Rev.	Description	Date	Prep.	Verif..	Construct	QA	Appr.
2	For design	09-02-17	VPY/PRG				FJV
1	For design	01-11-16	VPY/PRG	VFG			FJV
0	For approval	01-04-16	PRG	VFG	---	---	FJV

CLIENT:

الشركة السعودية للكهرباء
Saudi Electricity Company

DUBA GREEN INTEGRATED SOLAR COMBINED CYCLE POWER PLANT

CONSULTANT (OE´S):

TRACTEBEL Engineering
GDF SUEZ

CONTRACTOR:

INITEC Energía

S.S.E.M

TITLE:

SOLAR STEAM GENERATOR CALCULATION

Scale	Job Number	Ud	System	Disc	Document	Type	Doc.Orig	Doc nr.	Sheet Number	Free
NA	15071								001	
Size	Project								Num.of Sheets	Rev.
A4	D U B	0 4	W T B	B C			I E M	0 5 4	008	2

INDEX

1 OBJECT

The aim of this document is the presentation of the criteria, calculation methodology and results of the Solar Steam Generator engineering design.

2 BRIEF SYSTEM DESCRIPTION

The Solar Steam Generator (SSG) is comprised of two trains of 50% of capacity based on heat exchangers in series arrangement.

This system is in charge of heating up water from the Combined Cycle (CC), turning into steam and delivering superheated steam back to the CC. The energy proceeds from a heat transfer fluid (HTF) which is likewise heating up by means of the solar irradiation when it flows through a solar field. Therefore, HTF System is a closed circuit which only can transfer the heat collected to the water-steam cycle during sunny hours.

SSG trains are fed by water from CC Feedwater Pumps (BFW) and integrate its superheated steam with high pressure saturated steam coming from steam drum outlet of one or both Heat Recovery Steam Generators (HRSG). Each of the SSG trains counts with a steam by-pass station connected to the main Condenser (in GE scope).

3 DESIGN CRITERIA

The Solar Field Island (SFI) and thus the Solar Steam Generator System (SSG) have been sized in order to meet with Client's requirements as follows:

- ✓ SSG shall be able to deliver 100 thermal megawatts (MWt) at reference site conditions to the Combined Cycle.
- ✓ All Solar Balances cases provided by GE (operation conditions for inlet of BFW and for the outlet solar steam as a requirements for design).
- ✓ SSG will be able to provide more than 90% of the steam mass flow at least 950 hours per year according to the typical meteorological one.

This kind of solar heat integration did design the Solar Field and hence the SSG to be consistent.

Further, Combined Cycle H&M balances were taken into account to design a SSG system able to work in the required conditions and reaching the wished performance at every operating case.

Apart from the guaranteed cases, all H&M balances with SFI integration were assessed in order to find the sizing one (Thermoflex: *design mode)*. Regarding to meteorological data, GE Company H&M balances as gas turbines, steam turbine and HRSGs supplier, following cases were considered:

- H&M balance at RSC (nominal), corresponding to GE code CCA21139 means maximum summer site conditions.
- H&M balance at RSC (maximum flow), corresponding to GE code CCA21167.
- H&M balance at OP1 (nominal), corresponding to GE code CCA21137-OP1 means summer site conditions.
- H&M balance at OP2 (nominal), corresponding to GE code CCA21135-OP2 means spring and autumn site conditions.
- H&M balance at OP3 (nominal), corresponding to GE code CCA21133-OP3 means winter site conditions.

Moreover, partial loads at RSC nominal (means maximum summer site conditions) have been simulated for SFI performance as information purposes (Thermoflex: *off-design mode*):

- H&M balance at RSC (nominal) – Solar 100% : Solar Steam mass flow for HMBD calculation 100%
- H&M balance at RSC (nominal) – Solar 80% : Solar Steam mass flow for HMBD calculation 80%
- H&M balance at RSC (nominal) – Solar 60% : Solar Steam mass flow for HMBD calculation 60%
- H&M balance at RSC (nominal) – Solar 40% : Solar Steam mass flow for HMBD calculation 40%
- H&M balance at RSC (nominal) – Solar ≅30% : Solar Steam mass flow for HMBD calculation ≅30% (minimum HTF flow across solar field, 3.75kg/s per loop)

Additionally, it has been included another important case in order to evaluate the minimum solar steam flow (kg/s) that SFI could deliver to the cycle, in this case minimum ANI (winter site conditions): is taken into account (Thermoflex: *off-design mode*):

- H&M balance at min flow in winter site conditions (minimum HTF flow through SSG) – Solar 10%: Solar Steam mass flow for HMBD calculation 10%. Likewise, in order to guarantee minimum HTF flow across solar field the rest of the HTF flow will be bypassed.

4 CALCULATIONS

SSG equipment definition and sizing were carried out by using Thermoflex version 25.0 (belongs to Thermoflow software) as engineering tool.

Once Solar Field configuration was set up, based on feedwater conditions and steam production, heat exchangers shell and tubes type were selected resulting two trains consisted each one of economizer/preheater, evaporator and superheater.

According to Best Engineering Practices and in order to achieve the commitment between optimum technical efficiency and the feasible proposal from the economical point of view, these are the design parameters taken into account:

- Evaporator Level control valves were located at Economizer/Preheater outlet in order to prevent water from steaming in tube side of this equipment.
- Minimum pinch point allowed at Evaporator: 3 ºC.
- Minimum approach temperature at Superheater: 8 ºC.
- It was looked for taking advantage of the whole HTF temperature increasing at Solar Field, i.e.: trying to transfer the almost 100 ºC to the water-steam cycle.
- Proper pressure drop values across pipelines and heat exchangers were considered according to Mechanical and Process Design Criteria of the Project (DUB-04-T-MR-IEM-004).
- Despite of 1% blowdown of the water mass flow which enters in each SSG train during normal operation, no blowdown is considered when performance tests.
- Fouling factors and other mechanical characteristics according to SSG Technical Specification (DUB-04-LB-MI-IEM-457).
- Thermal losses have been considered 1% in equipment, 2 kJ/kg for water/steam lines and 3 kJ/kg for HTF lines .
- Dowtherm A has been considered as heat transfer fluid.
- Pressure drop in equipment is according SSG Technical Specification (DUB-04-LB-MI-IEM-457), and taking into account the fitting in the pressure drop of the control valve in the inlet of the kettle.
- Design Balance cases simulated by Thermoflex software have been checked by Steam Generation System supplier (own supplier´s software): CCA21139-RSC nominal, CCA21167-RSC max flow, CCA21137-OP1, CCA21135-OP2, CCA21133-OP3

5 RESULTS

After simulating all cases mentioned above, it was concluded that H&M balance RSC (nominal), corresponding to GE code CCA21139 was actually the design one. Clearly, the Solar Steam Generator System complies with all guaranteed cases.

