Hybrid cooling tower in geothermal high temperature plants

MATChING
MATERIALS & TECHNOLOGIES FOR PERFORMANCE IMPROVEMENT OF COOLING SYSTEMS IN POWER PLANTS

October 2nd - 3rd , 2018

Rome, Italy

Alessio Bardi – EGP,

Luca Bertocchi – SPIG,

Lorena Freire Piñeiro - AIMEN

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- Task 4.2 DEMO Facility realization
- Task 4.3 Hybrid CT demonstration
- Next step

WP4 status update

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WP 4

Task 4.2: Demo facility realization

MS6: Commissioning of DEMO module

Task 4.3: Hybrid CT demonstration

KPIs DEMO

- Advanced packing performance assessment
- Hybrid configuration assessment

Task 4.4: Final assessment of coatings and materials

KPIs Laboratory

Final assesment

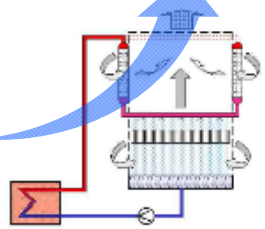
WP 7

Task 7.3: Techno-economical evaluation of cooling concept for geo p.p.

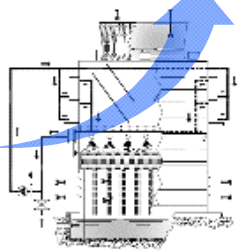
KPIs Global

CAPEX/OPEX → NPV analysis

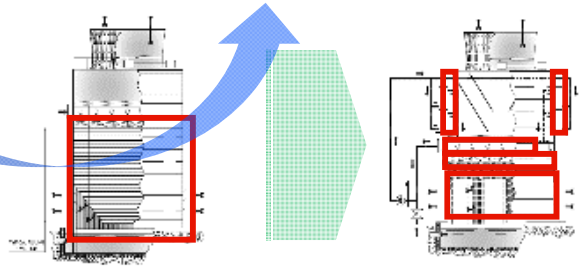
Design and erection



Demonstration



Sensitivity analysis



Task 4.3 Hybrid CT demonstration

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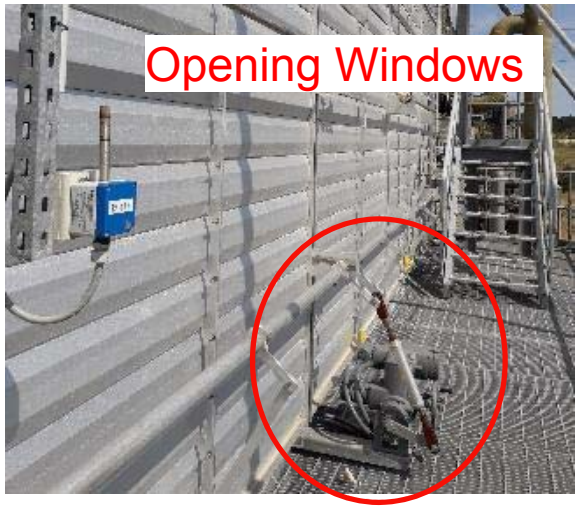
The main change in the task is the arrangement of demonstration phases: instead of sequential phase 1 (wet assessment) and phase 2 (hybrid assessment) there is a unique demonstration phase with a **daily switch from wet to hybrid.**



Phase I: wet operation

(M12→M18)

+

Phase II: hybrid operation

(M18→M24)

Operation constraints

Hybrid operation/Wet operation

(M24→M36): ***a weekly*** switch from hybrid to wet

Fire event occurred

Hybrid operation/Wet operation

(M36→M42): ***a daily*** switch from hybrid to wet

Content

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Task 4.2 DEMO Facility realization

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Main Objective: Design, supply, installation, commissioning of the demo module for Nuova San Martino geothermal power plant (40 MW):

- **Subtask 4.2.1 – Design and supply of demo module**. Enable hybrid operation, equipped with instrumentation and devices for technology validation.
- **Subtask 4.2.2 – Erection and commissioning**. Civil, mechanical, electrical work, commissioning and start-up.

Six forced CTs → One will be modified in MATChING, based on an innovative hybrid technology and will be operated in parallel with the five conventional ones.

Task 4.2 DEMO Facility realization

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Task 4.2 DEMO Facility realization: CT data sheet

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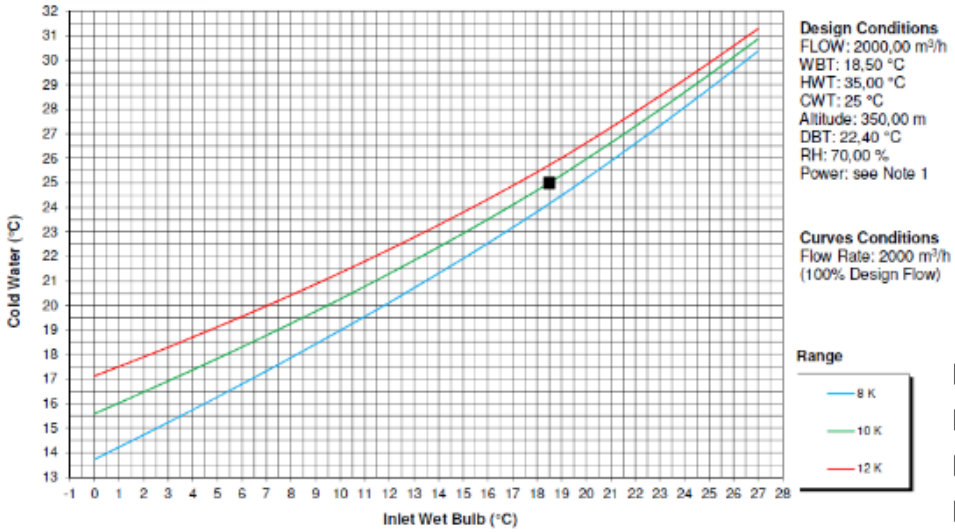
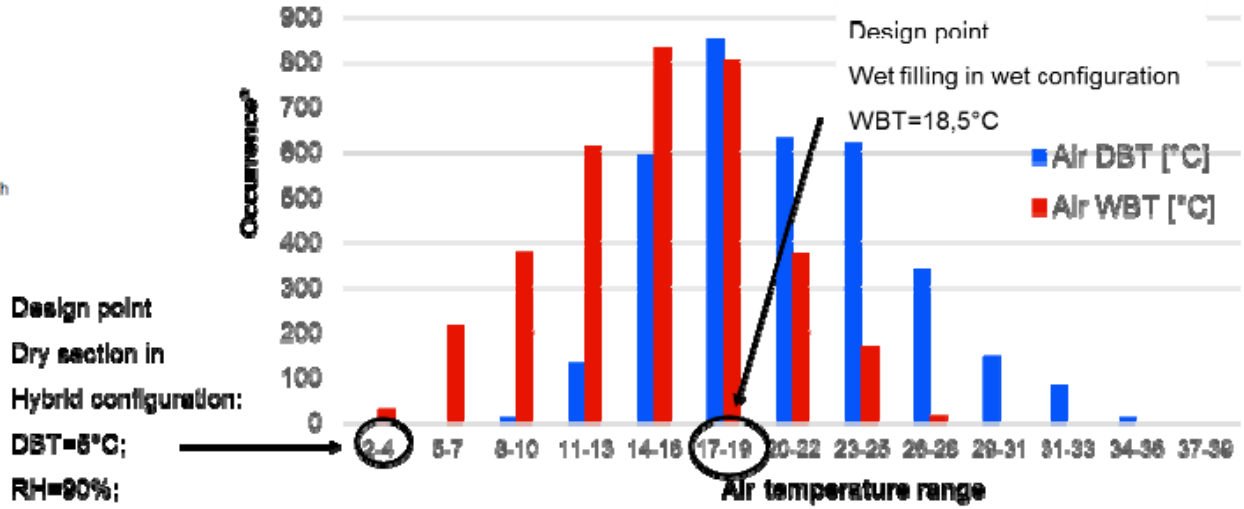
PROCESS DATA - DESIGN CONDITION	
Cell Waterflow WF (m^3/h)	2000
Hot water temperature HWT (°C)	35.0 (wet mode)
Cold water temperature CWT (°C)	25.0 (wet mode)
Range HWT-CWT (°C)	10.0 (wet mode)
Entering Wet bulb temperature WBT (°C)	18.5
Approach (°C)	6.5
No plume condition	5°C / 90%
Drift loss (%)	≤ 0.0005
Evaporation loss (%)	1.40% wet mode / 1.25% hybrid mode
Water specific load ($m^3/h*m^2$)	11.02

The design of new hybrid unit was based on heat load demand and main approach temperature difference → (most likely seasonal ambient WBT)

The NO PLUME condition had to be respected for the most likely lowest WBT



Note 1: For fan speed and power consumption in wet and hybrid mode see data sheet S-HORA16-IT-D-004



Task 4.2 DEMO Facility realization

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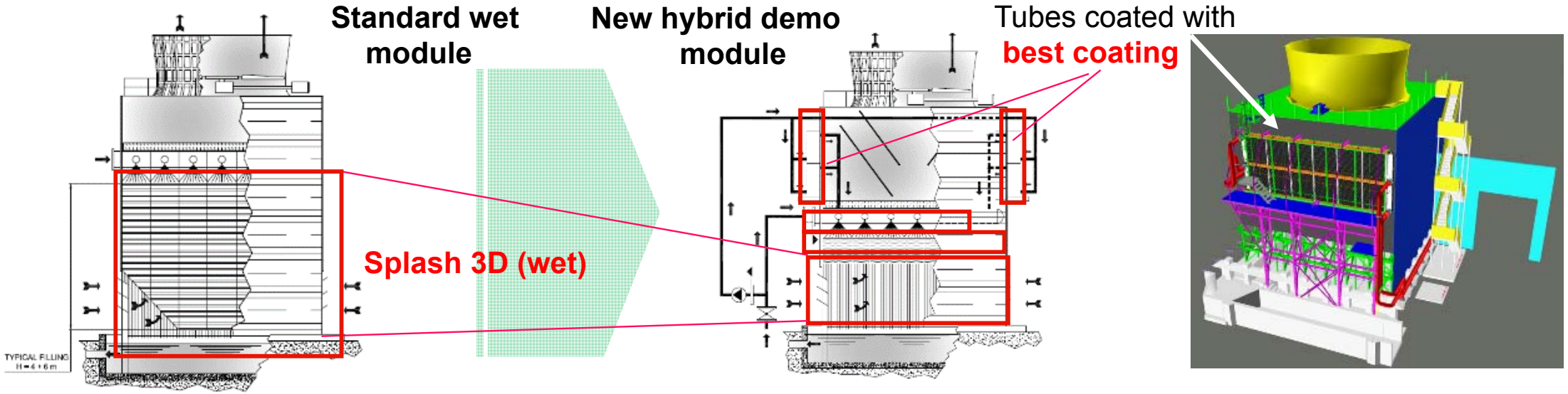
Subtask 4.2.1 –Design and supply of demo module (completed): The design of equipment is completed. The features design of process equipment are:

- (wet) Reduction of the wet filling height down to 1.8 m: SPLASH 3D **STAR X20** (from subtask 4.1.1)
- (dry) 4 heat exchangers equipped with tested coating materials (from subtask 4.1.2) : 1 Carbon steel tubes coated with **best coated** and 1 equipped with aluminium tubes coated by the same;



