Minimum Energy Efficiency Standards (MEES) for Water-Cooled Chilled Water Systems in Industrial Facilities

Measurement & Verification (M&V) Guidelines

National Environment Agency
Safeguard · Nurture · Cherish

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Overview of MEES Requirements

MEES is applicable to any electrically-driven, water-cooled chilled water system or sub-system[1] with total installed capacity[2] ≥ 1055 kW_c (300 RT) and producing chilled water at a temperature of ≥ 3°C

- Operating chilled water system is to perform at or better than the following MEES levels:

Chilled water temperature (°C)[3]	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3
MEES levels (kW/RT)	0.492	0.503	0.513	0.524	0.535	0.545	0.556	0.566	0.577	0.587	0.598	0.608	0.619	0.630	0.640	0.651	0.661	0.672	0.682	0.693	0.703	0.714
MEES levels (kW_e/kW_c)	0.140	0.143	0.146	0.149	0.152	0.155	0.158	0.161	0.164	0.167	0.170	0.173	0.176	0.179	0.182	0.185	0.188	0.191	0.194	0.197	0.200	0.203

- Installation of permanent instrumentation and energy management system (EMS) for measurement and verification (M&V) of chilled water system performance is required
- Submission of First Report must be based on EMS data over a 2-week period, verified by EEO Assessor (with system-specific experience in chilled water systems) or PE (mechanical / electrical / chemical engineering)
- A new requirement to submit annual reports generated from the EMS will be imposed at a later date

[1] Other types of chillers (eg air-cooled chillers) and chillers solely utilising antifreeze in the same chilled water system will be exempt from MEES
[2] At AHRI standard rating conditions
[3] May refer to setpoint or operating temperature, rounded to the nearest 1°C

Objective of M&V

- Assurance and confidence of the energy efficiency of the chilled water system
- Assurance and confidence of savings reaped from implementing projects to improve energy efficiency of the chilled water system
- Better decision-making on operation, maintenance and control of the chilled water system, to improve energy efficiency and system reliability

Requirements on Permanent instrumentation

The following parameters must be measured at minimum, at a sampling interval of 1 minute:

Parameters	Minimum measurements required	Allowable end-to-end uncertainties of each measured parameter[1]
Temperature	• Chilled water supply & return temperatures at individual chiller(s) / chilled water header(s) • Condenser water supply & return temperature(s) at individual chiller(s) / condenser water header(s)	- 0.05°C ≤ U_T ≤ 0.05°C
Flow[2]	• Chilled water flowrate at individual chiller(s) / chilled water header(s) • Condenser water flowrate at individual chiller(s) / condenser water header(s)	-1% ≤ U_F ≤ 1%
Power	• Electrical power input to each of the following groups of equipment: chiller(s), chilled water pump(s), condenser water pump(s) & cooling tower(s)	-2% ≤ U_P ≤ 2%

The uncertainty of the overall measurement system, calculated as $\sqrt{(\Delta U_T)^2 + U_F^2 + U_P^2}$,

where $\Delta U_T = \sqrt{U_{T(\,CHWST)}^2 + U_{T\,(CHWRT)}^2}/\Delta T_{CHW}$[3], must be kept ≤ 5%

[1] End-to-end uncertainty refers to the combined uncertainty of the entire chain of measurement from the sensors to the energy management system
[2] Flow rate must be measured at individual chillers if temperature measurements are at individual chillers
[3] If there is > 1 ΔT value, the smallest value should be used

Temperature

- Temperature sensors should be installed in thermowells in direct contact with water in the pipeline
- Test plugs or additional thermowells should be installed before and after each temperature sensor, in a manner to enable sensors to be in direct contact with water in the pipeline
- To facilitate site verification, test plugs or additional thermowells should be made easy to access with no potential obstruction during insertion of temperature sensors if possible
- It is recommended to use thermistors as they show greater sensitivity for a similar change in temperature as compared to other types of temperature sensors
- It is recommended for temperature sensors to be installed away from pipe joints to ensure even mixing of water temperatures
- It is recommended to provide insulation for temperature sensors on the chilled water pipe lines

Guidelines on Temperature, Flow and Power Measurement (continued)

Flow

- It is recommended to use magnetic in-line flow meter, which has an uncertainty of ≤ 1%. An ultrasonic flow meter has a higher uncertainty and would not be able to comply with an end-to-end uncertainty of ±1%
- It is recommended to maintain a minimum clearance of 5 pipe diameters upstream and 3 pipe diameters downstream of the magnetic in-line flow meter, and install it away from distortion sources e.g. valves

Power

- Digital power meters should be installed at the incoming side of the power supply to VSDs, if present
- Uncertainties of voltage transformers and current transformers must be accounted for in the end-to-end uncertainty of the power measurement system, e.g. end-to-end uncertainty of a IEC Class 1 power meter and Class 0.5 current transformer = $\sqrt{U_{power\ meter}^2 + U_{current\ transformer}^2}$ = $\sqrt{1^2 + 0.5^2}$ = 1.1%

Recommended Laboratory Calibration of Measurement Instruments

Taken from SS591:2013

- It is recommended for the instruments to be calibrated against measurement standards that are traceable to national standards or equivalent
- It is recommended for each temperature sensor to be individually calibrated against a measurement standard with a maximum uncertainty rating of ±0.01°C
- It is recommended for tests conducted to measure the uncertainty of the flow measurement system be in accordance with ISO 4185:1980 / Cor 1:1993 or ISO 8316:1987
- It is recommended for tests conducted to measure the uncertainty of power meters, current transformers and voltage transformers be in accordance with IEC 62053-22:2003 for digital power meters, 61869-2:2012 for current transformers and IEC 61869-3:2011 / IEC 61869-5:2011 for voltage transformers