Results are shown in Annex I. The information included in these H&M balances were used to fill in the SSG related equipment Data Sheets (DUB-04-LB-MH-IEM-457).

On the other hand as an informative purposes for the performance test, they are included an examples of partial load cases for the Steam Generation from 100% to minimum HTF flow 10% in Annex II.

6 REFERENCES

- GE Heat balances: CCA21139, CCA21137, CCA21135, CCA21133 and CCA21167.
- Mechanical and Process Design Criteria: DUB-04-T-MR-IEM-004
- SSG Technical Specification: DUB-04-LB-MI-IEM-457
- SSG Data Sheets: DUB-04-LB-MH-IEM-457
- SSG Data Sheets (from supplier): DUB-04-HAC/HAD/HAH-MH-AFW-001
- Heat balances (from supplier): DUB-04-VAC-MC-AFW-002

7 ANNEX

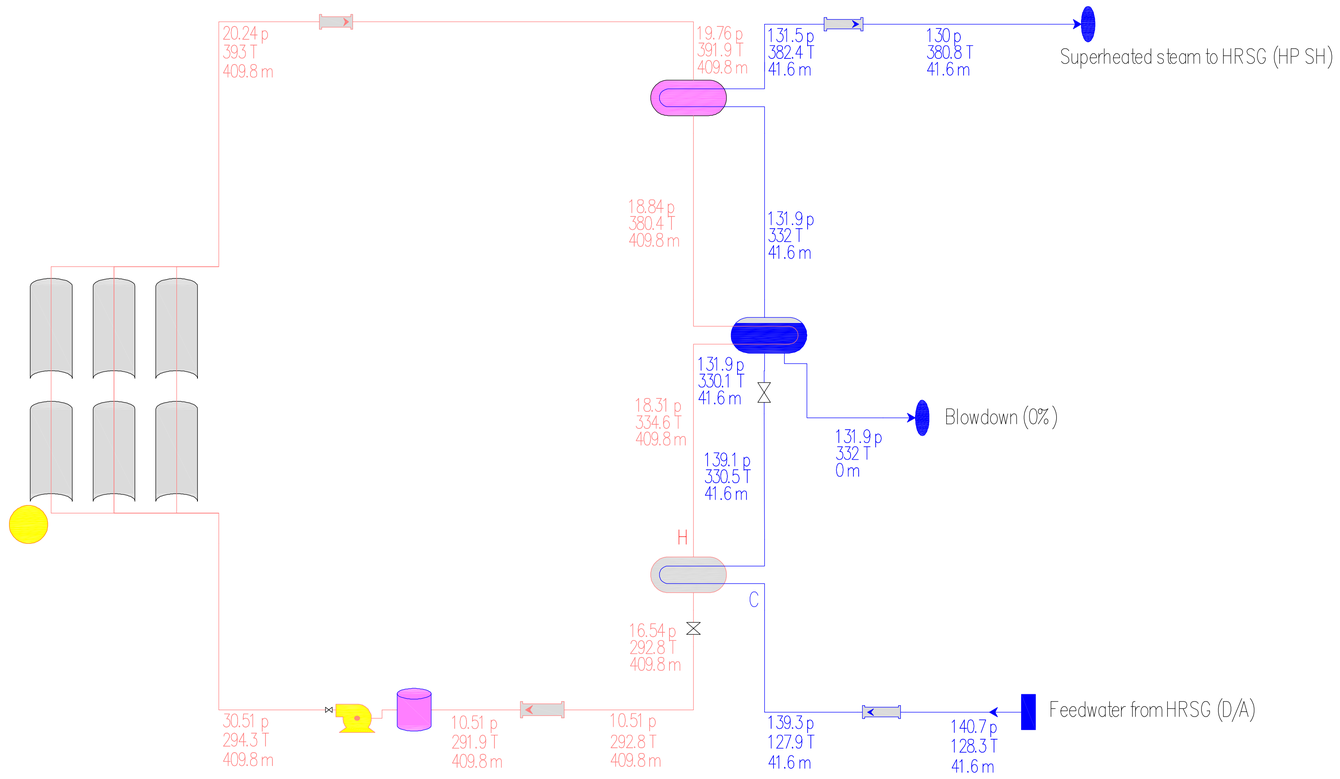
- ANNEX I: H&M balances for SSG design
- ANNEX II: H&M balances for SSG partial loads

ANNEX_I

bar | C
kg/s | kJ/kg

Duba Green – H&M balance at RSC nominal (21139)

Ambient temperature	45 C
Ambient relative humidity	30 %
Number of existing flow paths	31
Net heat absorbed by field	100995 kW
Aperture normal direct irradiance	800 W/m2



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CONSULTANT (DE'S)

TRACTEBEL Engineering
GDF SUEZ

CONTRACTOR

INITEC Energía

s.s.e.m.