Task 4.2 DEMO Facility realization

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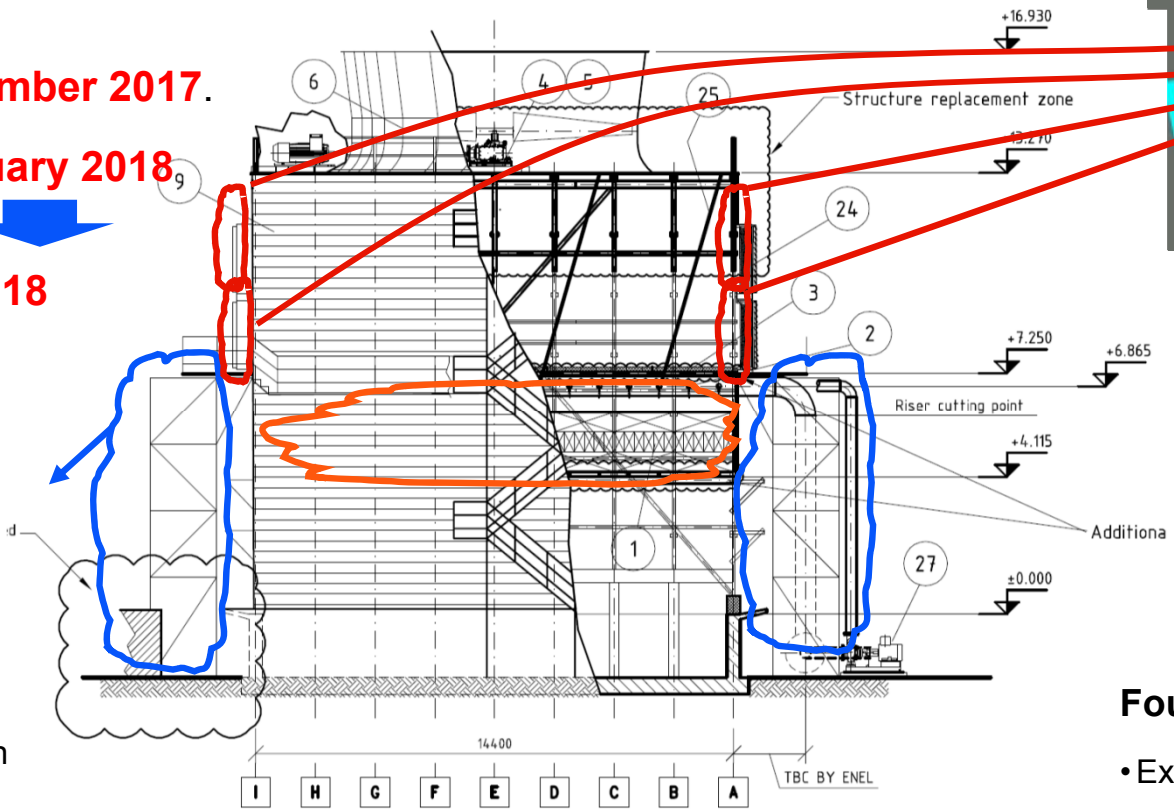
Task 4.2 DEMO Facility realization

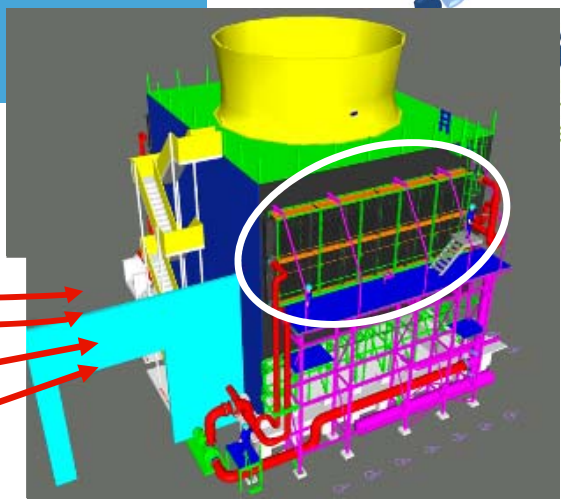
Subtask 4.2.2 – Erection and commissioning.

Start of erection **November 2017**.

End of erection: **February 2018**

April 2018





Process & mechanical works

- Dismantle of existing filling
- Installation of wet/dry sections
- Piping modification (lowering of distribution level; connection to dry section piping)

Carpentry and auxiliary structures

- Erection of carpentry that will support the dry section

Foundations reinforcements:

- Execution of civil works

Task 4.2 DEMO Facility realization: civil works

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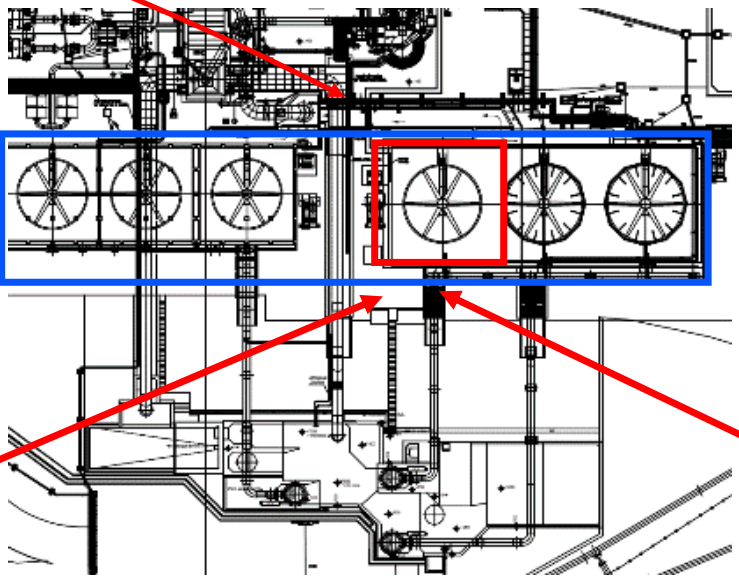
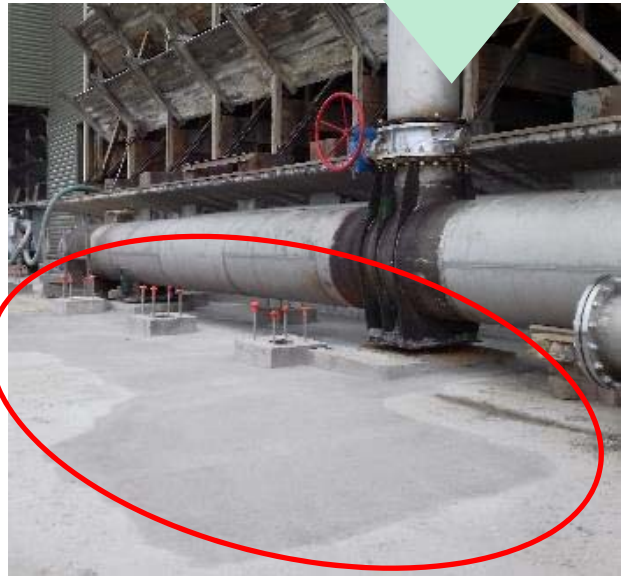
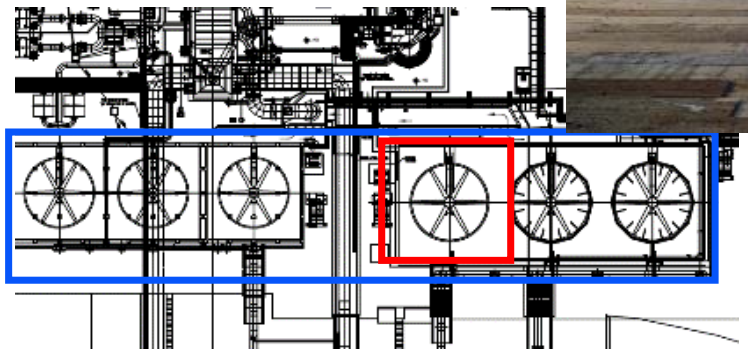
Civil works





Task 4.2 DEMO Facility realization: existing CT dismantle

Dismantle of chimney and fan



Dismantle of existing filling

Task 4.2 DEMO Facility realization: process & mech works

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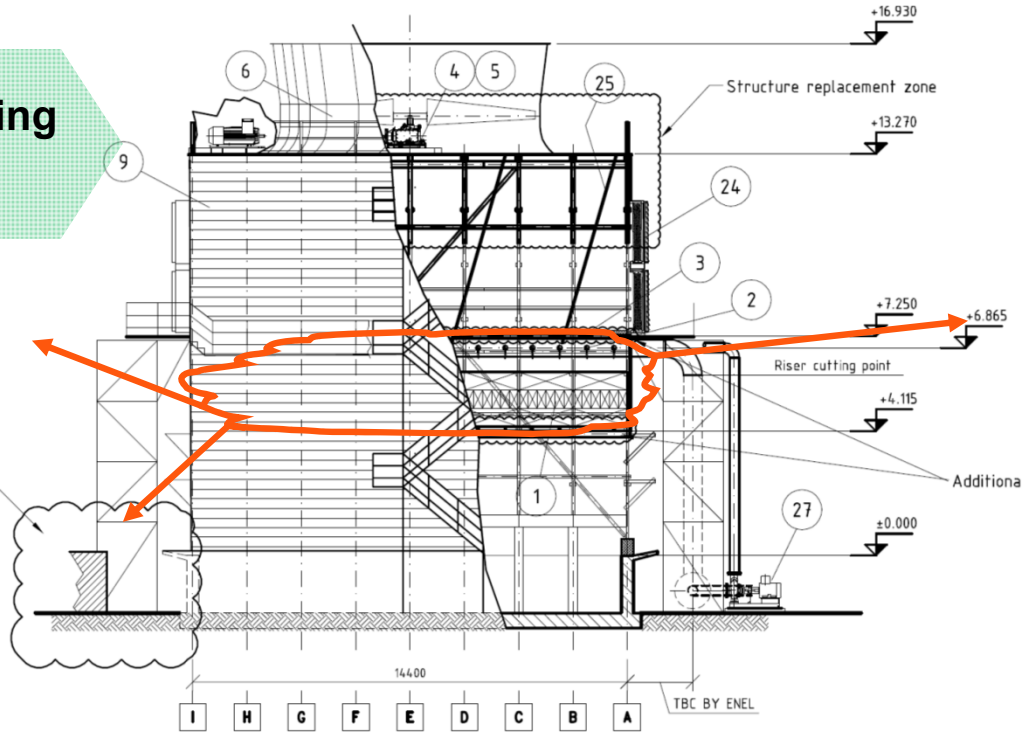
Installation of new existing filling media