Requirements on Energy Management System (EMS)

- The installed EMS must be capable of trending & calculating (where required) the following data:
  - ❖ Cooling load[1], heat rejection[1] and electrical energy and power consumption of the chilled water system and its components[2]
  - ❖ Energy performance of the chilled water system and its components
  - ❖ Percentage system heat balance of chilled water system
  - ❖ Operating hours of the chilled water system
- The EMS must be capable of trending data at 1-minute sampling interval and storing data to 3 d.p. for a minimum period of 3 years
- New requirements for the EMS to
  - display key data (including operating status of the chilled water system components, graphics of the layout of the chilled water system and instruments, and temperature set points); and
  - aggregate key parameters and performance indicators into monthly and annual data for annual report submission will be imposed at a later date

[1] In units of RT and RTh, or kW and kWh

[2] Should equipment/systems fall within the scope of measurements made by the permanent instrumentation (eg power measurement of cooling tower is also attributable to compressed air system or brine chillers sharing the cooling tower), the contribution of such equipment/systems must also be measured, calculated and removed from the determination of heat rejection and energy and power consumption of the chilled water system and its components

Requirements on Heat Balance

According to the conservation law of energy,

heat input to the chilled water system = heat output from the chilled water system, where:

- heat input = cooling load + work input
- heat output = heat rejection from chiller condenser

System heat balance, calculated as $\frac{Cooling\ load + Work\ input - Heat\ rejection}{Heat\ rejection} \times 100\%$ must be kept within ±5% for ≥ 80% of data points

Work input typically refer to work input into chiller compressors, where:

- Work input = measured power input to hermetically sealed compressor motor × VSD rated efficiency (if present); or
- Work input = measured power input to open-type compressor motor × motor rated efficiency × VSD rated efficiency (if present)

Work input may also refer to pump hydraulic loss if it constitutes a significant heat gain of the chilled water / condenser water, where

- Hydraulic loss = measured power input to pump motor × motor rated efficiency × (100% - pump rated efficiency) × VSD rated efficiency (if present)

VSD, motor and pump rated efficiencies should be provided by the equipment manufacturer

Reference formulae

- Cooling load [kWh] = $\dot{M}_{CHW}$[1] [kg/s] × C_p [kJ/kg °C] × ΔT_{CHW} [°C] × operating hours [h], where C_p ~ 4.19
- Heat rejection [kWh] = $\dot{M}_{CDW}$[1] [kg/s] × C_p [kJ/kg °C] × ΔT_{CDW} [°C] × operating hours [h], where C_p ~ 4.18
- Cooling load or Heat rejection [RT or RTh] = Cooling load or Heat rejection [kW or kWh] / 3.517

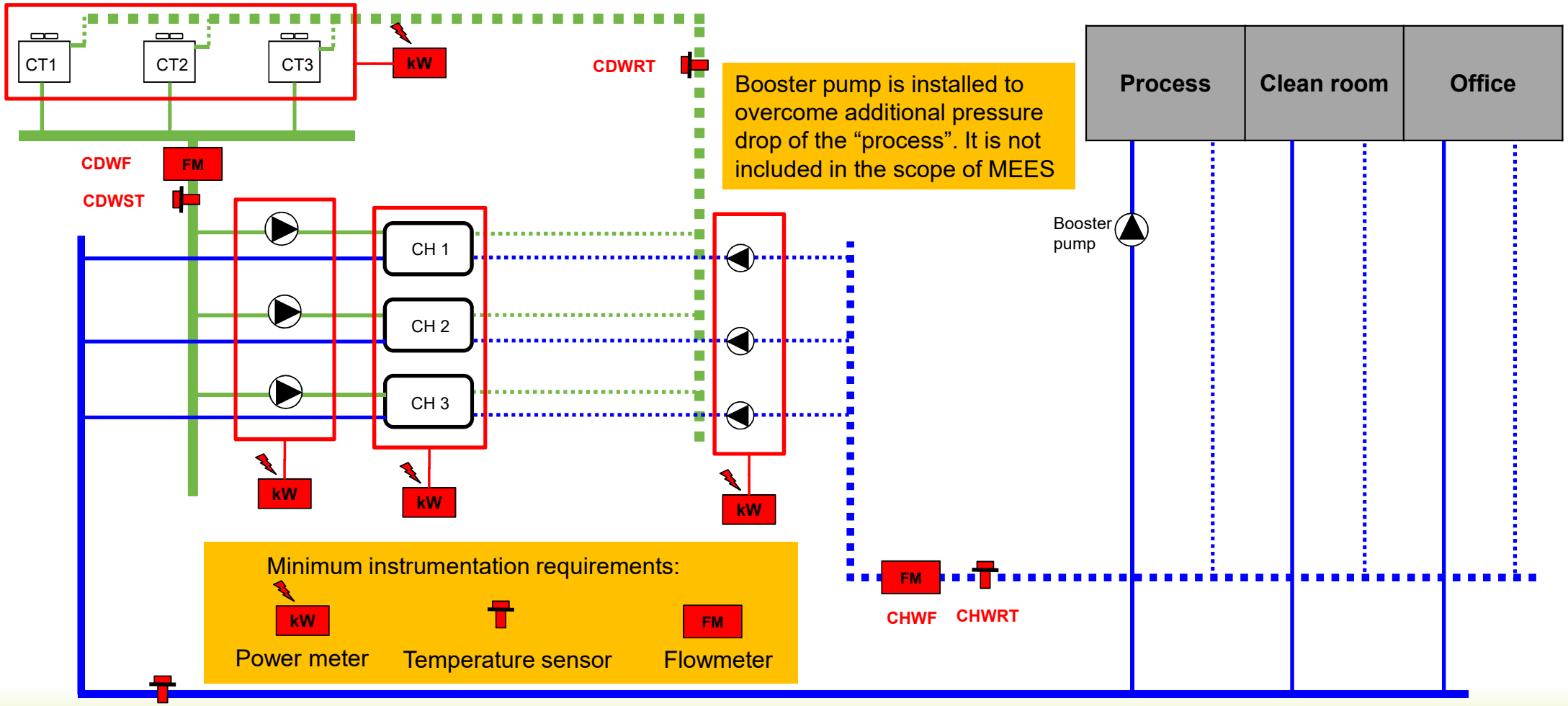
When condenser water pumps and cooling towers are shared amongst multiple systems, of which condenser water of the chilled water system is a proportion of total cooling water:

- Power consumption of shared condenser water pumps[2] attributable to chilled water system [kW_e] = total power consumption of condenser water pumps × $\dot{M}_{CDW}$ / $\dot{M}_{cooling\ water}$
- Power consumption of shared cooling towers attributable to chilled water system [kW_e] = total power consumption of cooling towers × heat rejection of chilled water system / total heat rejection of cooling towers

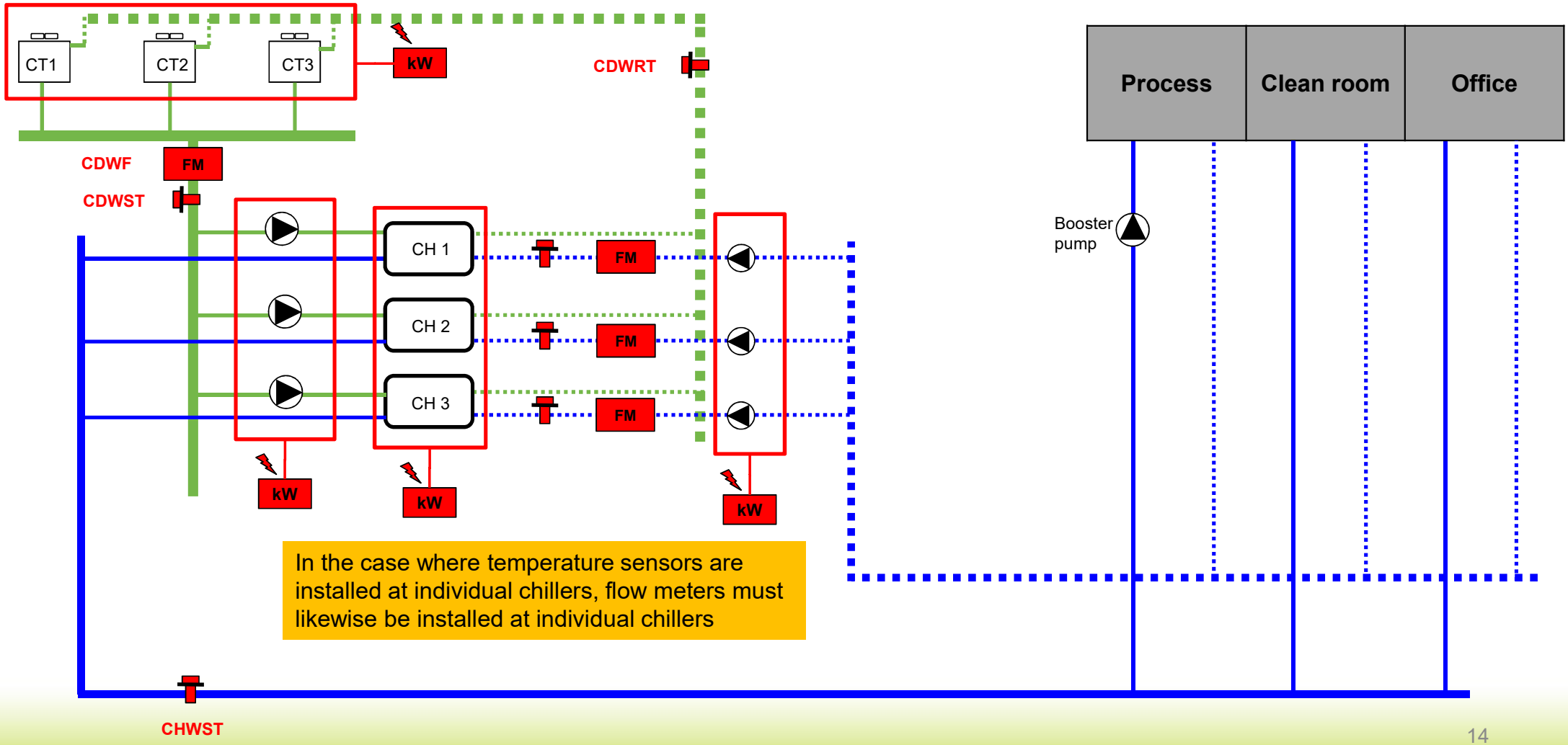
[1] Conversion of flowrate from l/s to kg/s can be approximated as 1 as the density of water is ~1kg/l
[2] Also applicable to chilled water pumps shared between water-cooled chilled water system and other systems