TITLE

DUBA GREEN – H&M BALANCE AT RSC NOMINAL (21139)

SUPPLIER LOGO

INITEC Energía

Scale	Job number	Unit	System	Discipline	Document	Type	Doc. Orig.	Doc. nº	Sheet Number	Free
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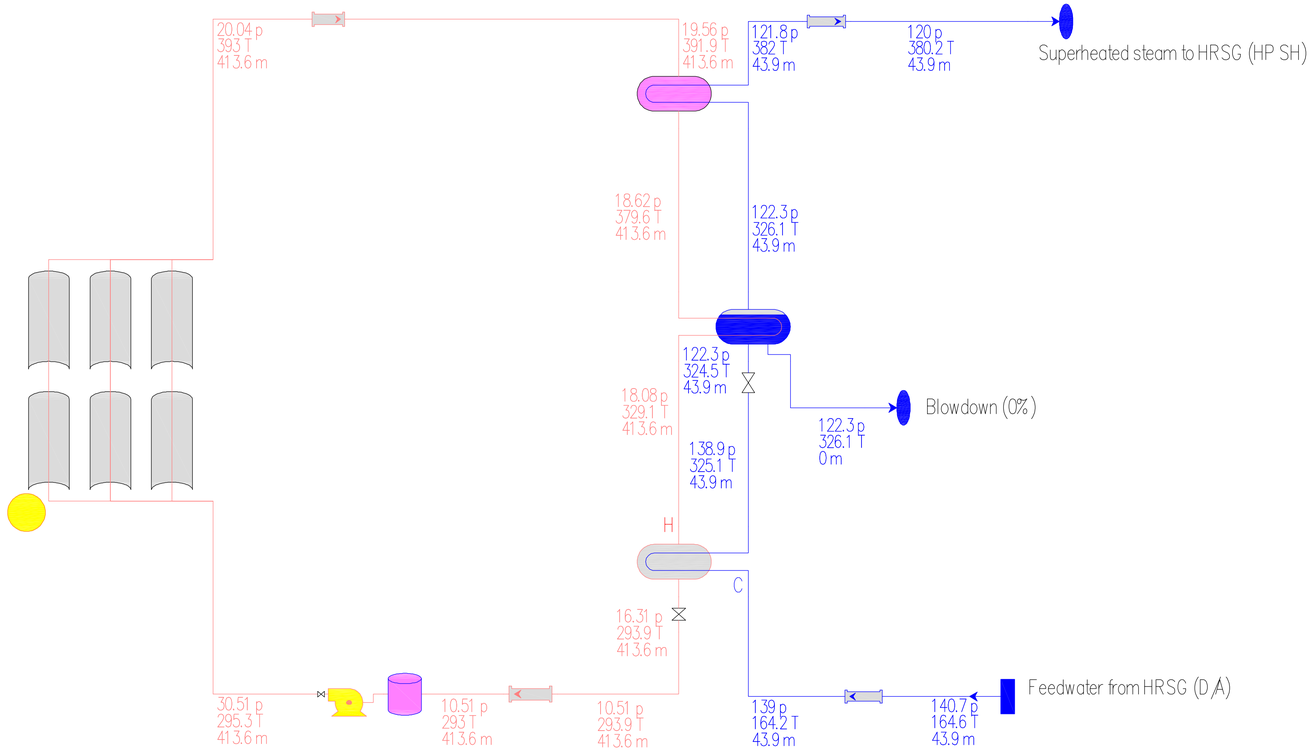
Size	Project								Num.of Sheets	Rev.
A1	DUB	U U	A A A	T	T	T	I E M	N N N	0 0 0	r

DIN A1 (841 x 594)

bar | C
kg/s | kJ/kg

Duba Green – H&M balance at RSC and max. flow (21167)

Ambient temperature	45 C
Ambient relative humidity	30 %
Number of existing flow paths	31
Net heat absorbed by field	100915 kW
Aperture normal direct irradiance	800 W/m2



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DUBA GREEN INTEGRATED SOLAR COMBINED CYCLE POWER PLANT

CONSULTANT (DE'S)

TRACTEBEL Engineering
GDF SUEZ

CONTRACTOR

INITEC Energía

S.S.E.M.

TITLE

DUBA GREEN – H&M BALANCE AT RSC MAX. FLOW (21167)

SUPPLIER LOGO

INITEC Energía

Scale	Job number	Unit	System	Discipline	Document	Type	Doc. Orig.	Doc. nº	Sheet Number	Free
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Size	Project								Num.of Sheets	Rev.
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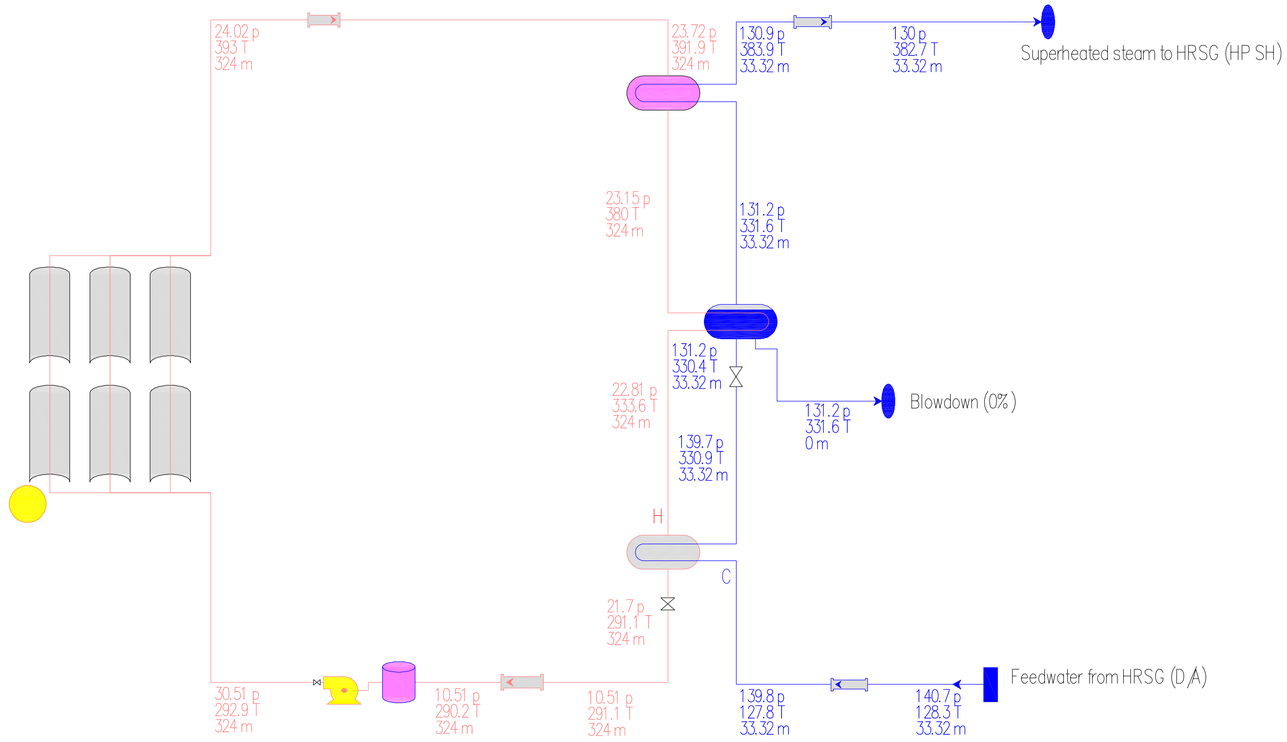
bar | C
kg/s | kJ/kg