Task 4.2 DEMO Facility realization: piping modification

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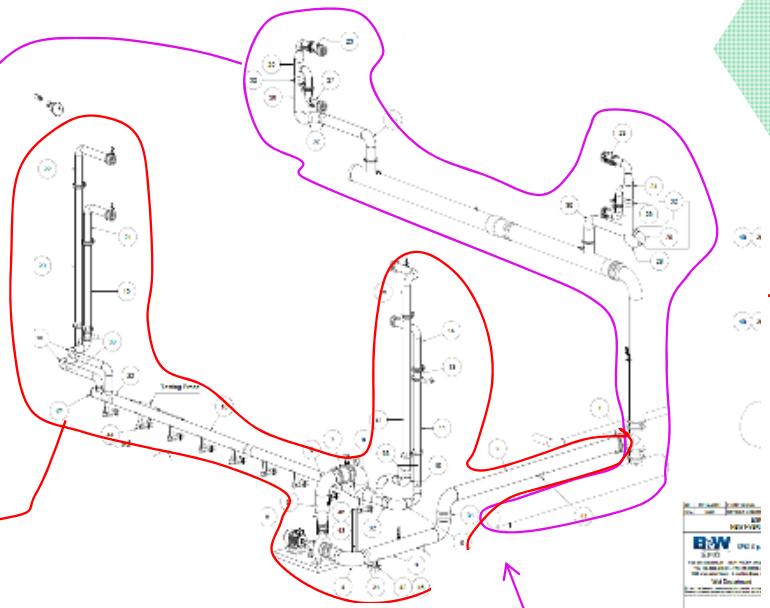
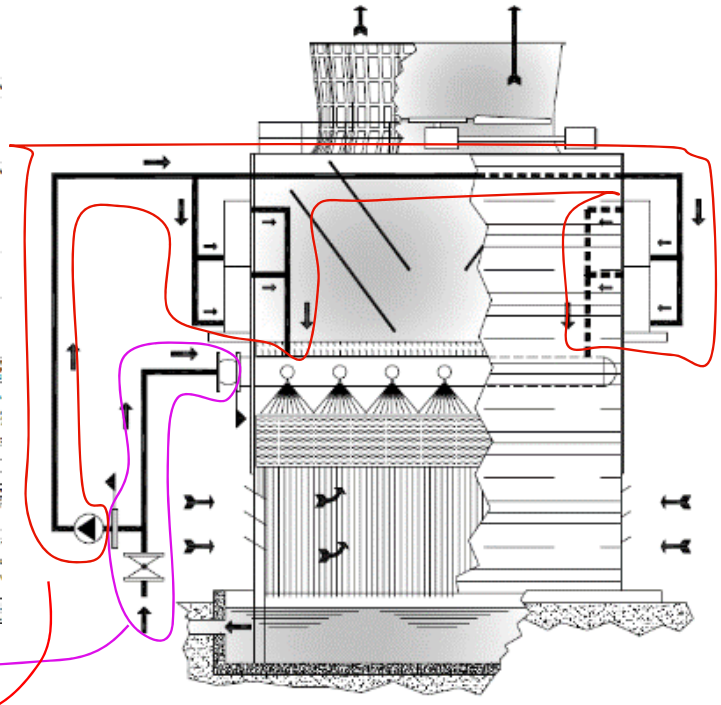
Piping modification





Piping modification of feeding hot water:

- Hybrid configuration → 35% to wet section, 65% to dry section;
- Wet configuration → 100% to wet section;

Task 4.2 DEMO Facility realization: dry section & carpentry

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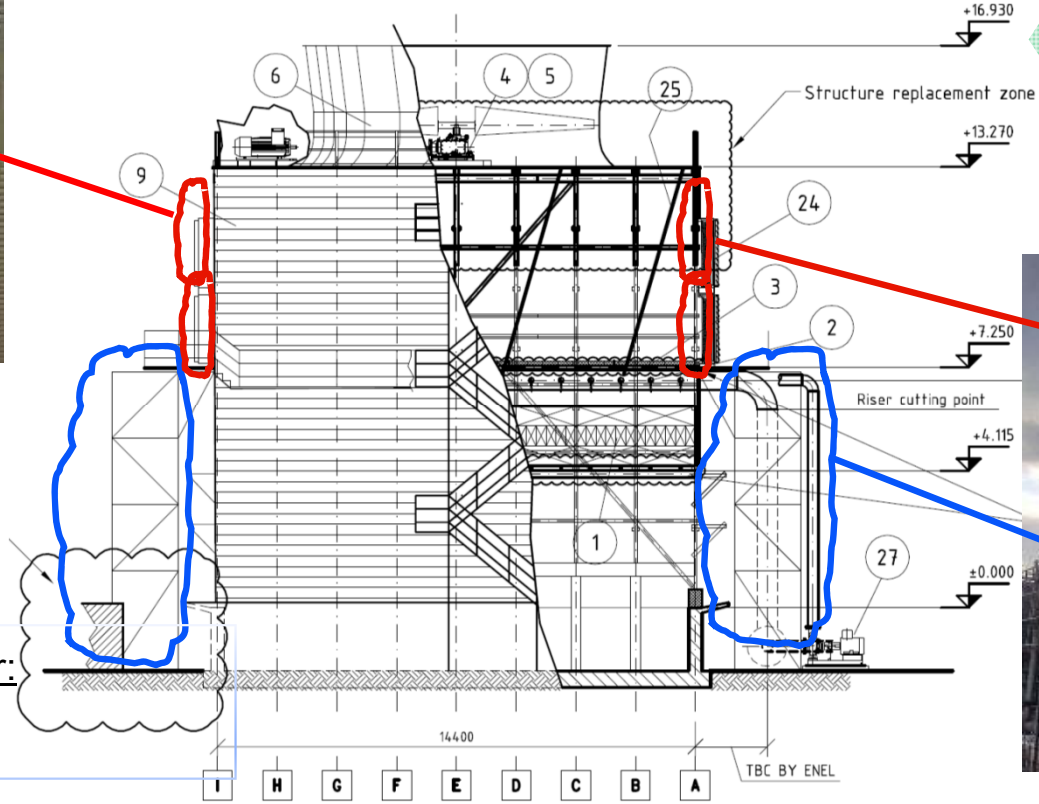
Dry section & carpentry



Piping modification of feeding hot water:

- 2 HX, 7 tonnes each side

WP4 status update

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MATERIALS & TECHNOLOGIES FOR PERFORMANCE IMPROVEMENT OF

	2017												2018												2019											
Month	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Mx	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46

CT Process design

Test of coatings (dry sect.) and adv. Filling (wet sect.)

Equipment design of the N.va San Martino CT

Foundation design

Permits for civil works

Equipment supply

Civil works

Dism. of CT

Erection of CT

SPIG (ext)

EGP -INN

EGP - E&C

EGP - O&M

GA project meeting
Mar 07, 2017

Permits to start construction
Jun 07, 2017

Shut down of CT and partial load operation
Nov 17, 2017

Commissioning CT
Mar 22, 2018

Start of DEMO operation
Apr 23, 2018

Restoring activity

DEMO operation

End of demonstration

Task 4.2 DEMO Facility realization: Fire event

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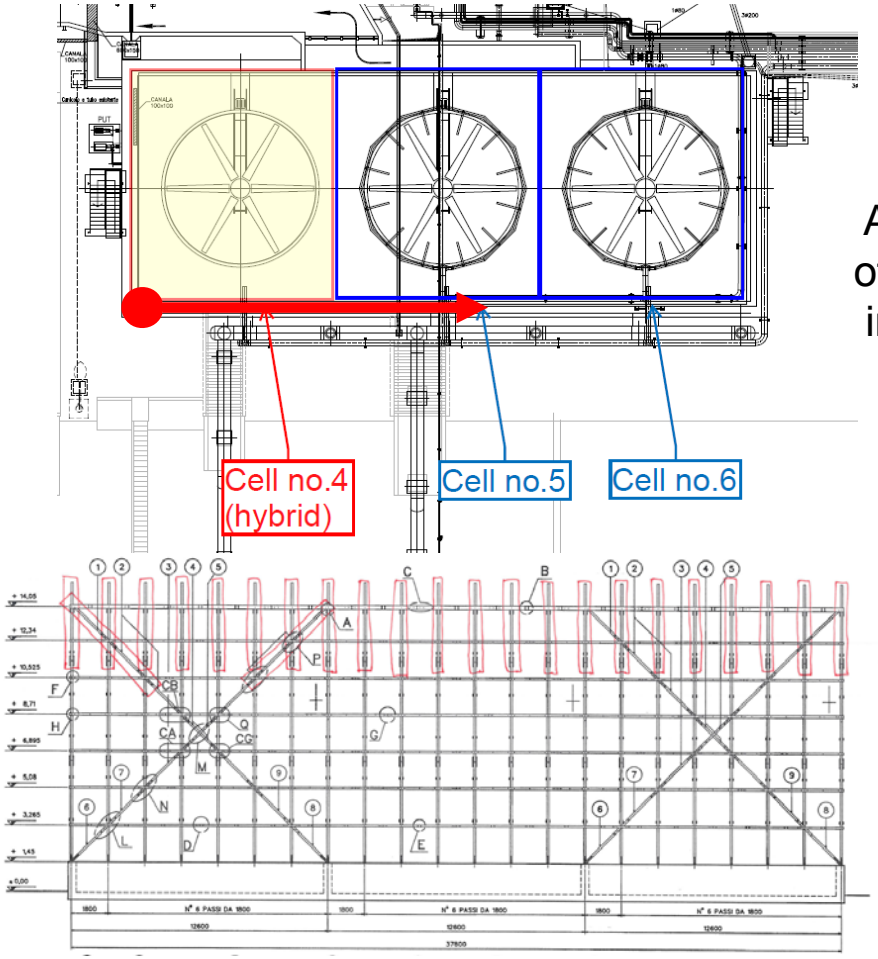
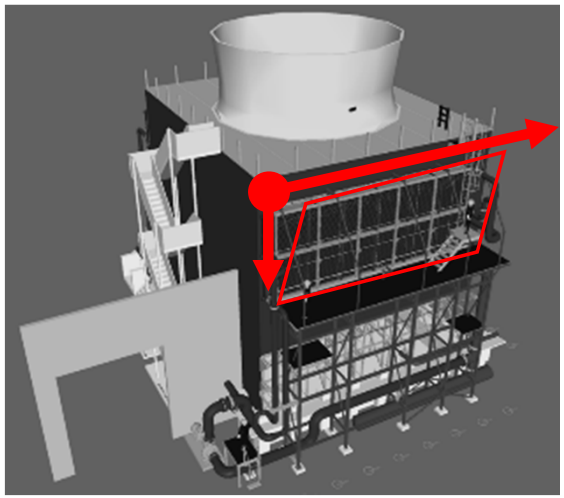


An internal investigation came to the conclusion that the ignition of fire started from the top vertex and developed through the south side interesting the other 2 cells.