Examples of M&V for different Chilled Water System Configurations

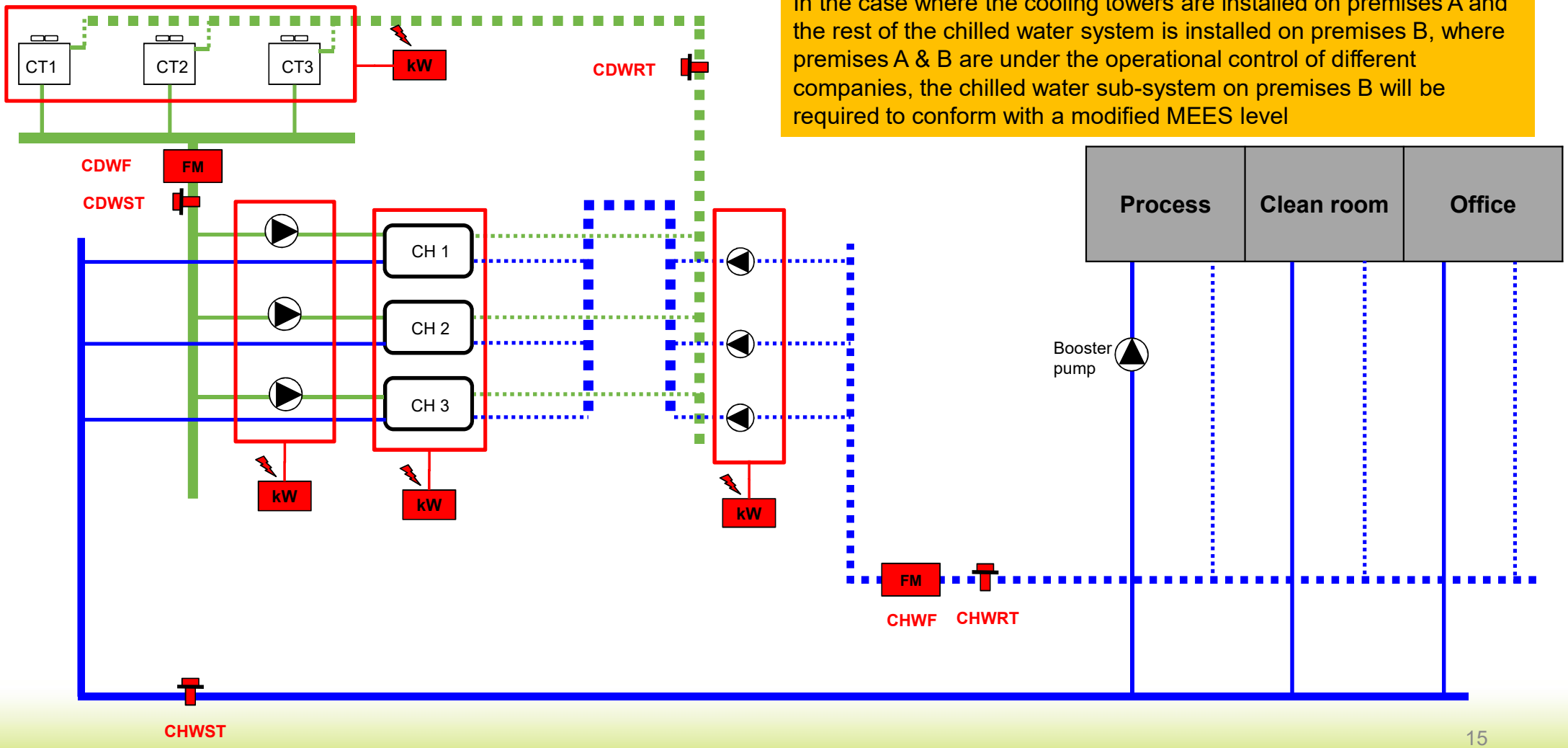
Plant A – Constant Primary Chilled Water System



