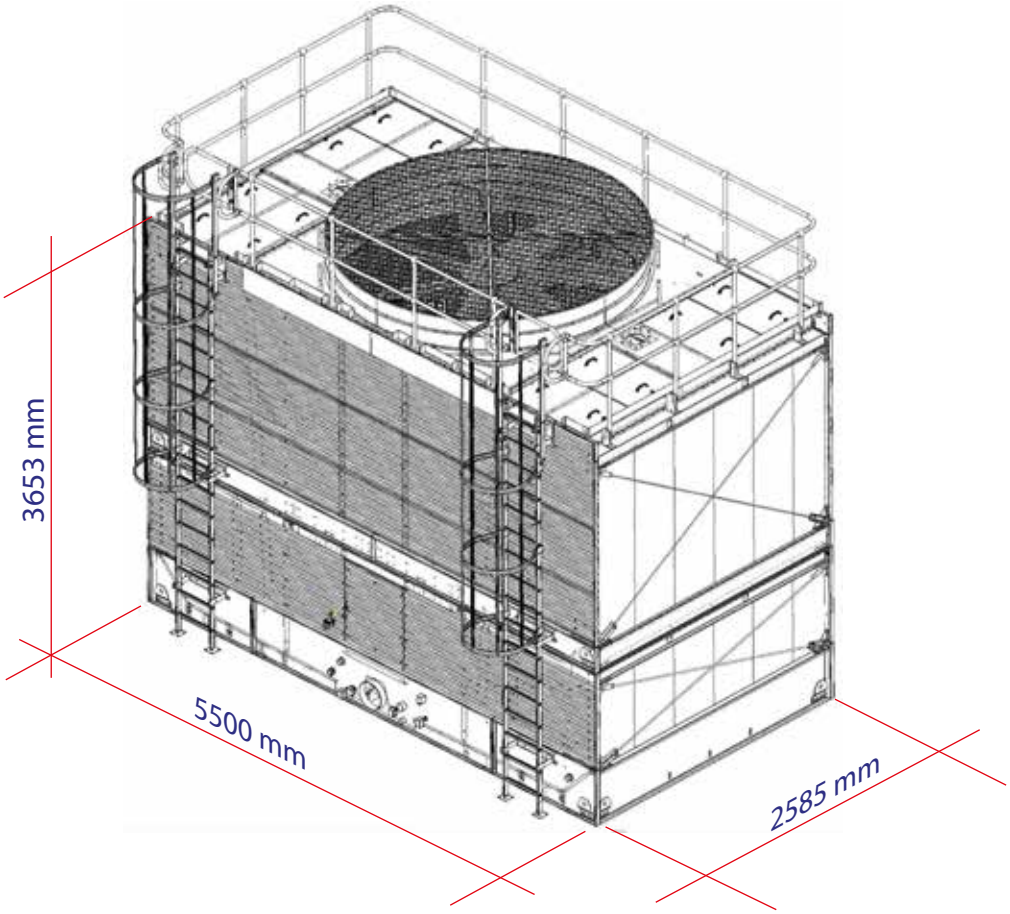


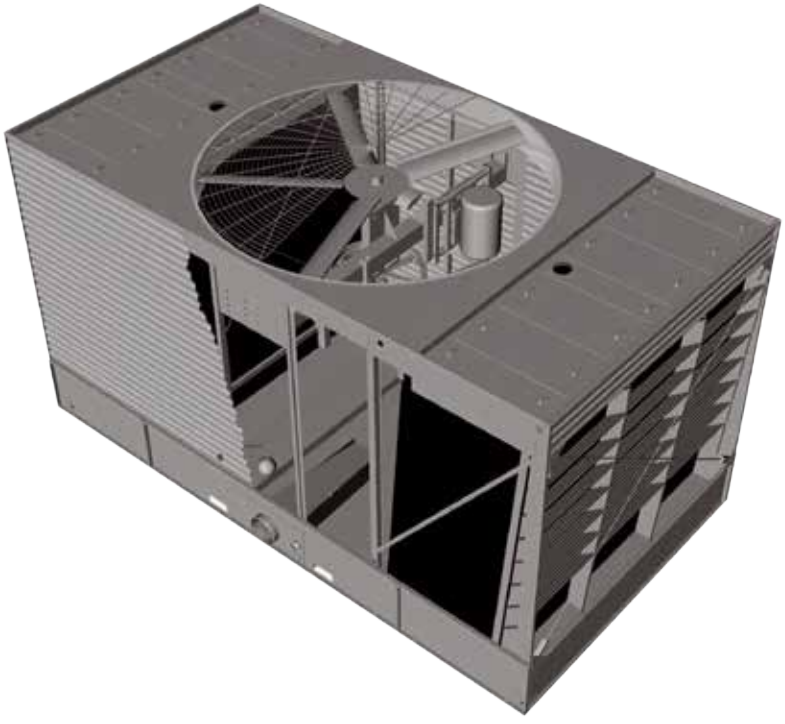
Please note that the skid requires at least 1.5 meters of free space on all sides for easier maintenance access.

Zuccato Energia, being the system developer and manufacturer may also build the skid in non-standard dimensions different from the above, to tailor the system on the client's needs.

COOLING TOWER

The cooling tower is an optional unit that has the purpose to dissipate residual heat from working fluid condensation whenever it is not used for other purposes (ambient heating, fuell dessiccation...). It occupies a 5.5 x 2,6 m area by 3,7 m high, as in the following drawings.





Please keep in mind that, beside the space required for maintenance access, ample space is required around the tower meter to allow proper air circulation, as air is drawn in from the sides.

This required space doubles between this and any other already present cooling tower, to avoid interference between the two.

IN SHORT

Galvanized steel construction

Dimensions: 550 x 259 cm h 365 (not including optional ladders and handrails)

Required area: 650 x 360 cm

Minimum distance from other cooling towers: 2 meters

Working weight: ~ 8.4 t

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