Task 4.2 DEMO Facility realization: damages outside the tower

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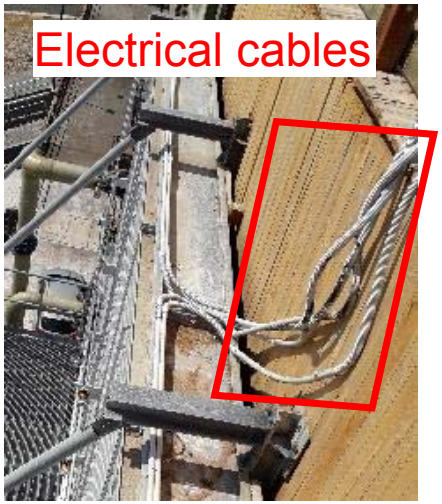
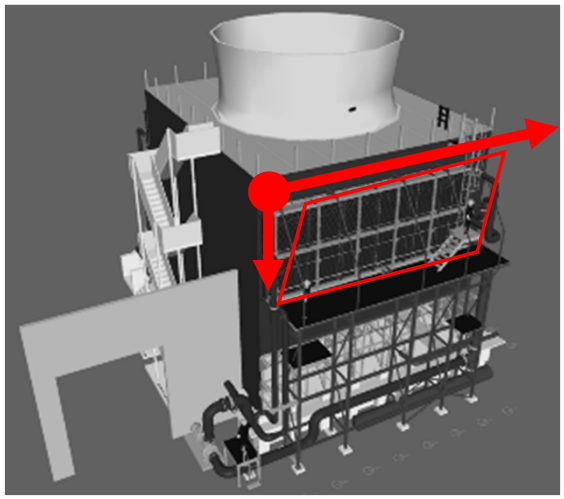
Wooden deck/lateral panels and electrical cables have been partially damaged





Task 4.2 DEMO Facility realization: damages inside the tower

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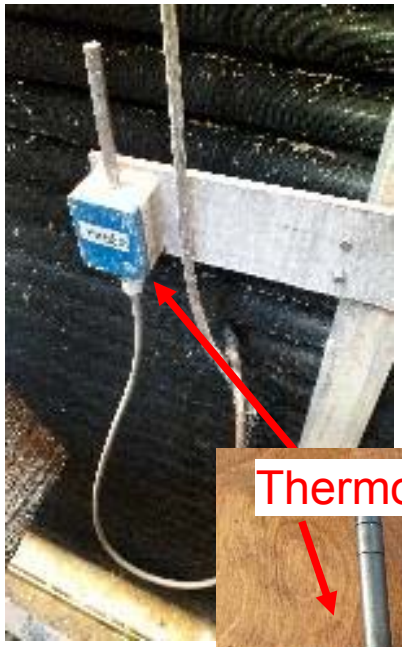
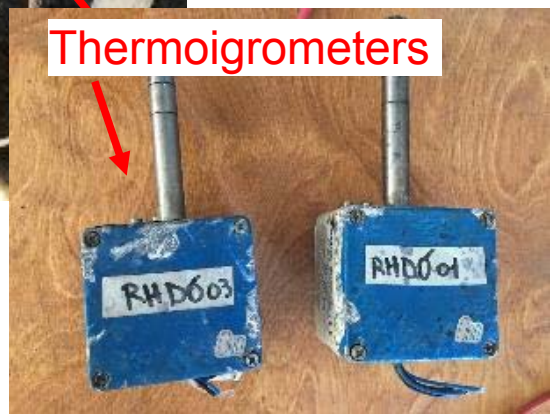
Some structural wooden beams, walkways, electrical and data cables, and drift eliminators were damaged.





Task 4.2 DEMO Facility realization: restoring works

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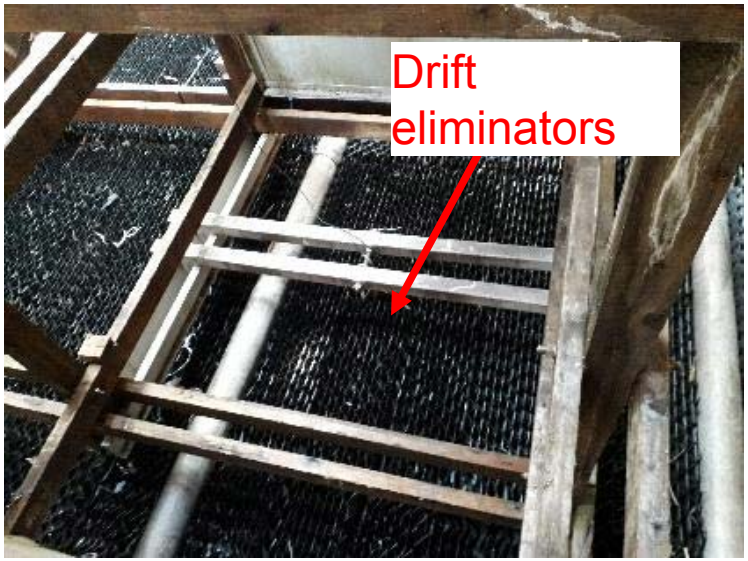
The restoration activities involved only fixings, assemblies and cold working: no hot working were carried out on the tower for the restoration operations.



Both the deck and the internal parts of the tower were kept wet by the hoses on the deck and by the humidification system.

Task 4.2 DEMO Facility realization: dry section & carpentry

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TITLE: AVAILABLE LANGUAGE: EN

NUOVA SAN MARTINO - MATCHING

HYBRID COOLING TOWER (CELL NO.4)

Restoration works as a result of the partial fire event (17/04/2018)

Causes:
…it was not possible to identify a exact cause of the fire principle…

Restoring works:

- Carbonized wooden beams/deck/panels replaced
- Drift eliminators replaced
- Instrumentation & data connections replaced
- Inspection on HEAT EXCHANGERS integrity (hydraulic test)

	DURATION	2-Jun-18	...	30-Jun-18	1-Jul-18	WEEK 1 2-Jul-18	8-Jul-18	WEEK 2 9-Jul-18	15-Jul-18	WEEK 3 16-Jul-18	22-Jul-18	WEEK 4 23-Jul-18	29-Jul-18	WEEK 5 30-Jul-18	5-Aug-18	WEEK 6 6-Aug-18	12-Aug-18	WEEK 7 13-Aug-18	19-Aug-18
RESTORATION WORKS AND UPGRADING OF THE CONCRETE TOWER CELL NO.3	29 days																		
Restoration works of the structure, filling upgrading, access, etc.	29 days																		
RESTORATION WORKS ON THE WOODEN TOWER DAMAGED	49 days																		
Restoration works for cell no. 6	14 days																		
Restoration works for cell no. 5	14 days																		
Restoration works for cell no. 4 (hybrid cell of Matching Project)	21 days																		

Wooden material (deck+panels)	8 k€
Electrical works	30 k€
Tower crane + platform	10 k€

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- **Task 4.3 Hybrid CT demonstration**
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Task 4.3 Hybrid CT demonstration

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WP 4

Task 4.2: Demo facility realization

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Task 4.4: Final assessment of coatings and materials

WP 7

Task 7.3: Techno-economical evaluation of cooling concept for geo p.p.

KPIs DEMO

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KPIs Global

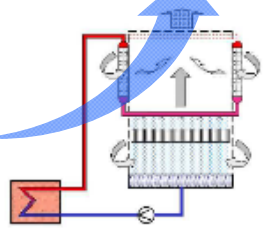
MS6: Commissioning of DEMO module

- Advanced packing performance assessment
- Hybrid configuration assessment

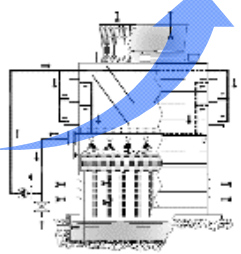
Final assesment

CAPEX/OPEX → NPV analysis

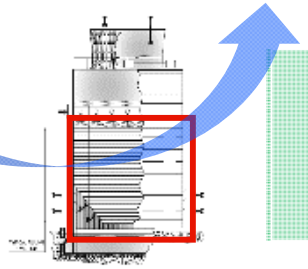
Design and erection

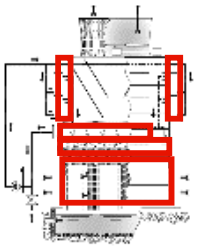


Demonstration



Sensitivity analysis





Task 4.3 Hybrid CT demonstration

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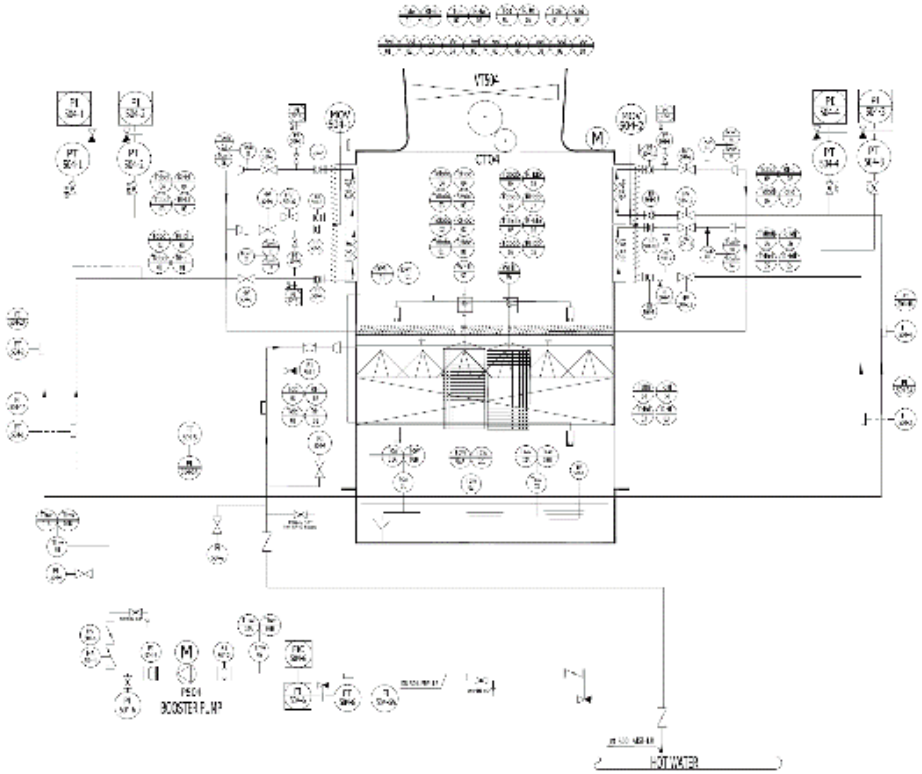
Subtask 4.3 –KPI evaluation → Dedicated Automation & Control

Wet section KPIs	Scale	Variable measured
4.1.1 Filling cooling capability for filling height of 1 meter [-]	Lab/DEMO	*Inlet/out air DBT, RH, inlet/outlet water temp. , water flow rate*
4.1.2 Filling cooling capability per fan power consumption [kW^{-1}]	Lab/DEMO	*See 4.1.1 + Fan Power,*
4.1.3 Material costs of innovative fillings per MW [€/MW]	Lab/DEMO	*CAPEX*
4.1.4 Reduction of filling cooling capability over the time [$month^{-1}$]	**DEMO**	***See 4.1.1***
4.1.5 Increase of pack weight due to clogging [kg/month]	**DEMO**	***filling weight***
4.1.6 Increase of air pressure drop through filling due to clogging (Pa/month)	**DEMO**	***water pressure drop***
Dry section KPIs		
4.2.1 Reduction of dry module heat transfer coefficient due to fouling [W/(m^2*K*month)]	**DEMO**	***Inlet/outlet air temp., water flow rate, inlet/outlet water temp.***
4.2.2 Increase of dry module water pressure drop due to fouling [Pa/month]	**DEMO**	***water pressure***
4.2.3 Coating corrosion resistance [Ωcm^2]	**DEMO**	***Electric current***
4.2.5 Cost increase compared to standard dry module sections [%]	**DEMO**	***CAPEX***