Duba Green – H&M balance at OP1 nominal (21137)

Ambient temperature	34 C
Ambient relative humidity	37 %
Number of existing flow paths	31
Net heat absorbed by field	80933 kW
Aperture normal direct irradiance	791 W/m2



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CONSULTANT (DE'S)

TRACTEBEL Engineering
GDF SUEZ

CONTRACTOR

INITEC Energía

S.S.E.M.

TITLE

DUBA GREEN – H&M BALANCE AT OP1 NOMINAL (21137)

SUPPLIER LOGO	Scale	Job number	Unit	System	Discipline	Document	Type	Doc. Orig.	Doc. nº	Sheet Number	Free
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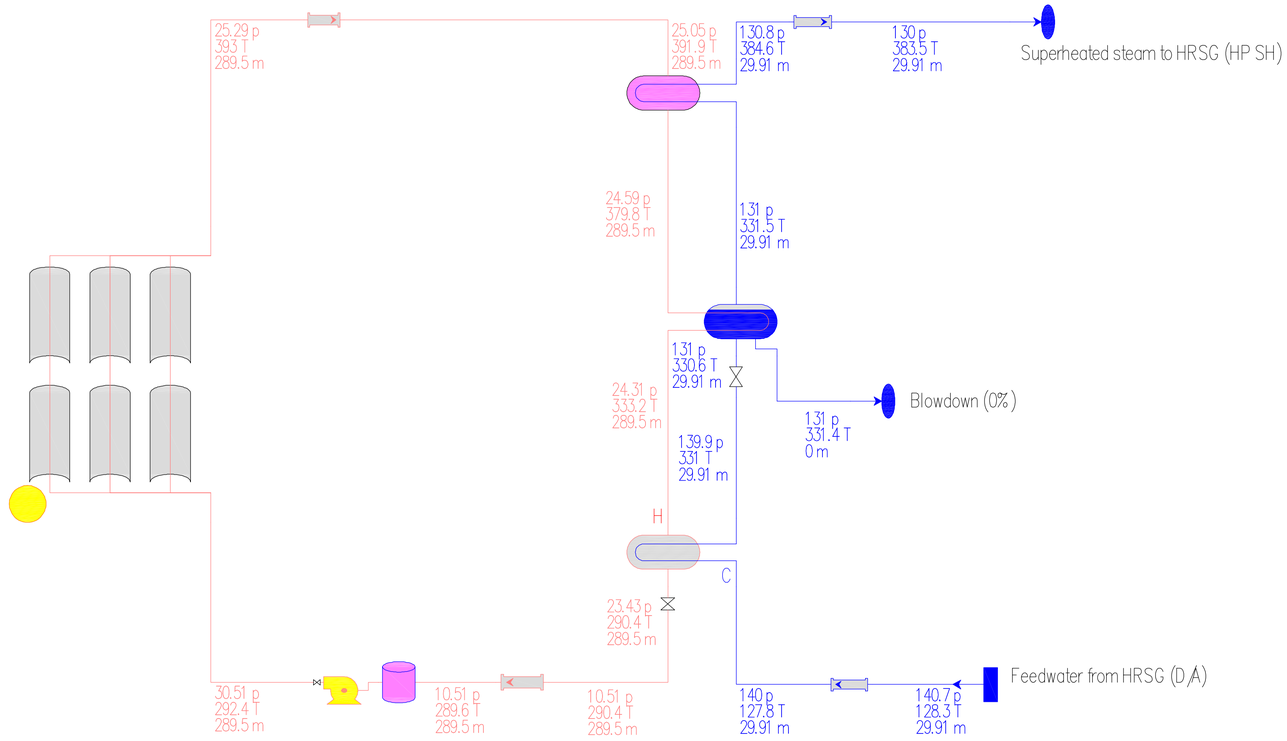
	A1	DUB	U U	A A A	T	T	T	I E M	N N N	0 0 0	r

DIN A1 (841 x 594)

bar | C
kg/s | kJ/kg

Duba Green – H&M balance at OP2 nominal (21135)

Ambient temperature	29 C
Ambient relative humidity	38 %
Number of existing flow paths	31
Net heat absorbed by field	72618 kW
Aperture normal direct irradiance	757 W/m2



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CONSULTANT (DE'S)

TRACTEBEL Engineering
GDF SUEZ

CONTRACTOR

INITEC Energía

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TITLE

DUBA GREEN – H&M BALANCE AT OP2 NOMINAL (21135)

