MinWaterCSP

Minimized water consumption in CSP plants

Deluge heat exchanger concept tests

WP 8, Deliverable 8.2

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Document History

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Date	Version	Person/Partner	Comments
17/09/2018	REV00	Francois Louw (Kelvion Thermal Solutions)	Construction and commissioning completed

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Table of Contents

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1 Introduction

As part of the present EU funded MinWaterCSP project, a hybrid (dry/wet) condenser system is being researched. This system can be used in conjunction with forced/induced draft air-cooled heat exchangers (ACHEs) as depicted in figure 1.1. The condenser system would typically consist of an axial flow fan in forced or induced draft configuration together with a delugeable (bare tube) bundle assembly. Dry operation of the deluge bundle (similar to air-cooled condensers in general) could typically occur when the cooling system is operated under design conditions, alternatively the fans of deluge cells could be turned off when the system operates at lower ambient temperature, in order to reduce auxiliary power consumption. Wet operation would be employed by means of deluging the bare tube bundles forming part of the deluge cell, under adverse operating conditions (such as windy periods or high ambient temperatures). Bearing the aridness of typical CSP locations in mind, together with the necessity for power station owners to have electricity production as high as possible, this technology is ideally suited for cooling in CSP plants for the following reason: It consumes at least an order of magnitude less water compared to typical wet-cooling systems, while possibly increasing nett power output up to approximately 2 % on a yearly basis compared to dry-only systems.