Task 4.3 Hybrid CT demonstration

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Hygrometer

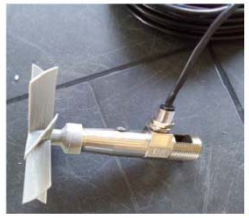
Accuracy = 0,2% RH

Range = 5 ÷ 95%

Termometer

Accuracy = 0,2% K

Range = -20 ÷ 50 °C



Velocimeter

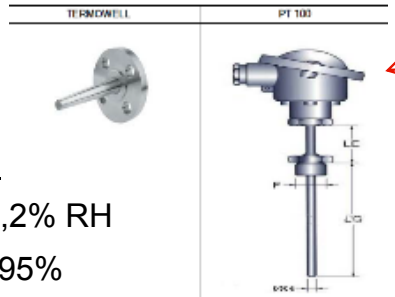
Accuracy =0,3 m/s

Range = 0-30 m/s

Anemometer

Accuracy = 0,2% K

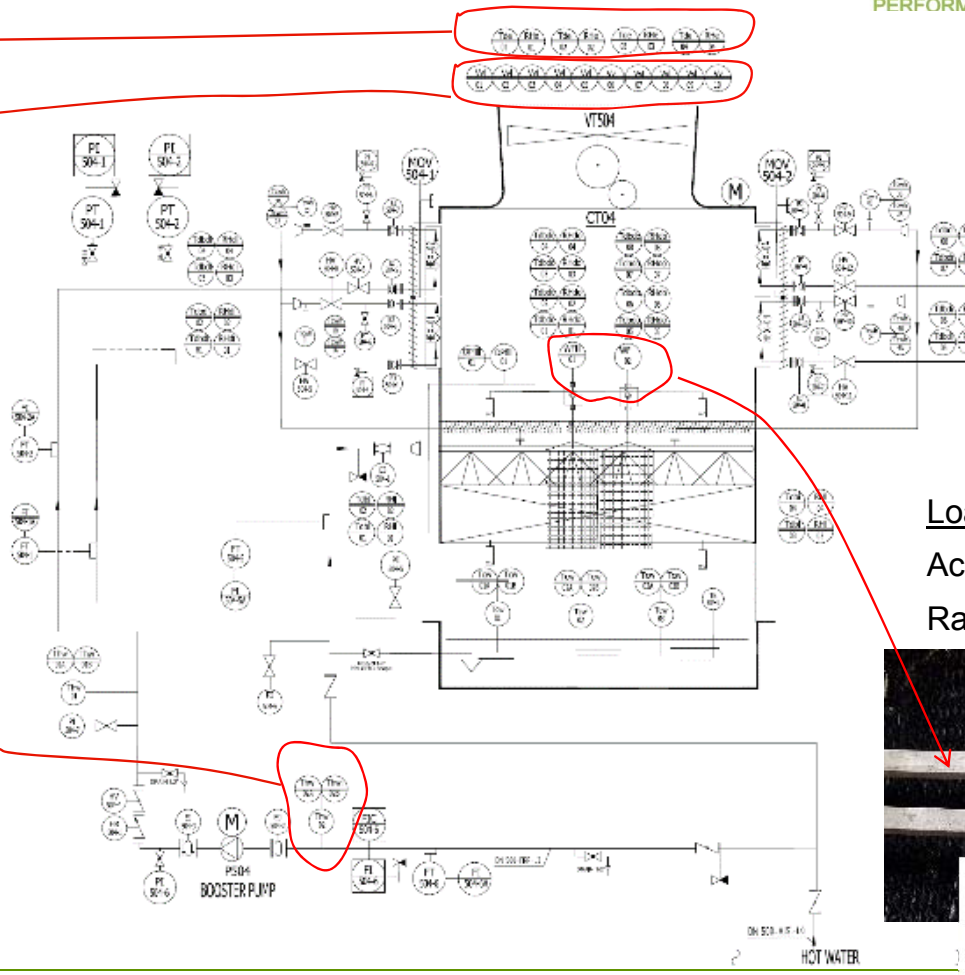
Range = -20 ÷ 50 °C



Termocouple

Accuracy = 0,2% RH

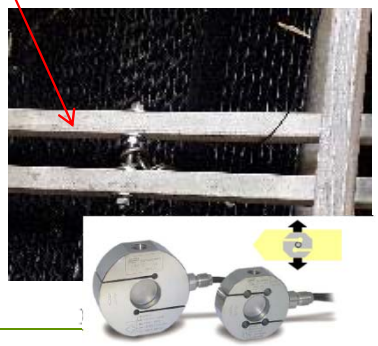
Range = 5 ÷ 95%



Load cell

Accuracy =0,023%

Range = 1 ÷ 7,5 tonnes



Task 4.3 Hybrid CT demonstration: KPI wet section

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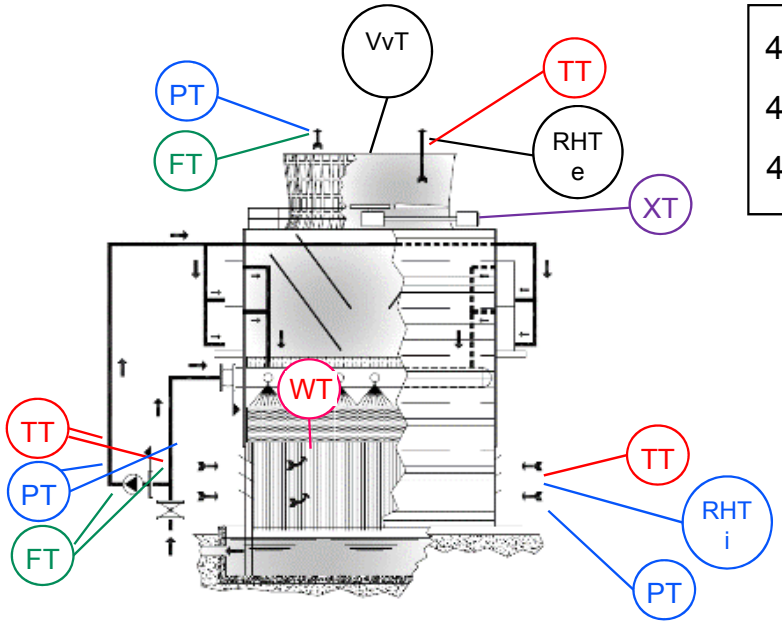

4.1.4 Reduction of filling cooling capability over the time [month^{-1}]

4.1.5 Increase of pack weight due to clogging [kg/month]

4.1.6 Increase of air pressure drop through filling due to clogging (Pa/month)

The KPI calculates the cooling capability of the advanced high- efficiency filling divided by the power consumption of the fan at the design operating conditions of the DEMO Module.

$$\frac{KaV / L}{P}$$

Calculation according to CTI (Cooling Technology Institute) standard: ATC-105 (Acceptance Test Code for cooling towers)

Measurement data:

- Cold and Hot water temperature
- Wet Bulb Temperature of entering air
- Circulating water flow → XT
- Power absorption (at fan motor shaft), P → XT

Task 4.3 Hybrid CT demonstration: dry section KPI

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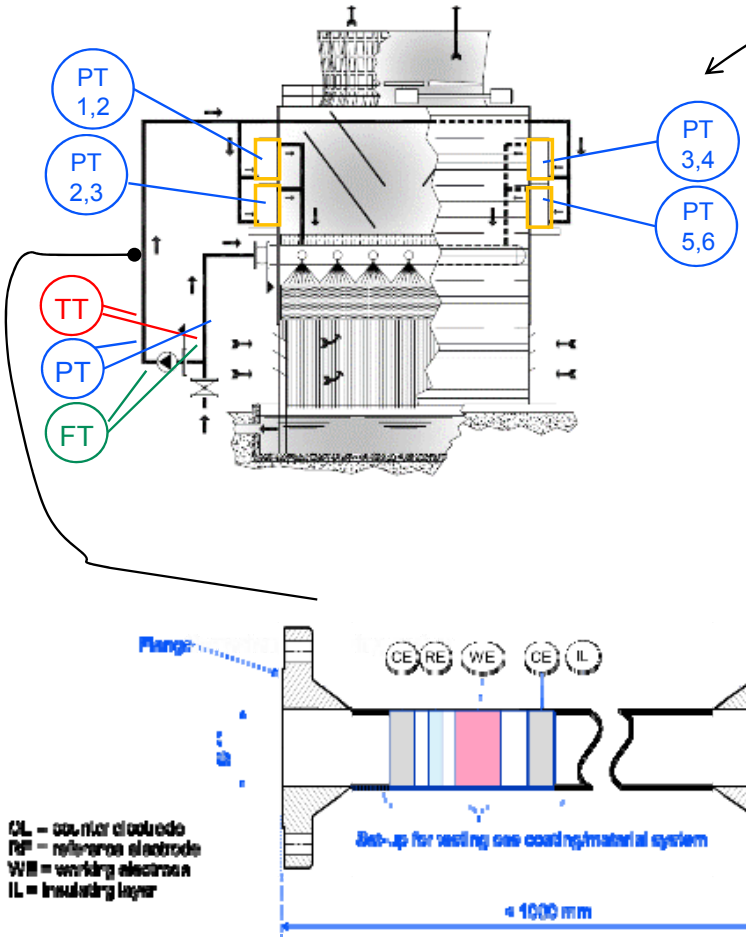

4.2.1 Reduction of dry module heat transfer coefficient due to fouling [W/(m²*K*month)]

4.2.2 Increase of dry module water pressure drop due to fouling [Pa/month]

4.2.3 Coating corrosion resistance [Ωcm2];

- Pipe diameter: 1”
- T=40ºC, Flow=1-2 m/s
- P=2 bars

A by-pass from the main pipe will be constructed to integrate the corrosion probe.

Task 4.3 Hybrid CT demonstration: KPI dry section

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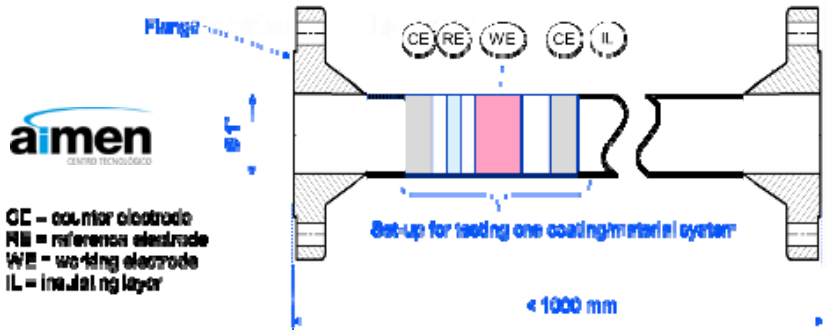

4.2.1 Reduction of dry module heat transfer coefficient due to fouling [W/(m²*K*month)]

4.2.2 Increase of dry module water pressure drop due to fouling [Pa/month]

4.2.3 Coating corrosion resistance [Ωcm2];

Working electrodes: 15 mm length

Not –coated Al
Coated Al
Coated CS
Not coated 316

Power suply

Ethernet

Online monitoring

EIS measurements

Electrical signals

Task 4.3 Hybrid CT demonstration

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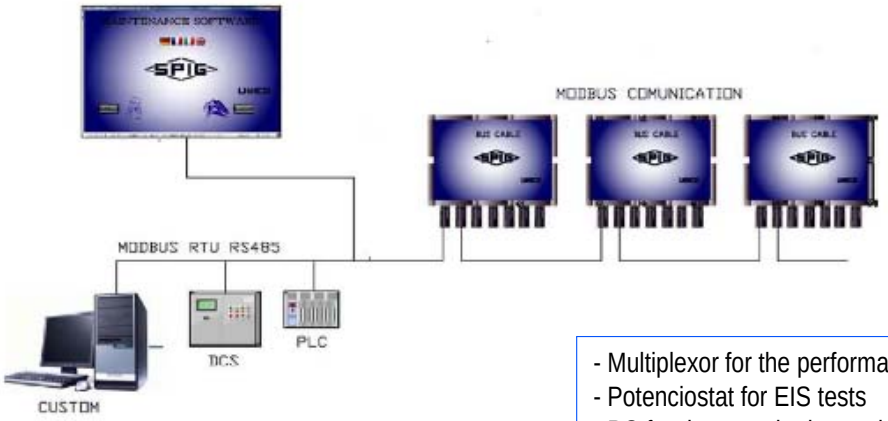
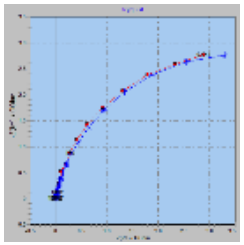