SUPPLIER LOGO	Scale	Job number	Unit	System	Discipline	Document	Type	Doc. Orig.	Doc. nº	Sheet Number	Free
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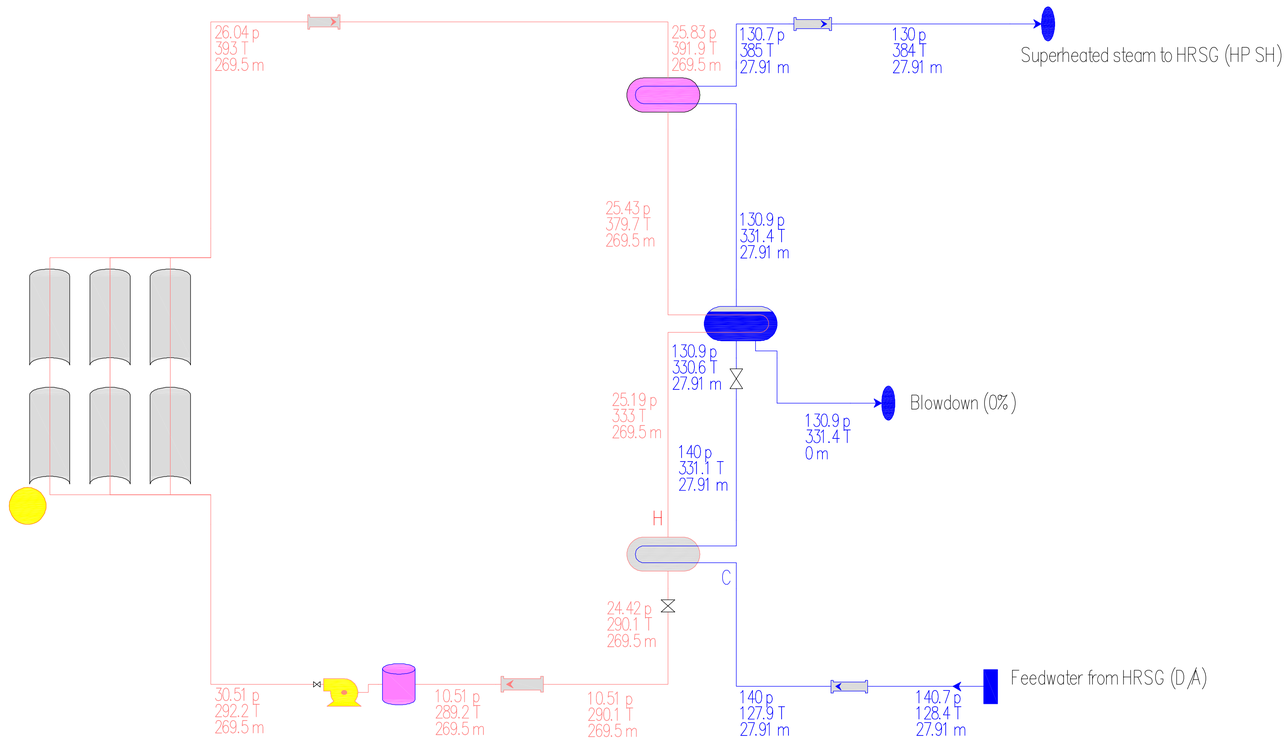
DIN A1 (841 x 594)

bar | C
kg/s | kJ/kg

Duba Green – H&M balance at OP3 nominal (21133)

Ambient temperature	21 C
Ambient relative humidity	39 %
Number of existing flow paths	31
Net heat absorbed by field	67721 kW
Aperture normal direct irradiance	560 W/m2



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CONSULTANT (DE'S)

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INITEC Energía

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TITLE

DUBA GREEN – H&M BALANCE AT OP3 NOMINAL (21133)

SUPPLIER LOGO

INITEC Energía

Scale	Job number	Unit	System	Discipline	Document Type	Doc. Orig.	Doc. nº	Sheet Number	Free
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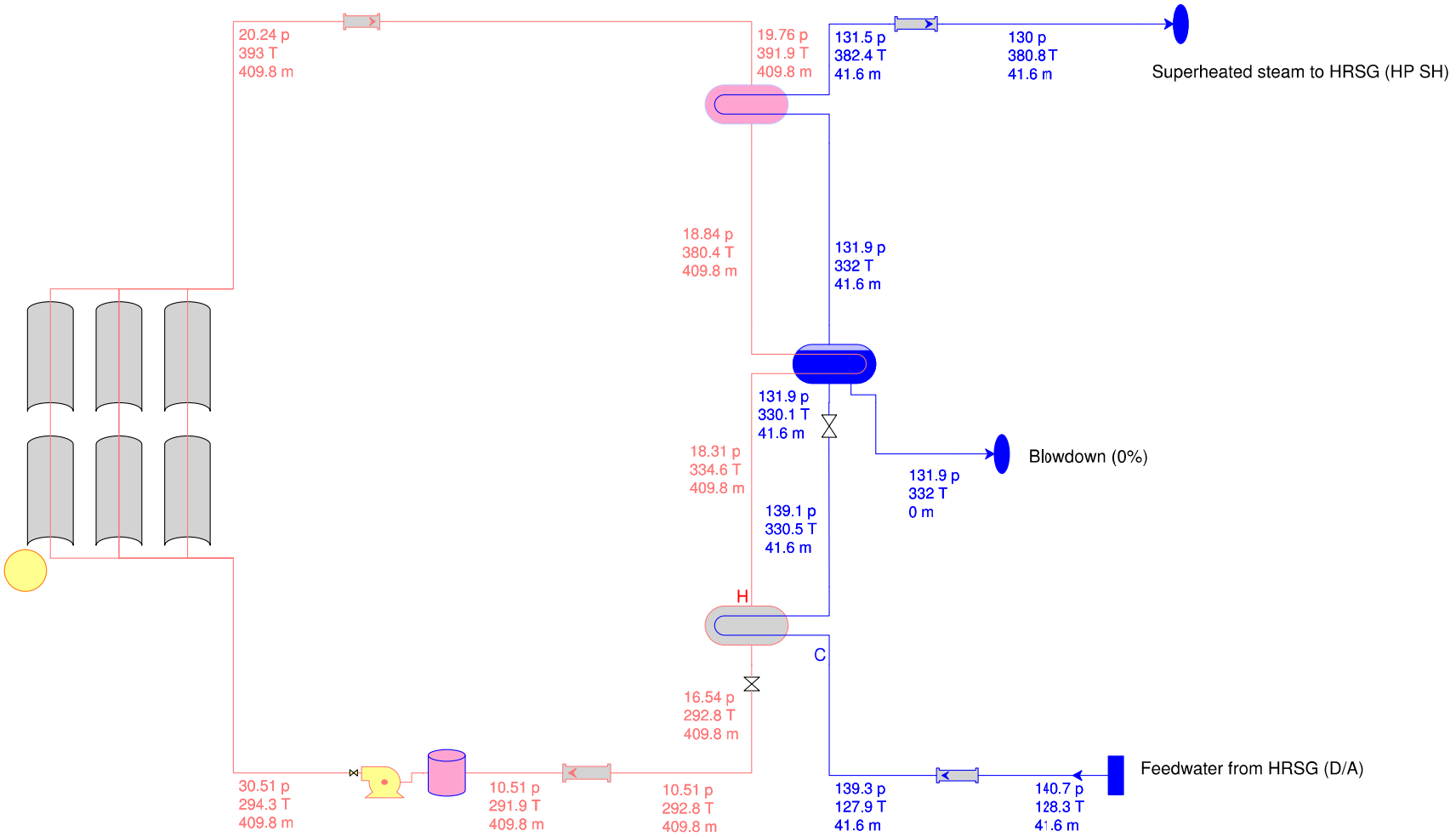
ANNEX_II