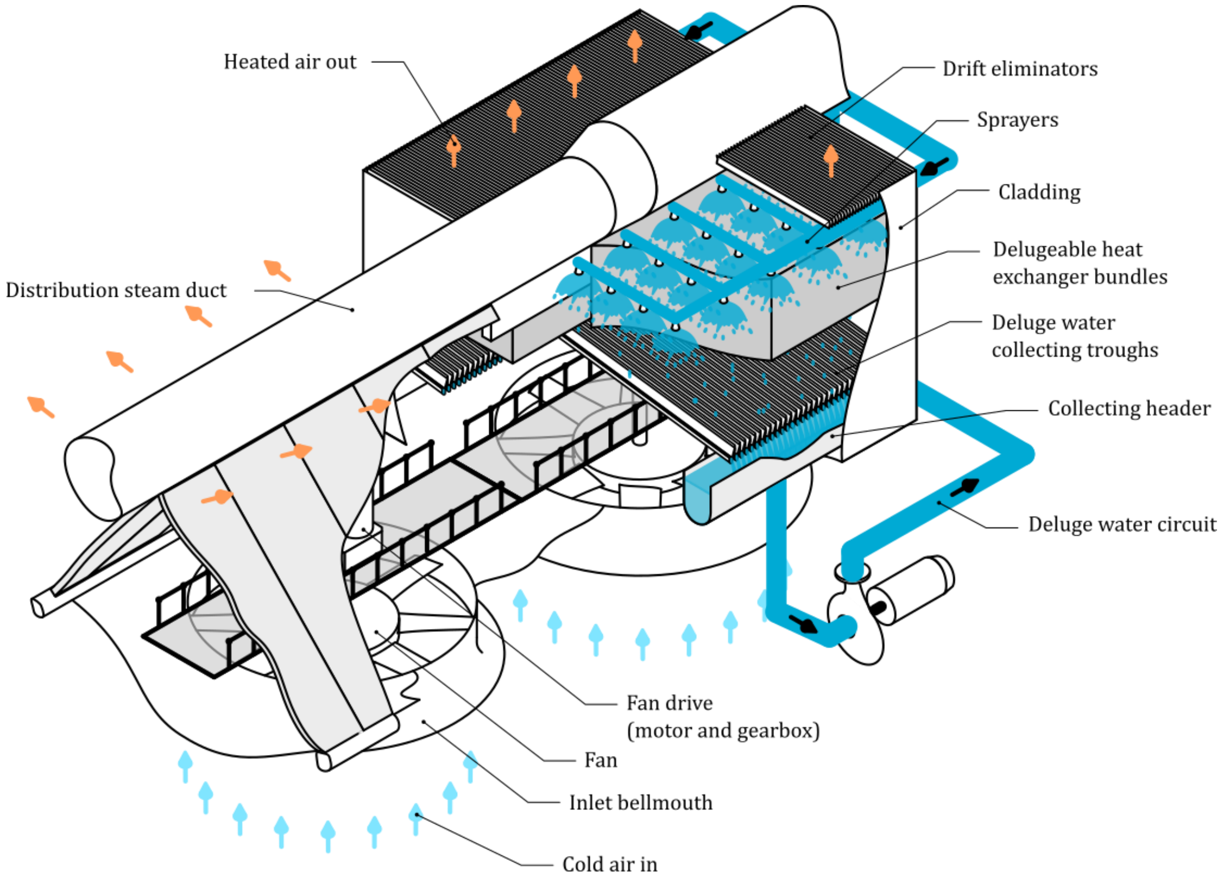

Figure 1.1: Deluge condenser cell in direct connection to an ACHE cell

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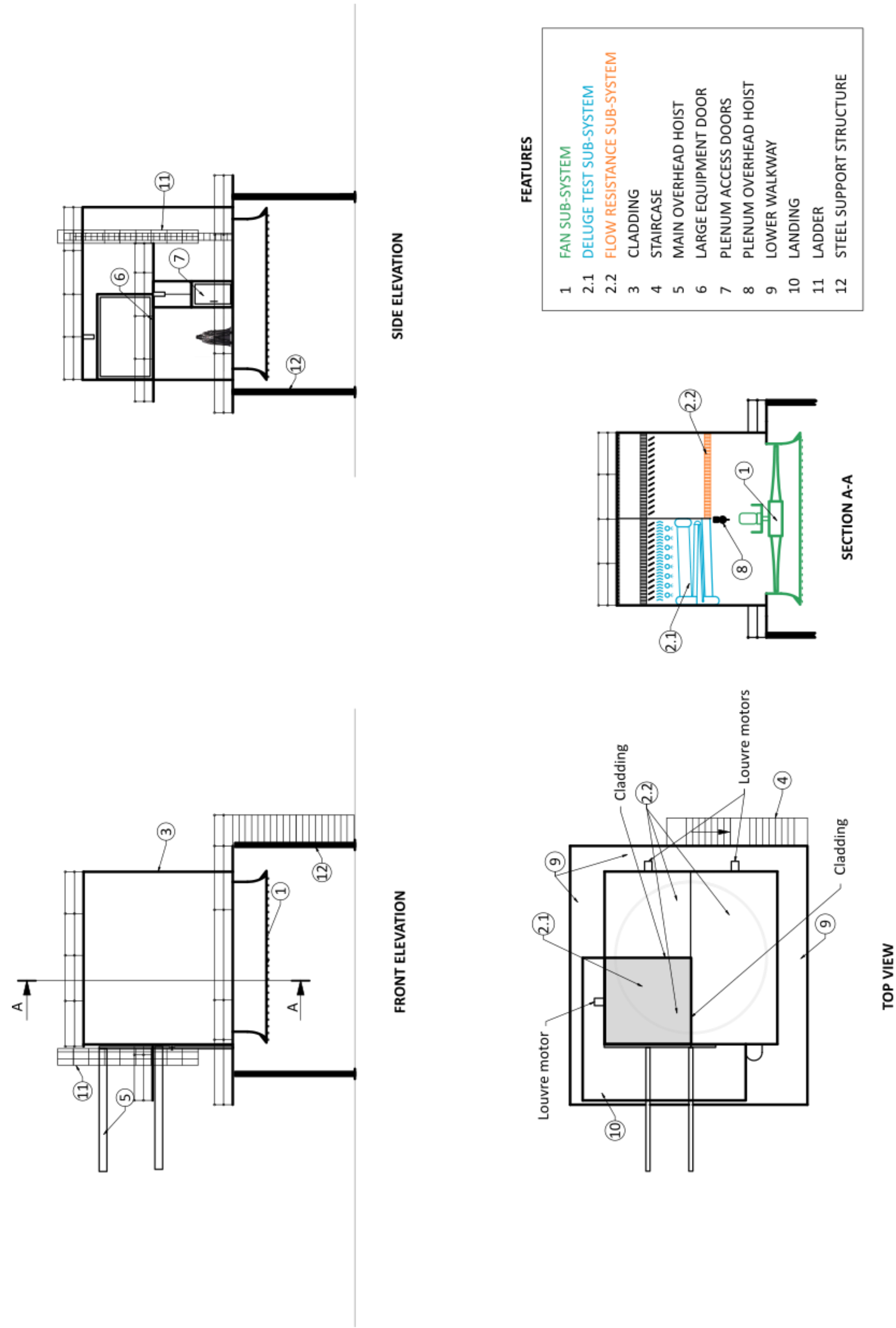