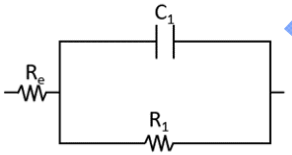
- Multiplexor for the performance of several measurements simultaneously
- Potenciostat for EIS tests
- PC for data monitoring and probe evaluation in real time
- Control platform developed by Labview® for measurements automatization
- Internet connection for remote control and online data back-up

aimen

Impedance spectra (Nyquist plot)

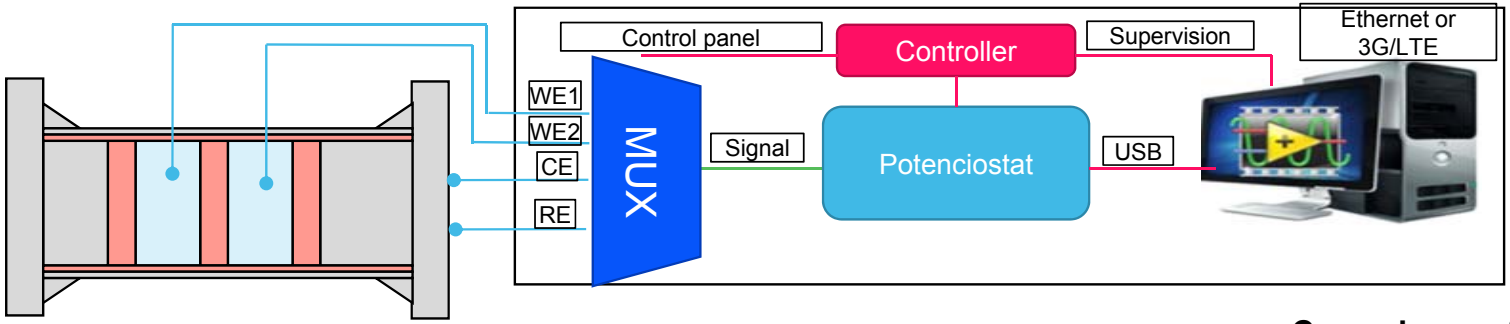


Fitting to an equivalent circuit model



Numerical simulation and analysis

R_p



Corrosion probe

Control unit

Corrosion performance by polarization resistance

Higher R_p values → better barrier properties of the coatings

Task 4.3 Hybrid CT demonstration: global KPI

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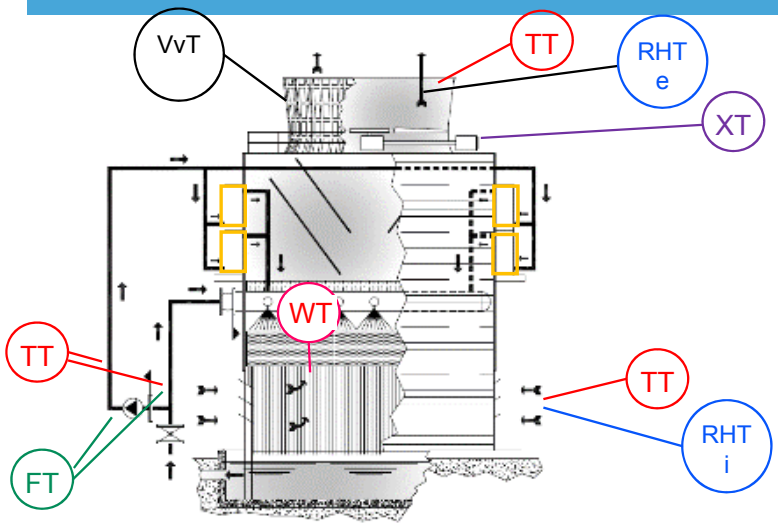
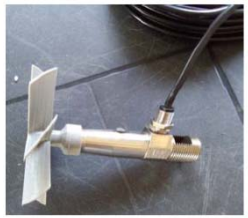


Hybrid configuration

Vs

Wet configuration



The worst accuracy measure deals with air mass flow rate.

$$\left(W_{out}^{water} * Cp^{water} * T_{out}^{water} - W_{in}^{water} * Cp^{water} * T_{in}^{water}\right) = W_{in}^{air} * h_{in}^{air}\left(H_r^{air}, T_{in}^{air}\right) - W_{out}^{air} * h_{out}^{air}\left(H_r^{air}, T_{out}^{air}\right)$$

$$Evaporation\ rate = W_{in}^{water} - W_{out}^{water} \cong W_{out}^{air} * \left[H_{a,out}^{air}\left(H_{r,out}^{air}, T_{out}^{air}\right) -, H_{a,in}^{air}\left(H_{r,in}^{air}, T_{in}^{air}\right)\right]$$

Too low accuracy in outlet water flow measurement

Task 4.3 Hybrid CT demonstration: global KPI

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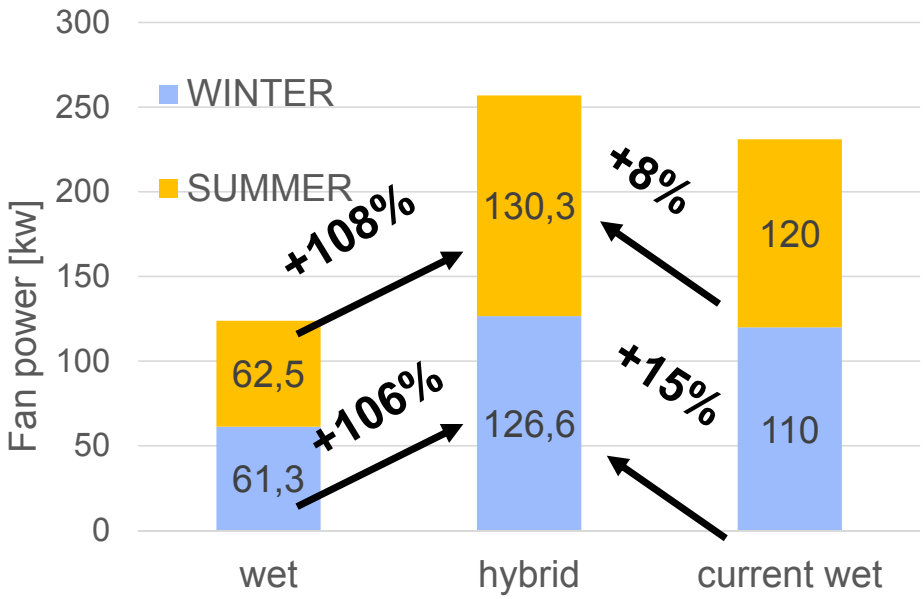
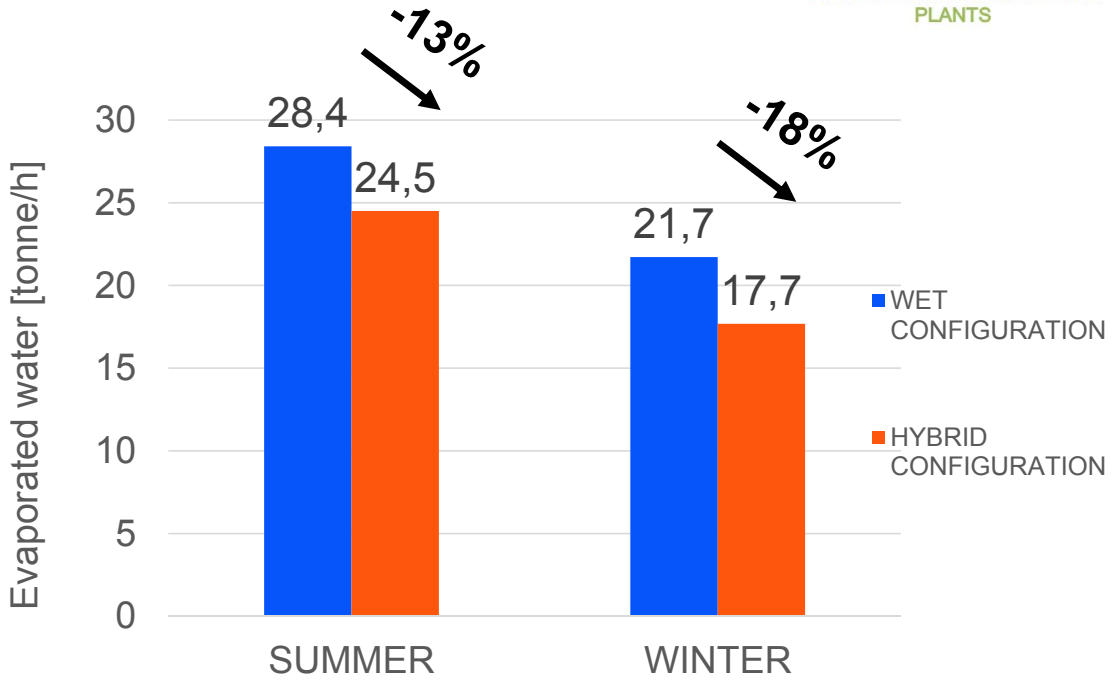
Expected performances

On the basis of simulations with ambient data the expected evaporation rate was calculated for summer and winter season.





A yearly estimation of evaporated water is going to be calculated by-means of historical data.

Task 4.3 Hybrid CT demonstration: positive side effect

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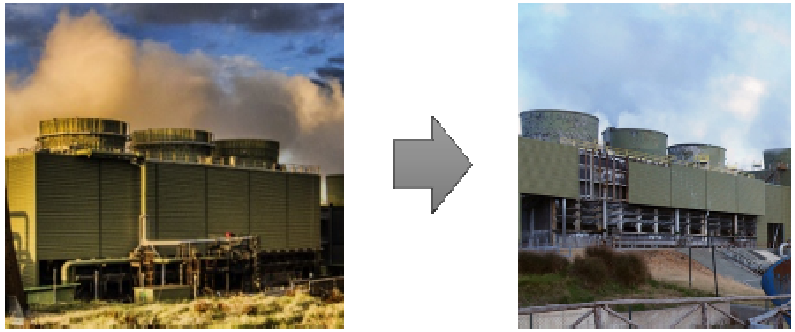
Side effect:

A positive side effect of the hybrid cooling tower retrofit is the avoidance of plume from the chimney. This effect is due because the thermodynamic state of the leaving air from the CT in under the saturation point.



The design of dry section heat exchanger is based on winter condition in order to avoid plume formation.

The design of wet section is based on summer condition in order to maximize plant efficiency.