Duba Green - H&M balance at RSC nominal (21139)

Solar_100%

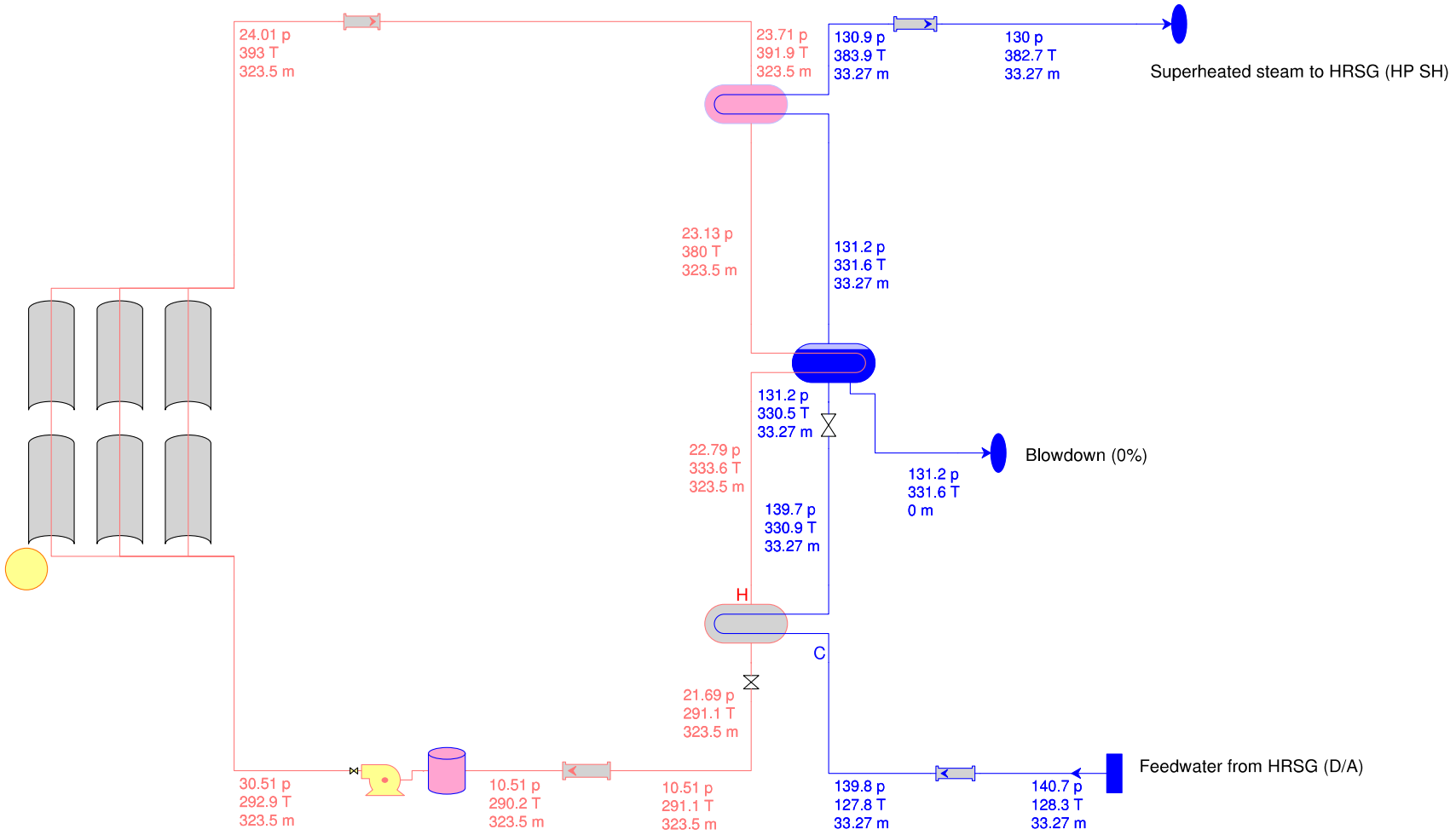
Ambient temperature	45 C
Ambient relative humidity	30 %
Number of existing flow paths	31
Net heat absorbed by field	100995 kW
Aperture normal direct irradiance	800 W/m^2