Plant A – Constant Primary Chilled Water System

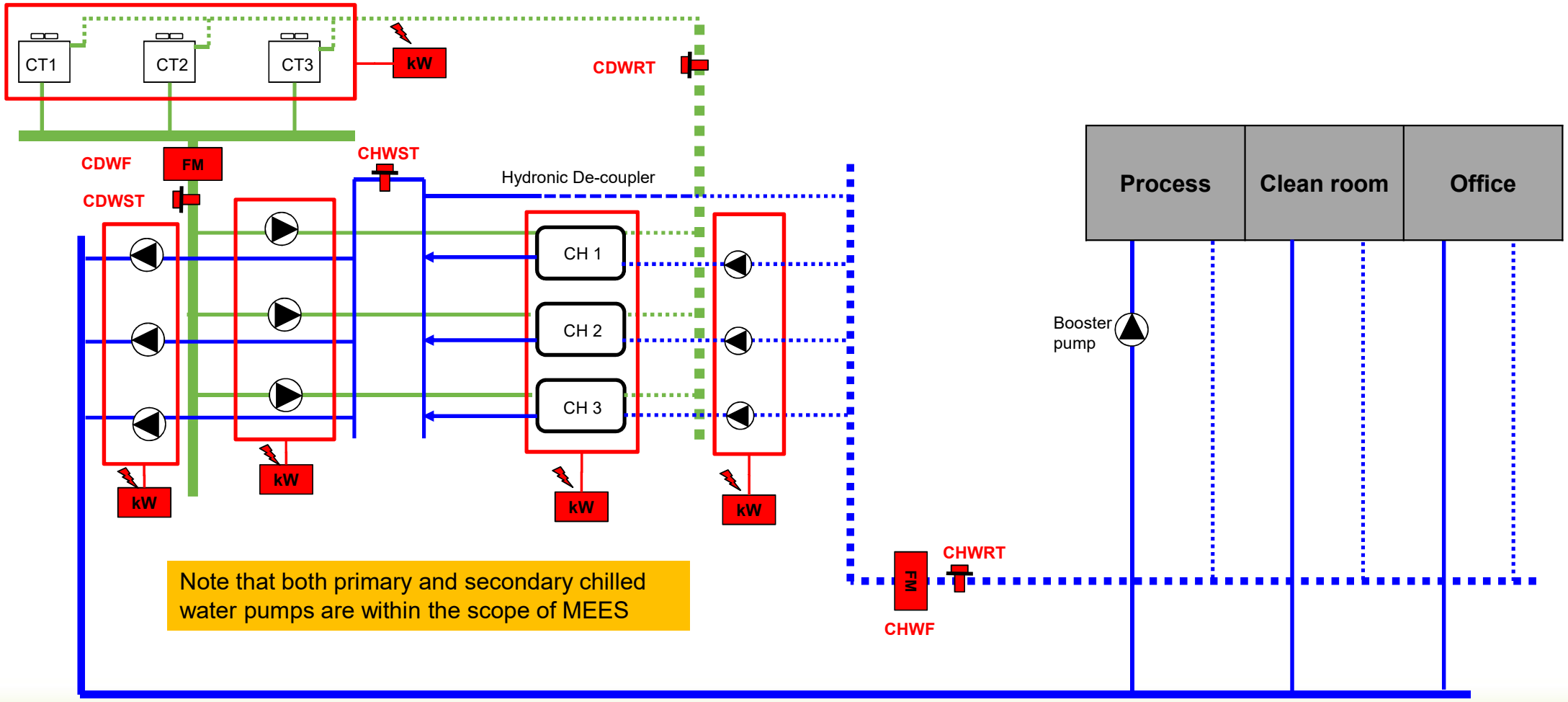


Plant B – Variable Primary Chilled Water System

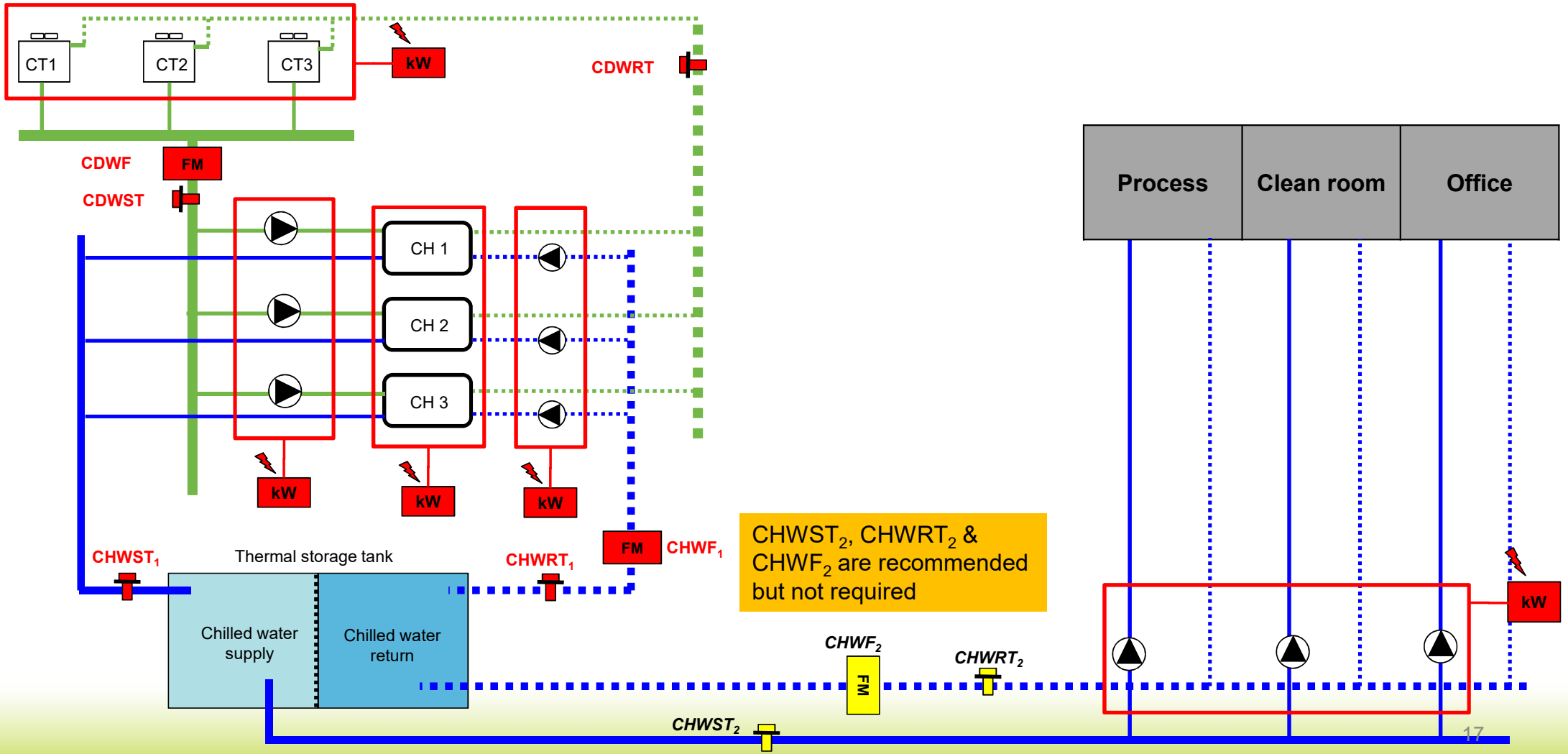


In the case where the cooling towers are installed on premises A and the rest of the chilled water system is installed on premises B, where premises A & B are under the operational control of different companies, the chilled water sub-system on premises B will be required to conform with a modified MEES level