Figure 1.2: MinWaterCSP WP8 Full scale test facility schematic

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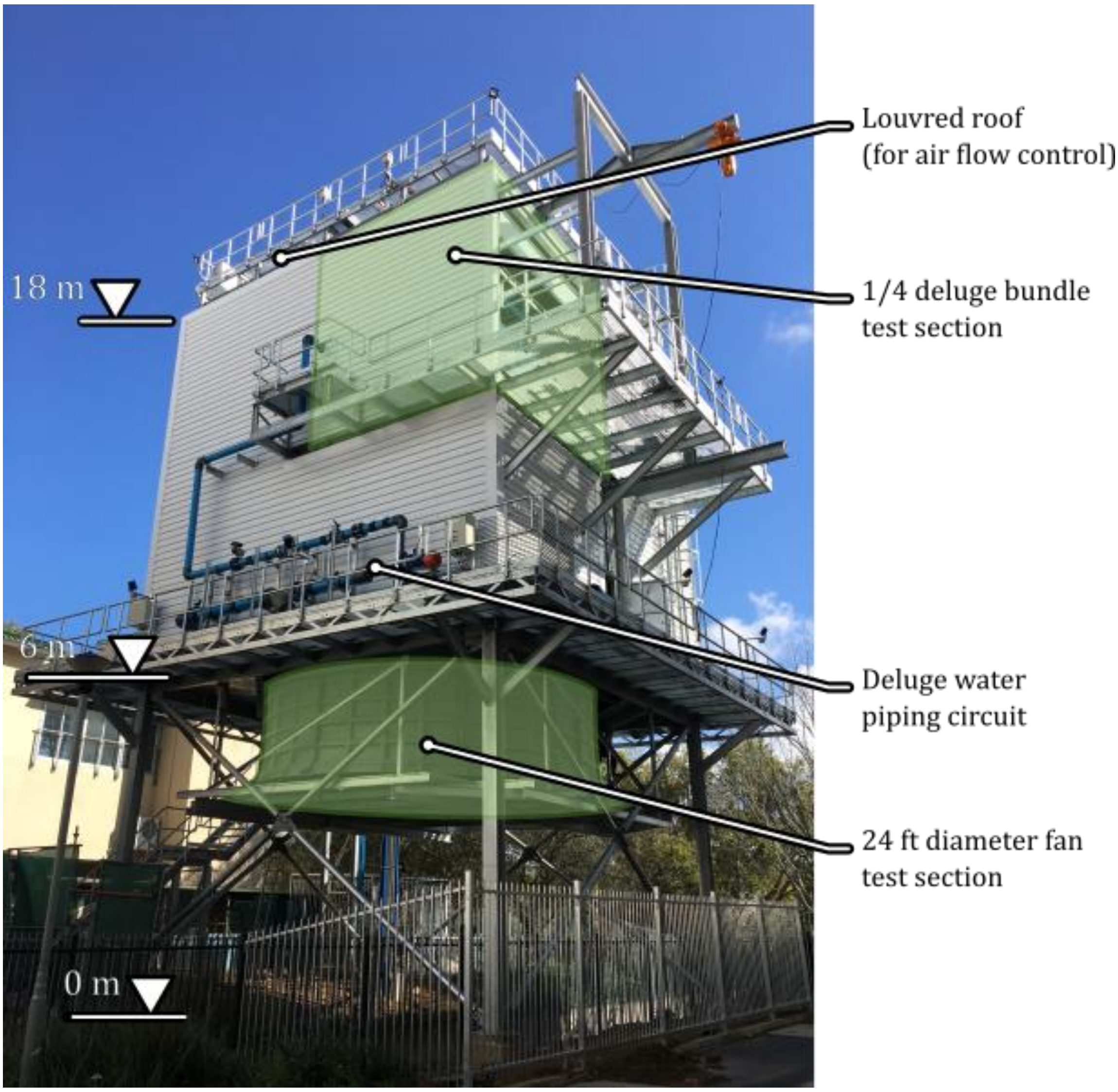