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Thank you for your attention

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Backup

Task 4.3 Hybrid CT demonstration

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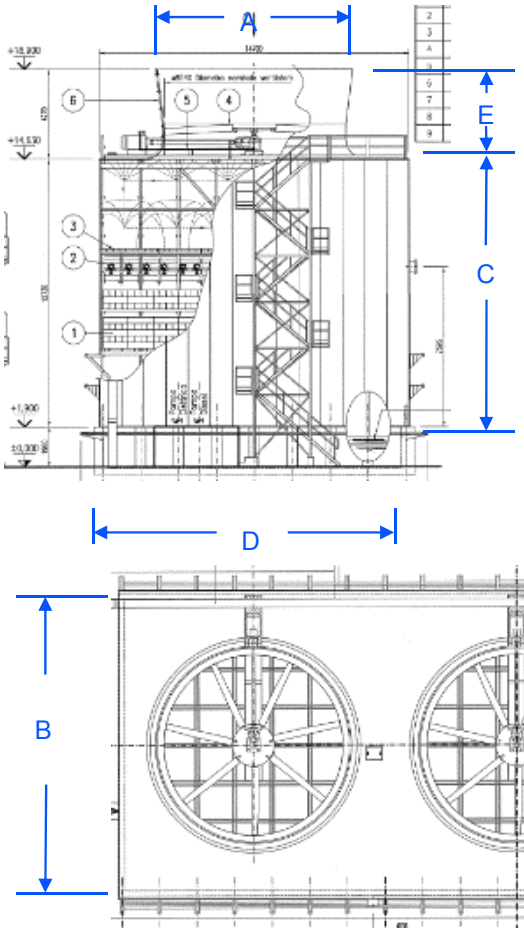
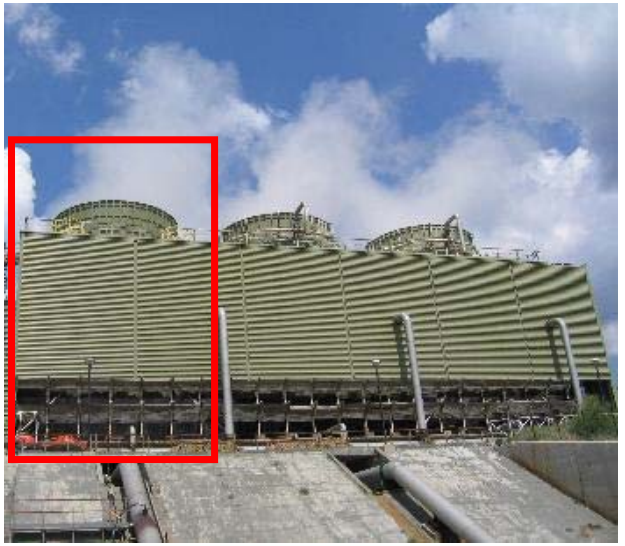
Actual engineering design data of existing wet cell



Cell construction data				
Fan diam.	*Lenght*	*Height*	*Width*	*Fan stack height*
A	B	C	D	E
8,54 m	*12,6*	*12,7 m*	*12,6 m*	*4,27 m*



Wet filling: splash				
Lenght	*Height*	*Width*	*Volume*	*Surface area*
12,6 m	*2,4*	*12,6 m*	*199 m^3*	*19.644 m^2*

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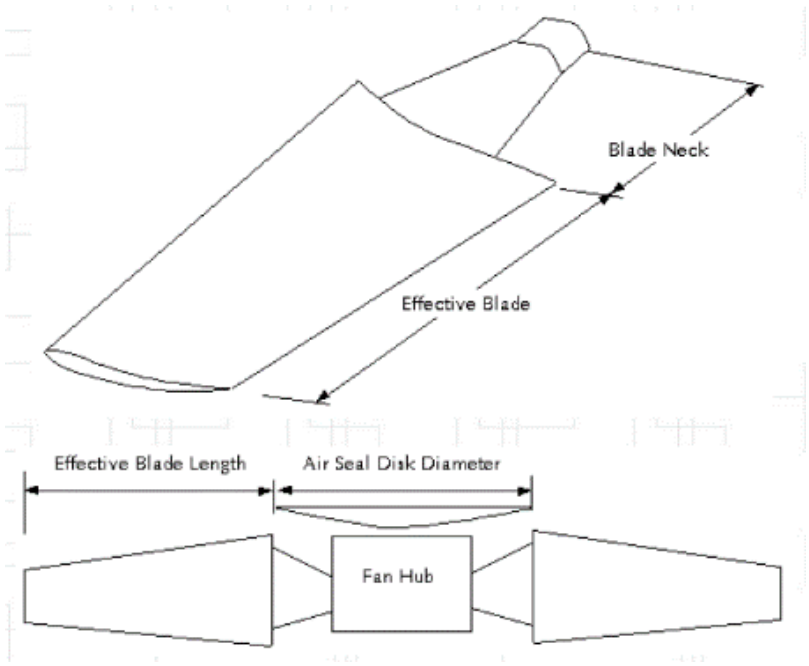
Fan characteristics

Fan characteristics		
Flow coeff.	*[-]*	*0,075*
Tip diameter	*[m]*	*8,54*
Hub diameter	*[m]*	*2,464*
RPM	*[RPM]*	*98*
Tip speed	*[m/s]*	*43,7*
Design axial air velocity	*[m/s]*	*9,487*
Angle tips	*[°]*	*14,9*
Static pressure at design point	*[mbar]*	*1,57*
Dynamic pressure at design point	*[mbar]*	*0,5105*
Design volume flow	*[Nm³/s]*	*472,2*
Fan electricity cons.at design point	*kW*	*145*



Task 4.2 DEMO Facility realization

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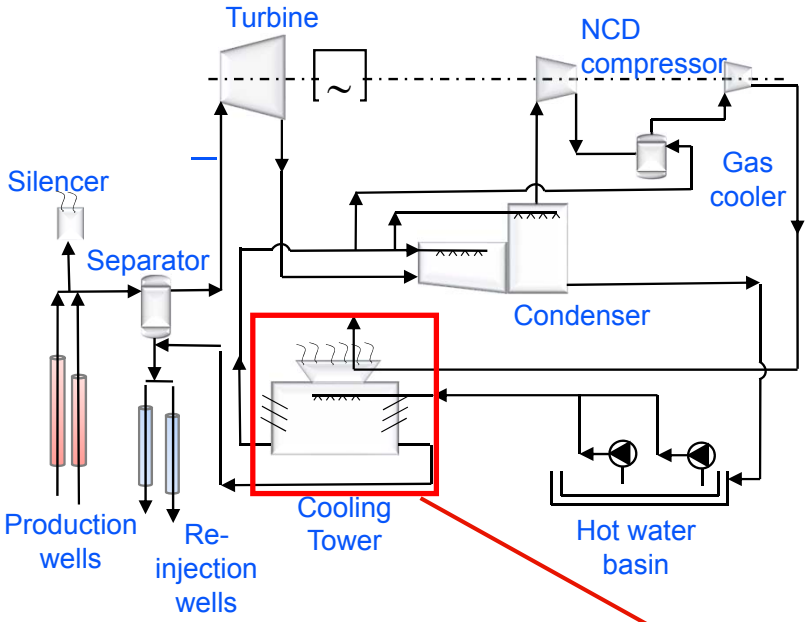
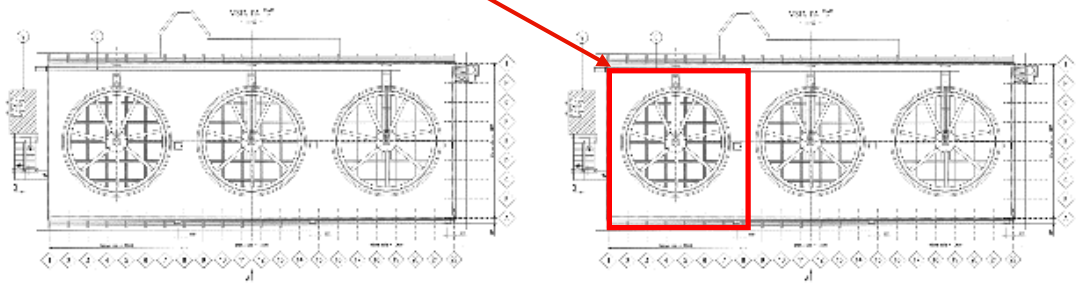


Main process data of Nuova San Martino power plant

- Consolidated Capacity: **40 MWe**
- Type of power plant: Dry Steam
- Cooling Tower (N°cells): **6**
- Cooling tower type: **Mechanical Induced draft counterflow**



3 Cells X 2 bay = 6 Cells

Task 4.2 DEMO Facility realization

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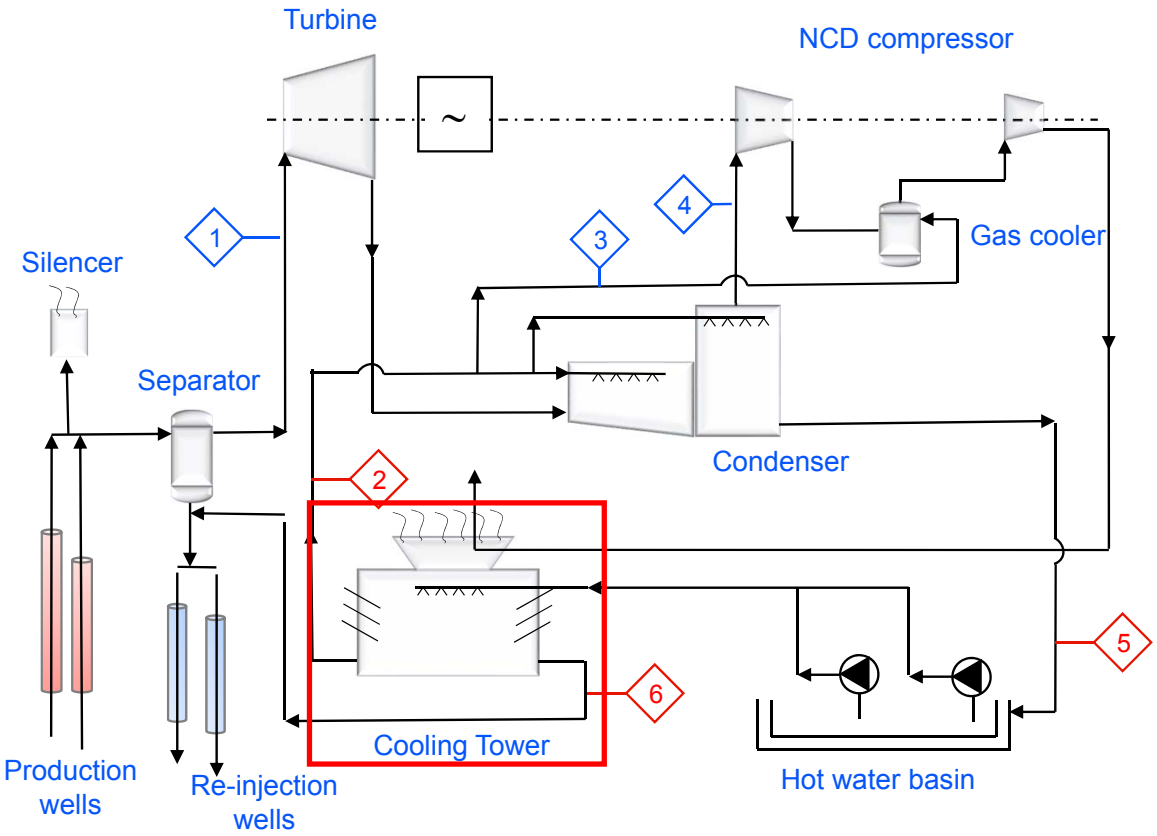
Actual process design data of Nuova San Martino (40 MW)



Process flow data							
Stream		**1**	**2**	**3**	**4**	**5**	**6**
Flow rate	*[t/h]*	*265*	*12.500*	*60*	*8,75*	*12.756*	*60*
Temperature	*[°C]*	*175*	*25*	*25*	*26*	*35*	*25*
Pressure	*[kPa]*	*850*	*100*	*100*	*6*	*100*	*100*
Enthalpy	*[kJ/kg]*	*2697*	*105*	*105*	*383*	*146*	*105*