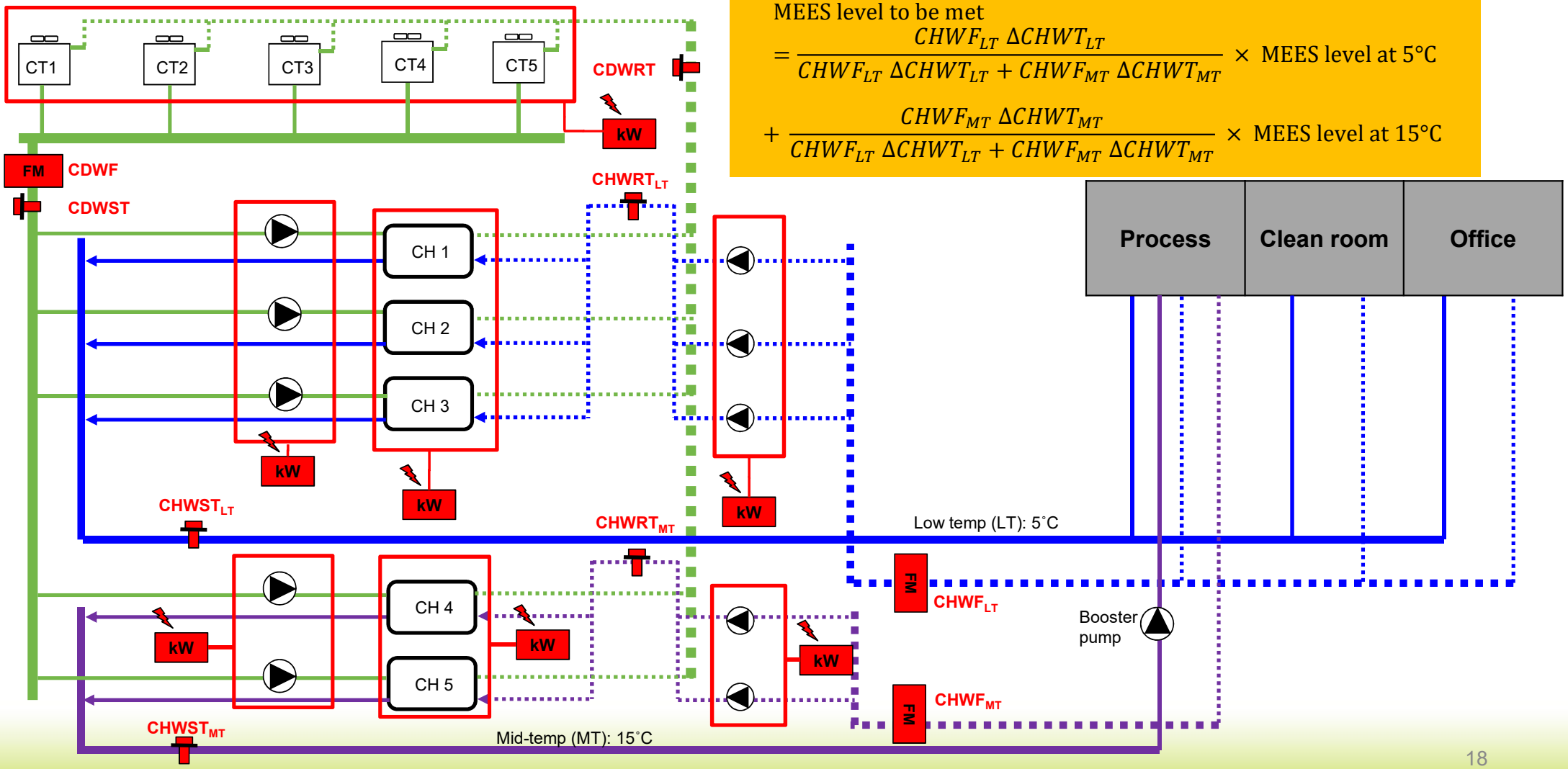
Plant C – Constant Primary & Variable Secondary Chilled Water System