Figure 1.3: MinWaterCSP WP8 Full scale test facility completed

For validation and testing purposes, a full scale test facility (shown schematically in figure 1.2 and the final product in figure 1.3) together with an adjacent control room and pump block were constructed at Stellenbosch University, (Stellenbosch, South Africa) to investigate the two main sub-systems forming part of the delugeable condenser system. These are:

- Deluge water circulation loop testing: This includes the bundle components being drift eliminators, sprayers, a bare tube bundle, droplet recollection system, recirculation pumps, piping and instrumentation. No heat transfer will be conducted, but only the functionality of the water- and air-sides of the heat exchanger be tested and demonstrated.

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- Custom designed large cooling fan testing: This includes construction and testing of the newly developed a 24 ft, (7.3 m) CSP fan (designed by SUN in work package 3) at full scale.

1.1 Motivation for deluge testing

With the advantages of the deluge system already described, the main motivation for a full scale installation is to overcome the challenges and demonstrate the functionality of a system at such a scale. The following aspects are of interest and will be investigated:

1. Water collection effectiveness, here this effectiveness is the ratio between recollected and pumped water.
2. Pressure drop correlations over the collection trough and bundle components for a range of deluge water and air-flow rates.
3. Water distribution inside the system to gain insight into the wetting effectiveness throughout the tube bundle.

1.2 Motivation for large axial fan testing

The requirement for full scale fan testing, originates from uncertainties around:

1. Blade vibrational characteristics under various loading conditions, which differs as a function of the air flow rate.
2. Fan scaling effects, which cannot be considered at scale model level. Normally axial fans are aerodynamically tested for performance in a standardized test facility at scale level (typically 1.5 m in diameter). These performance results are scaled through turbomachinery scaling laws, but do not account for effects such as the change in Reynolds number.

For this reason full scale testing could provide valuable insights to research and verify fan vibrational, fatigue and aerodynamic performance characteristics.

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2 Test section commissioning

The present document confirms that construction and commissioning of both the fan and deluge test sections have been obtained. Both are discussed in subsequent subsections hereafter.

2.1 Deluge test section

2.1.1 Description

The deluge test section is briefly discussed with reference to figure 2.1 as well as 2.2 where the terminology “deluge test section” refers to the combination of the deluge bundle assembly and pumping network. For a real deluge system, the process fluid to be cooled would flow on the inside of the tube bundles, but in the present facility no process heat will be rejected. Hence only the cooling water- and air-sides are tested.