Duba Green - H&M balance at RSC nominal

Solar_80%

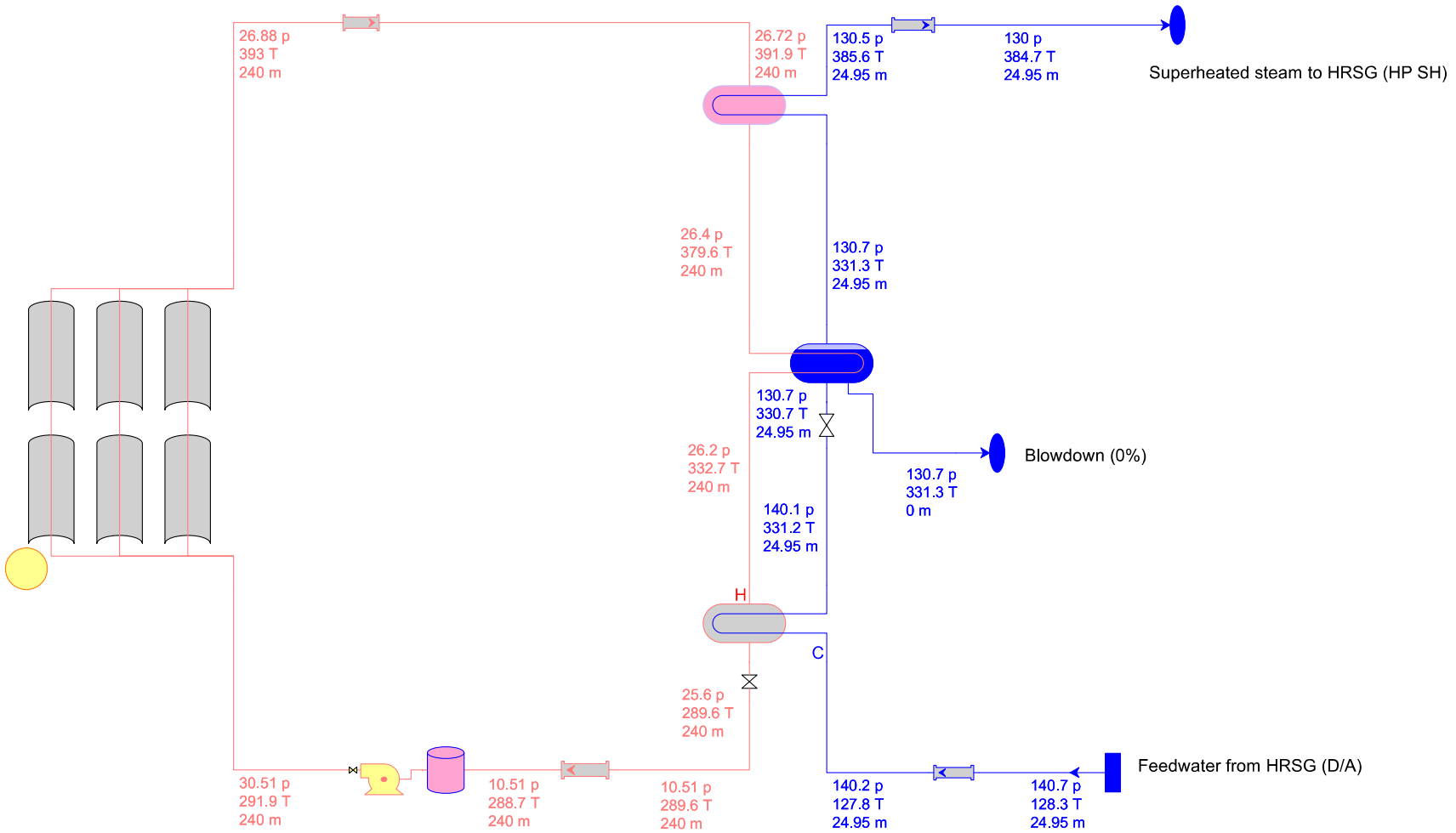
Ambient temperature	45 C
Ambient relative humidity	30 %
Number of existing flow paths	31
Net heat absorbed by field	80815 kW
Aperture normal direct irradiance	800 W/m^2



Duba Green - H&M balance at RSC nominal

Solar_60%

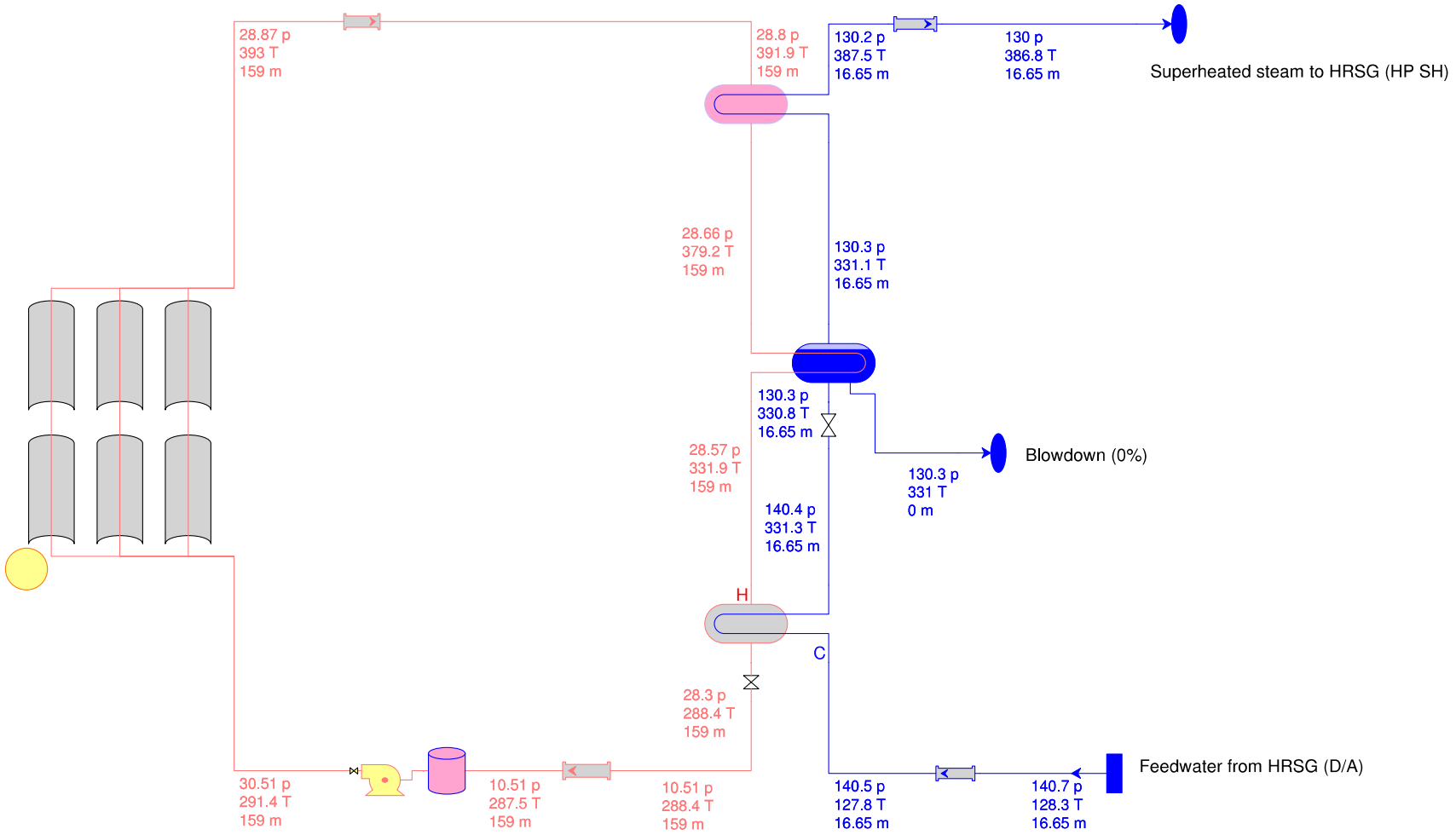
Ambient temperature	45 C
Ambient relative humidity	30 %
Number of existing flow paths	31
Net heat absorbed by field	60499 kW
Aperture normal direct irradiance	800 W/m^2