Plant D – Chilled Water System with Thermal Storage



Plant E – Chilled-Water System with multiple supply temperatures



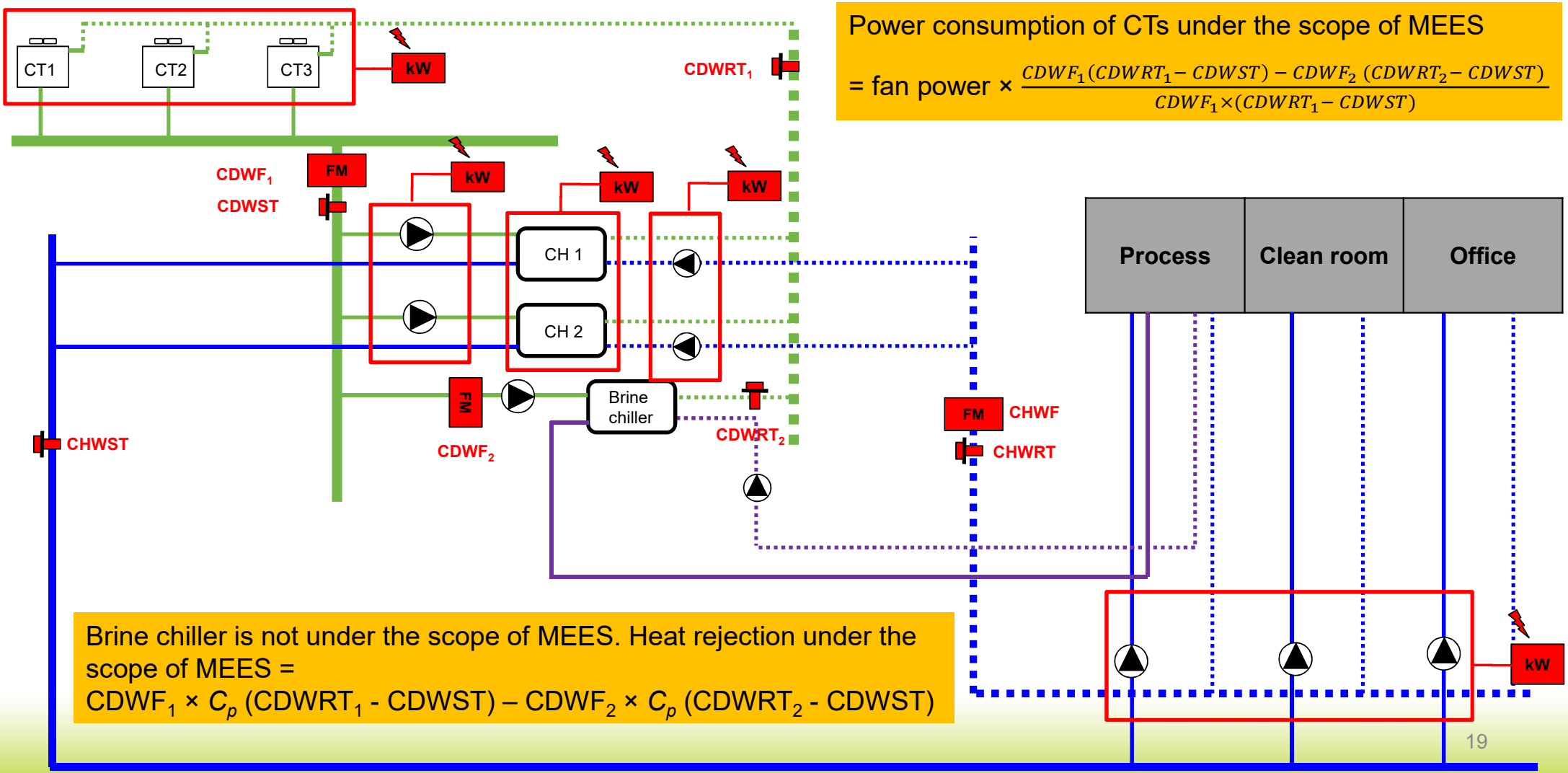
$$\text{MEES level to be met} = \frac{CHWF_{LT}\,\Delta CHWT_{LT}}{CHWF_{LT}\,\Delta CHWT_{LT} + CHWF_{MT}\,\Delta CHWT_{MT}} \times \text{MEES level at 5°C}$$

$$+ \frac{CHWF_{MT}\,\Delta CHWT_{MT}}{CHWF_{LT}\,\Delta CHWT_{LT} + CHWF_{MT}\,\Delta CHWT_{MT}} \times \text{MEES level at 15°C}$$

Plant F – Chilled-Water System with Shared Cooling Towers

Power consumption of CTs under the scope of MEES

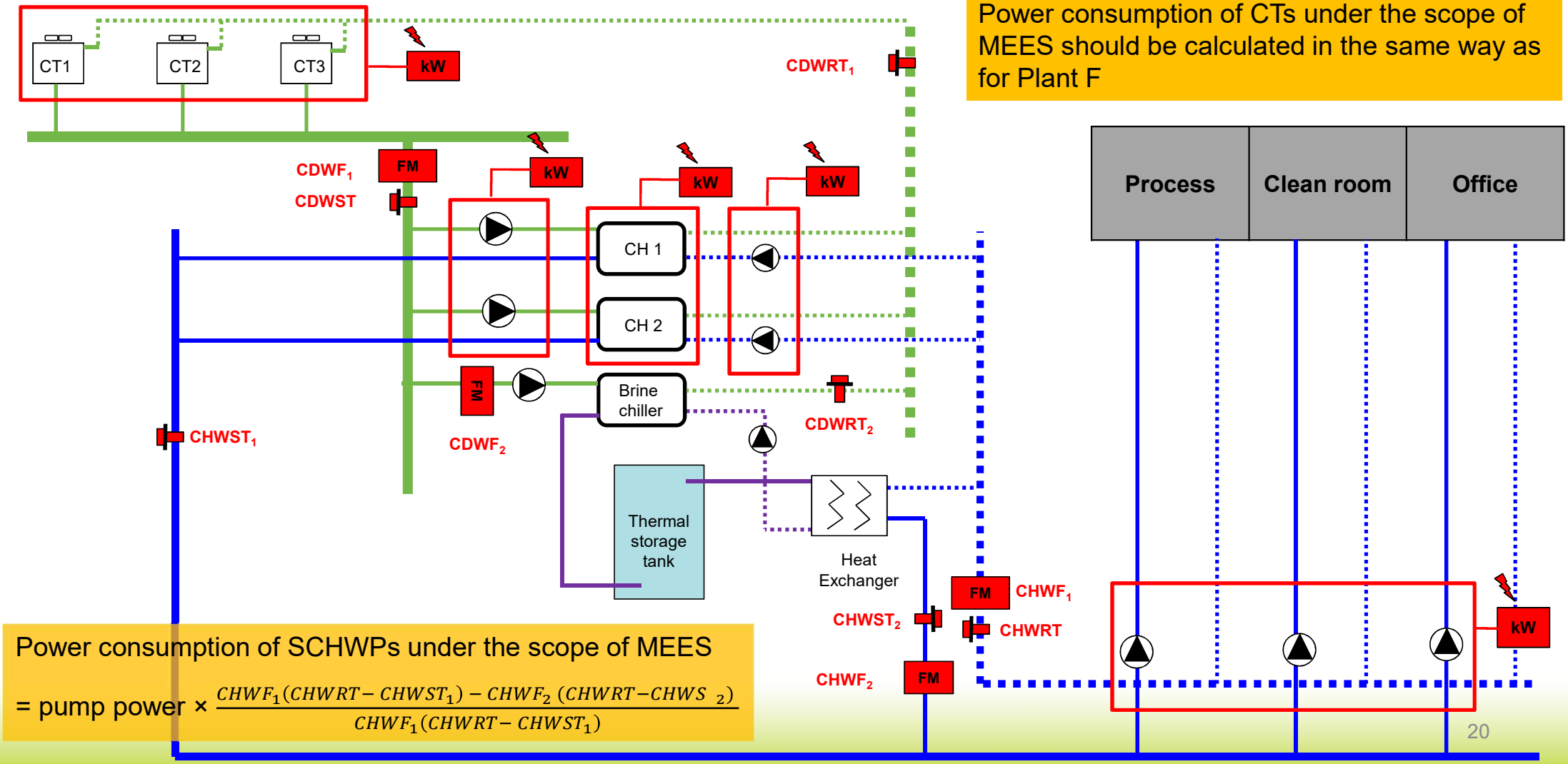
$$= \text{fan power} \times \frac{CDWF_1(CDWRT_1 - CDWST) - CDWF_2\,(CDWRT_2 - CDWST)}{CDWF_1 \times (CDWRT_1 - CDWST)}$$