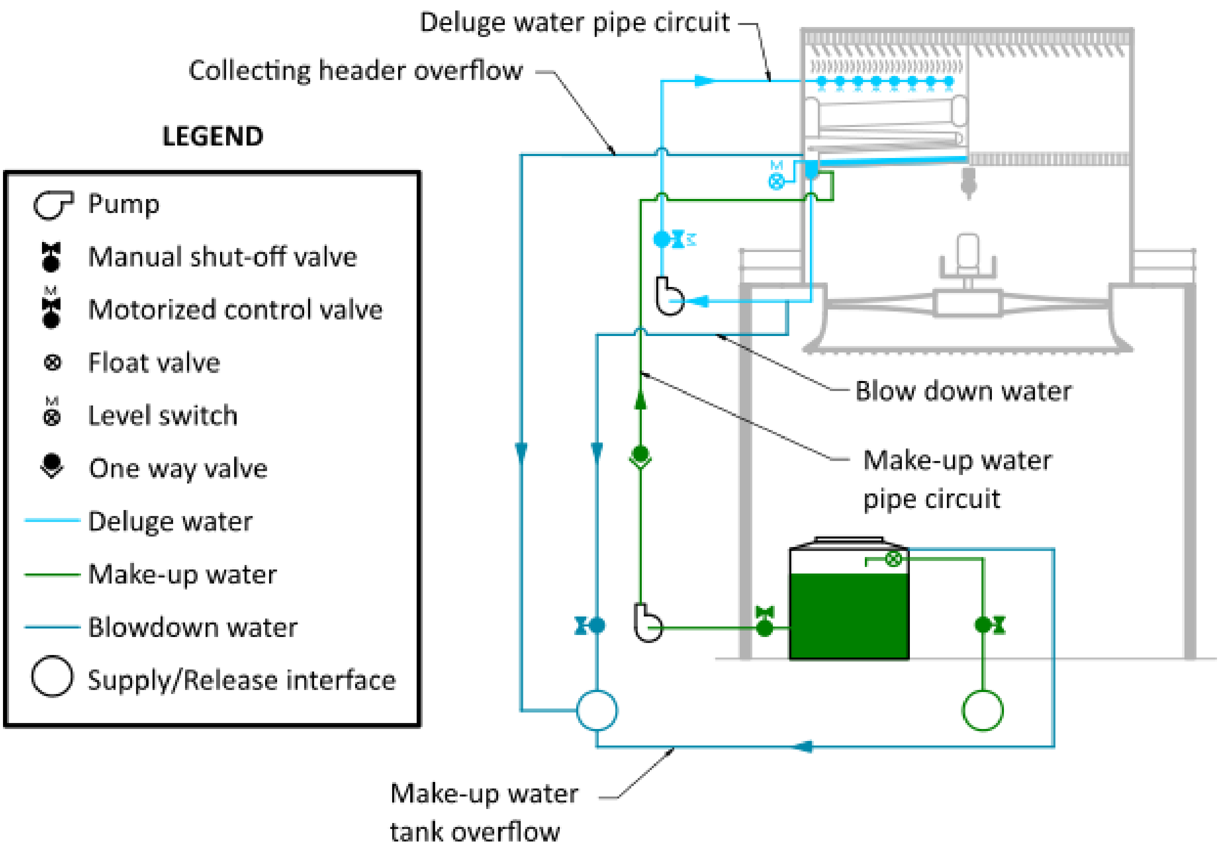

Figure 2.1: Details of the deluge sub-system piping and pump layout

Due to symmetry, only one quarter of the deluge section are constructed and is sufficient to provide representative results comparable to a complete system. During operation the deluge water level is maintained in the collecting header and made up from a holding reservoir at ground level. Deluge water is circulated from here through a deluge pump to a spray frame that distributes the water across a bundle of bare tubes. During cooling water circulation, the deluge water trickles through the bundle while air is forced

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across the bundles in a counter flow direction by the axial flow fan. The droplets falling through beneath the bare tubes are then collected by a novel collecting trough system and accumulated in a collecting header. From here the deluge cycle repeats itself.

Measurements are continuously made on both the water and air-side. On the water side, the water flow rate to the sprayers and from the collecting headers are measured to determine collecting efficiency. As part of the project, component pressure drops and water distributions will also be measured below the sprayer and bundle components at various air and deluge water flow rates. On the air side, flow rate is controlled through a set of louvres at the deluge system outlet. This flow is measured at the fan inlet through an array of 6 radially spaced anemometers, mounted on an articulating boom. The boom conducts a full 360 degree sweep per louvre setting whereafter the total flow rate can be calculated. Air dry- and wet-bulb temperatures are also measured through a series of temperature stations placed at the fan inlet (3) and at the deluge bundle outlet (4). All of this information is inevitably used in the data analysis process to determine the abovementioned water collecting effectiveness and pressure drop correlations for a range of water and air flow rates through the system.