Duba Green - H&M balance at RSC nominal

Solar_40%

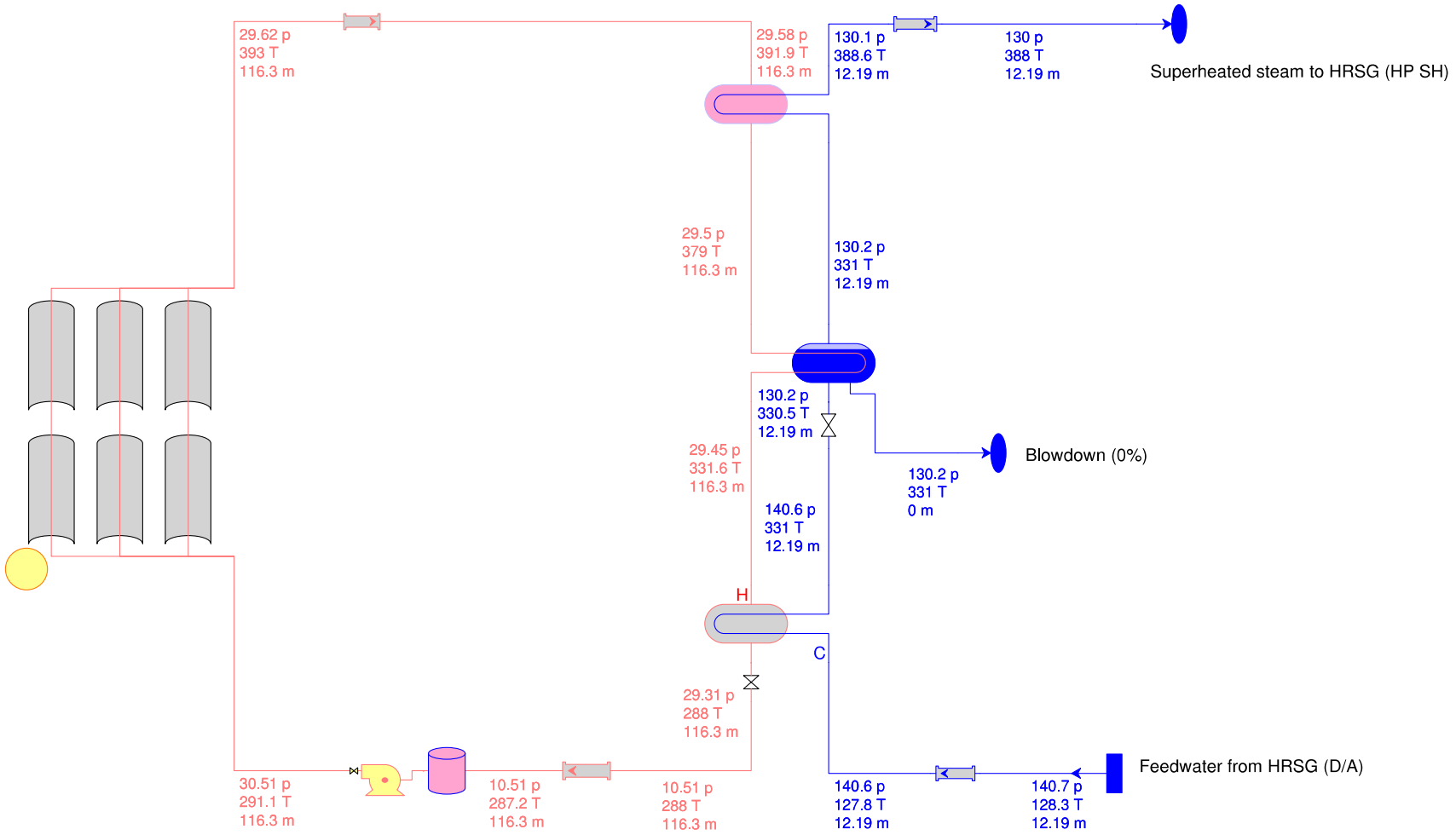
Ambient temperature	45 C
Ambient relative humidity	30 %
Number of existing flow paths	31
Net heat absorbed by field	40269 kW
Aperture normal direct irradiance	800 W/m^2



Duba Green - H&M balance at RSC nominal

Solar_30%

Ambient temperature	45 C
Ambient relative humidity	30 %
Number of existing flow paths	31
Net heat absorbed by field	29533 kW
Aperture normal direct irradiance	800 W/m^2



Duba Green - H&M balance MIN MIN FLOW 130bara Solar_10%

Ambient temperature	21 C
Ambient relative humidity	39 %
Number of existing flow paths	31
Net heat absorbed	11011 kW
Aperture normal direct irradiance	560 W/m^2