Total evaporation = **196 tonne/h** over **12.756 tonne/h**

Task 4.2 DEMO Facility realization

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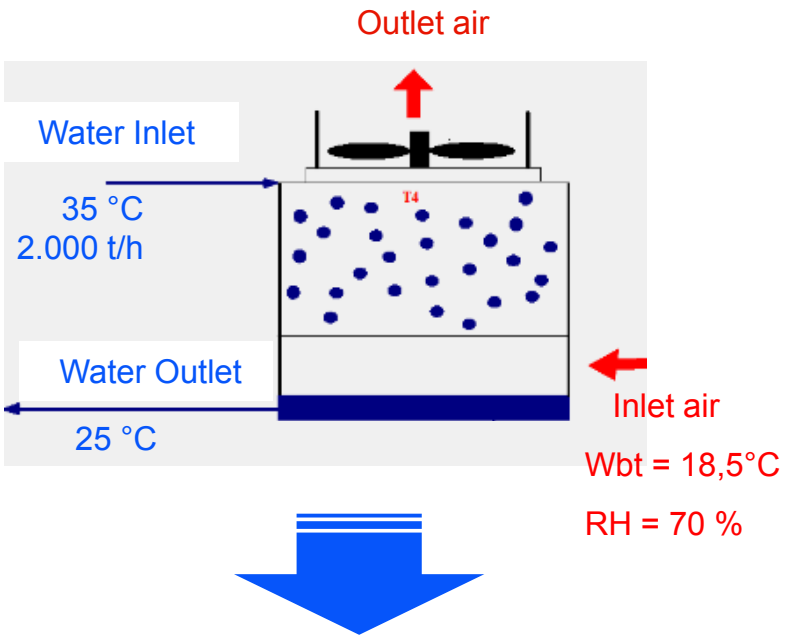
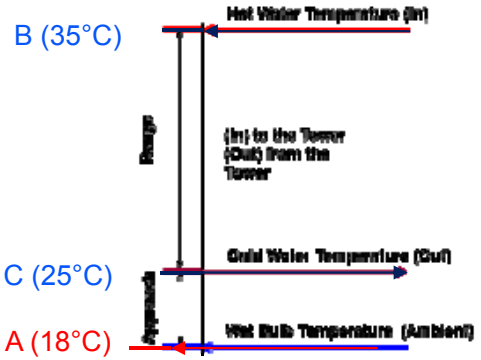
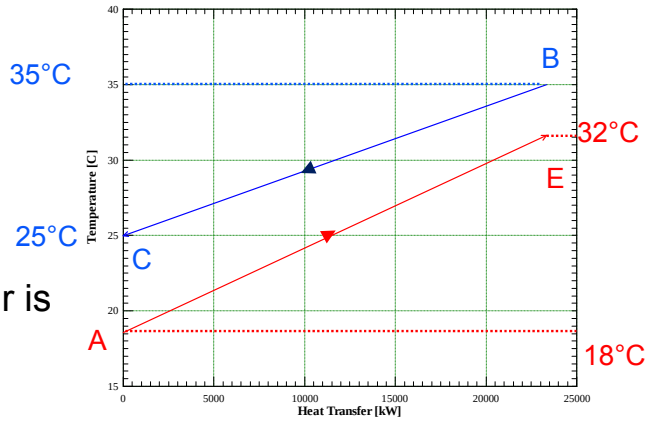
Process design data of STANDARD wet unit

- Water flow rate = 2.000 t/h
- Cold water approach = 6,5°C
- Range = 10°C
- Wet bulb temperature = 18°C
- Hot water tempertaure = 35°C
- Cold water temperature =25°C
- Relative humidity = 70%







The design heat load rejected from wet cooling tower is **23,1 MWt** and the evaporated water is **28 t/h**

Task 4.2 DEMO Facility realization

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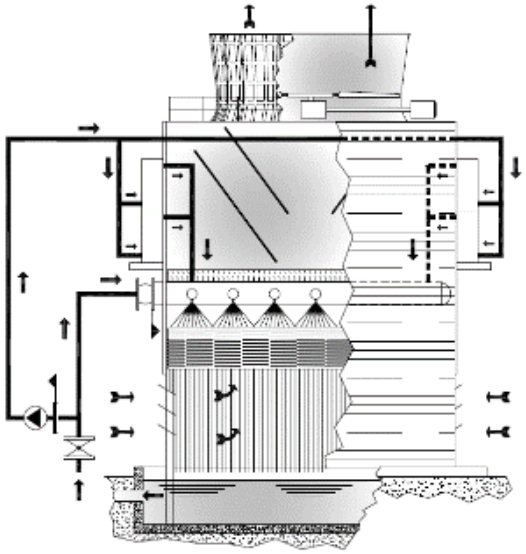
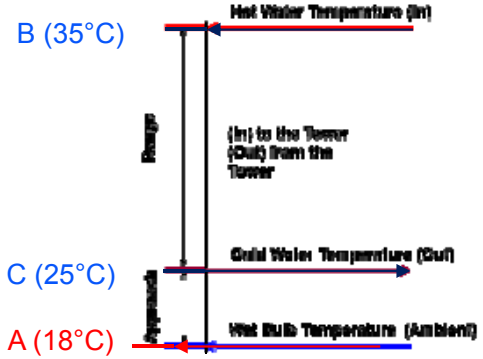
Hybrid design data

The design of new hybrid unit is based on current heat load demand and approach temperature difference.

The approach temperature difference depends on ambient temperature and humidy and the operation during season. So different design point were taken into account for wet configuration and hybrid configuration (dry section design).





Task 4.2 DEMO Facility realization

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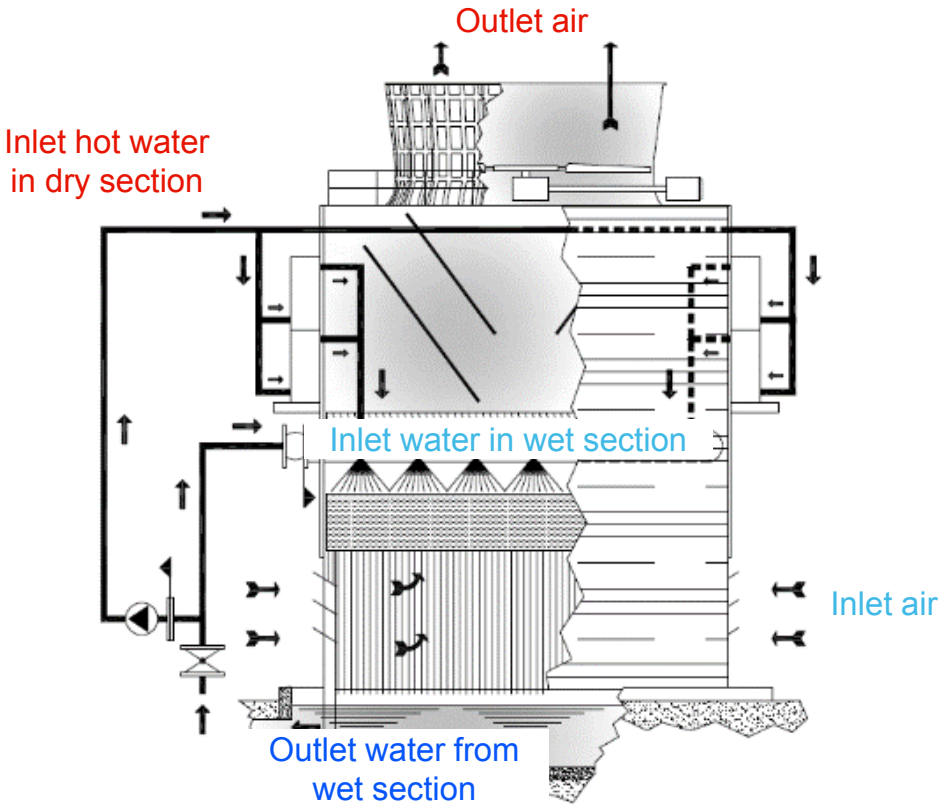
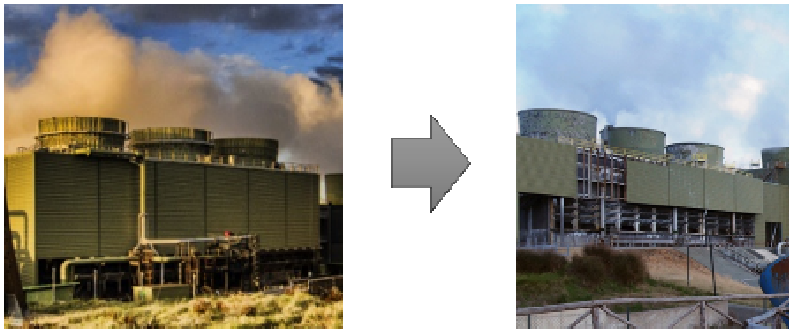
Hybrid configuration design data





The design of dry section heat exchanger is based on winter condition in order to avoid plume formation.

The design of wet section is based on summer condition in order to maximize plant efficiency.

Task 4.2 DEMO Facility realization

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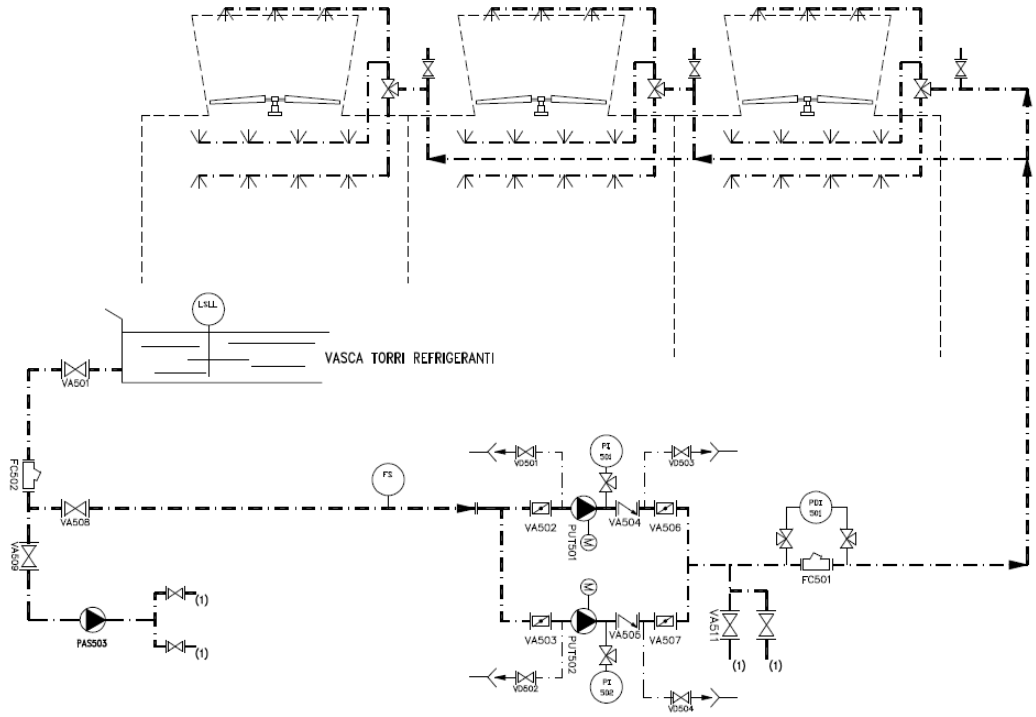
SCHEMA IMPIANTO DI UMIDIFICAZIONE TORRE REFRIGERANTE A TIRAGGIO INDOTTO



(1) ATTACCO PER MANICHETTA UNI 9487

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Thank you for your attention