With a longer term vision in mind, the deluge-assembly is manufactured such that it can be removed with relative ease, since it might be required to remove these components and the test bundle for certain fan tests or future testing of other bundle prototypes. Hence, all components within the deluge test section is mounted on carriages and slideable for easy installation and/or removal.

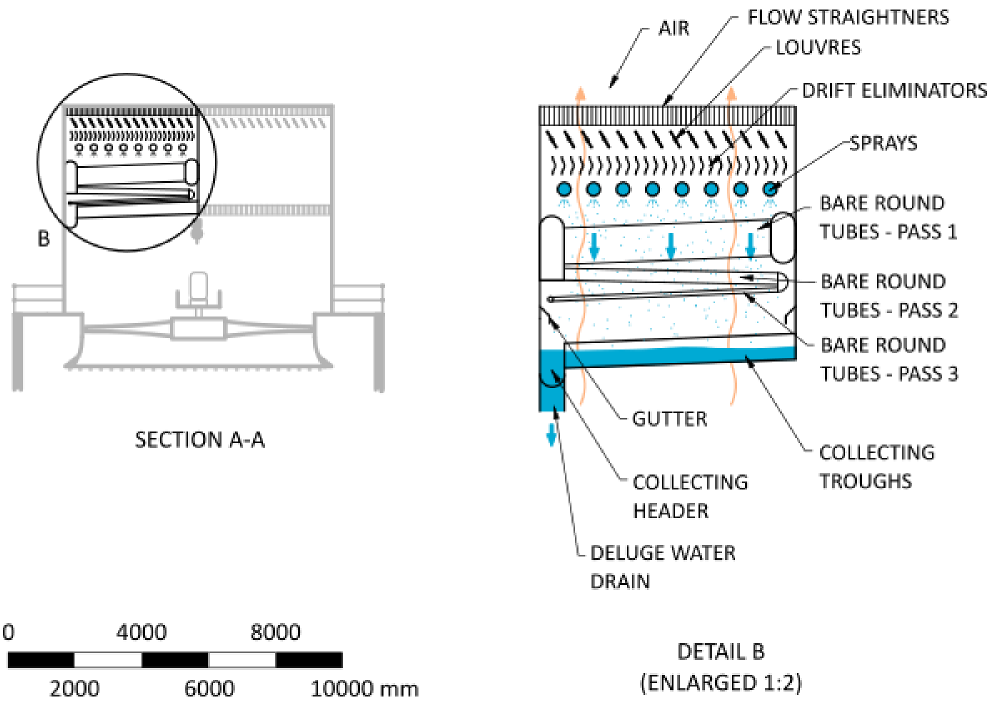

Figure 2.2: Detail schematic of deluge test section

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2.1.2 Commissioning

Successful installation and commissioning of the system was obtained on 14 September 2018 as can be seen with the sprayers running in figures 2.3 to 2.5.

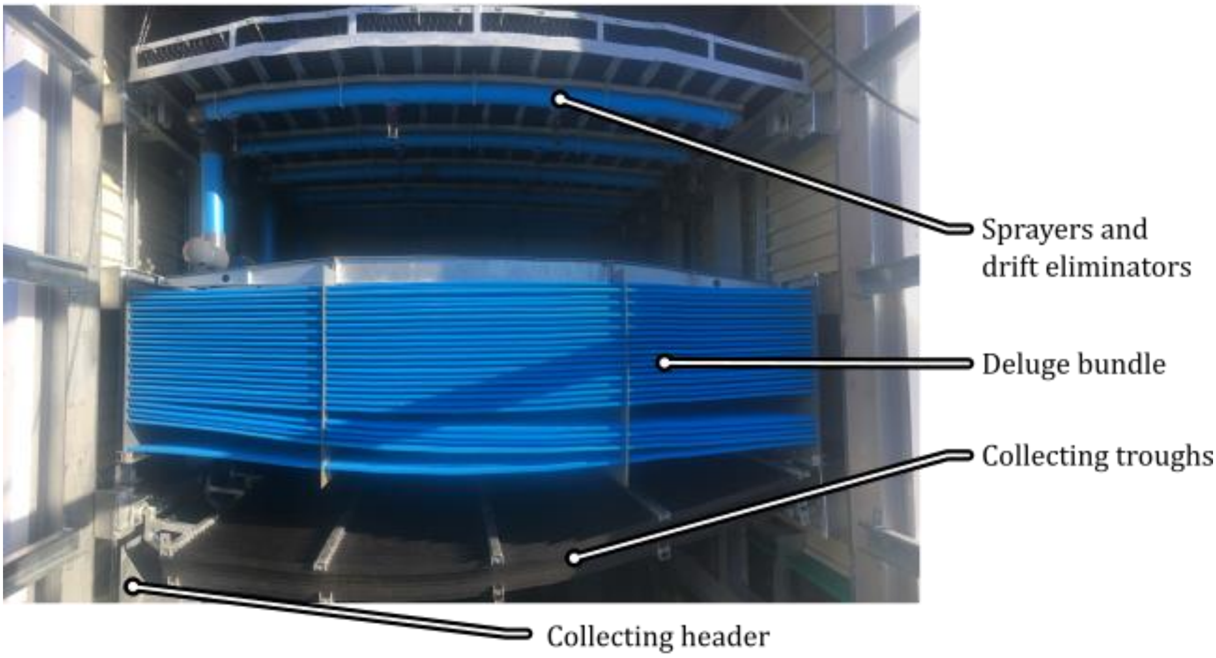

Figure 2.3: Frontal view of the installed deluge bundle inside the full scale test facility

Figure 2.4: Deluge system operational (please note the access door was lifted to get a view into the facility, but would be closed as a default)

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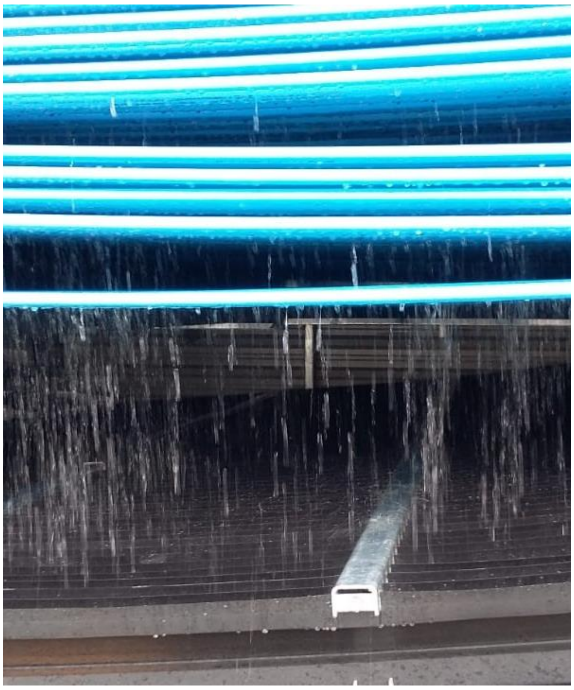

(a)

(b)

Figure 2.5: (a) Deluge water dripping below deluge bundle into collecting trough system and (b) Collected deluge water run-off into the collecting header

2.2 Fan test section

2.2.1 Description

The requirement for full scale testing, originates from uncertainties around:

1. Blade vibrational characteristics under various loading conditions, which differs as a function of the air flow rate.
2. Fan scaling effects, which cannot be considered at scale model level. Normally axial fans are aerodynamically tested for performance in a standardized test facility at scale level (typically 1.5 m in diameter). These performance results are scaled through turbomachinery scaling laws, but do not account for effects such as the change in Reynolds number.

For this reason full scale testing could provide valuable insights to research and verify fan vibrational, fatigue and aerodynamic performance characteristics.

The fan test section is depicted in figures 2.6 and 2.7, where the fan can be observed mounted and hanging from the output shaft of the gearbox. A 132 kW electric motor connected to a variable speed drive (VSD) allows for a range of fan operating speeds. The fan drive (motor and gearbox) is mounted on a bearing allowing free rotation, but held in place by means of a load cell for torque measurement from which fan power can be calculated. During a typical fan test, flow is controlled by the louvres at the facility outlet.

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Velocity measurements are conducted at the fan inlet by the same 6 anemometers as described previously. In addition to these, the inlet dry- and wet-bulb temperatures are also measured as previously stated and weather data from a local weather station is used as part of the data processing.

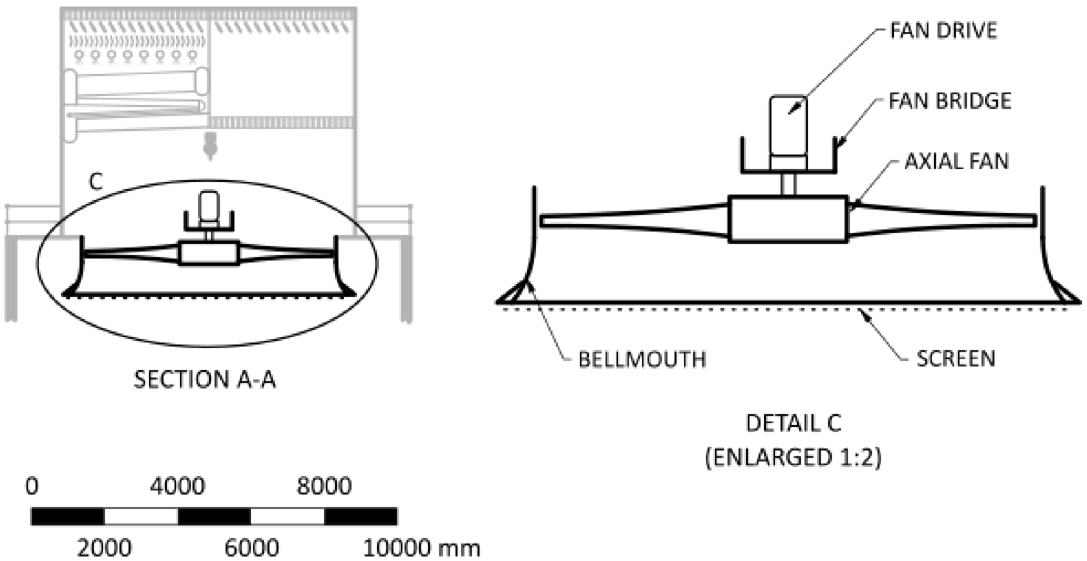

Figure 2.6: Detail schematic of fan test section

Figure 2.7: View of the inside of the test facility displaying the 24 ft axial fan test section

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2.2.2 Commissioning

Successful operation of the fan was obtained on 13 July 2018, when the fan was operated at full speed (151 rpm) as depicted in figure 2.8, concluding the commissioning of the fan test section.

Figure 2.8: 24 ft CSP fan operating at full speed 151 rpm

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3 Concluding remarks

The original deadline of deliverable 8.2 was December 2017 (month 24). However, due to a serious illness of the lead structural engineer, restructuring within ENEXIO, the municipal permission process taking a total of 13 months (longer than the 2 months expected), many rain delays and delays in procurement, the commissioning of the facility was delayed until now. This delay was communicated with the EU, but leaves 4 months for final testing.

Numerous analyses and measurements have however been completed within WP8 (such as full scale vibrational tests on two CSP fan blades and a detailed composite fatigue analysis on structural parts of such a fan). Further experimental setup has already begun inside the full scale test facility for the balance of testing. Remaining testing to be conducted are:

1. Full scale CSP fan aerodynamic performance testing.
2. Full scale CSP fan blade vibrational testing.
3. Deluge bundle collecting effectiveness testing.
4. Deluge bundle air-side pressure drop correlation testing as a function of various air through flow rates.
5. Deluge bundle water distribution measurement as a function of various air through flow rates.

It can be concluded that Deliverable 8.2 has now been fully completed and the WP8 team is still confident that the remaining measurements and analyses to be conducted as well as the reporting can be finalized within the remaining 4 months of the project up to December 2018 (month 36) which would then conclude the final deliverables 8.3 (deluge bundle testing) and 8.7 (CSP fan testing). Hence, it is not foreseen at this stage that the final deadline will be compromised.

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