Brine chiller is not under the scope of MEES. Heat rejection under the scope of MEES =

$CDWF_1 \times C_p\,(CDWRT_1 - CDWST) - CDWF_2 \times C_p\,(CDWRT_2 - CDWST)$

Plant G – Chilled-Water System supplemented with Brine Chillers

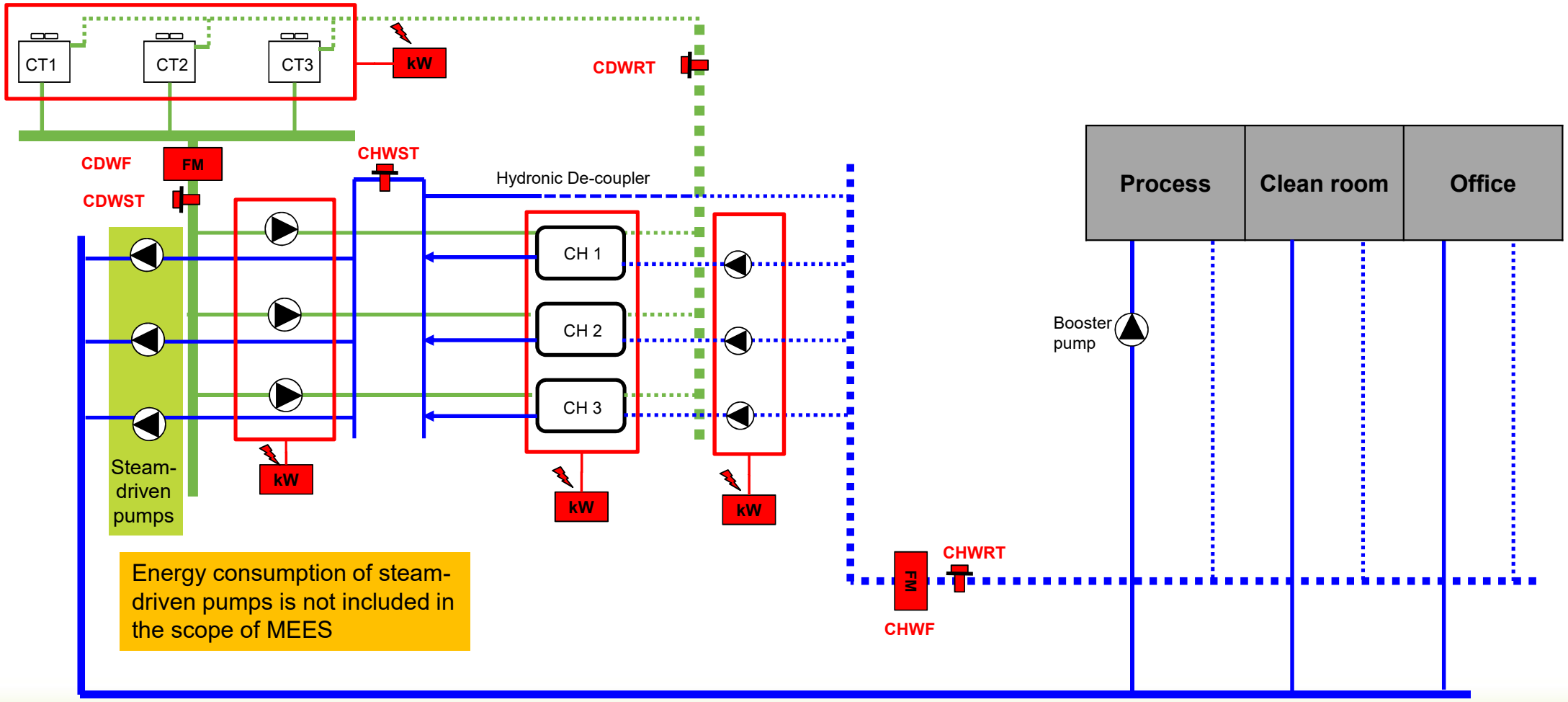


Power consumption of CTs under the scope of MEES should be calculated in the same way as for Plant F

Power consumption of SCHWPs under the scope of MEES

$$= \text{pump power} \times \frac{CHWF_1(CHWRT - CHWST_1) - CHWF_2\,(CHWRT - CHWS\ _2)}{CHWF_1(CHWRT - CHWST_1)}$$

Plant H – Chilled-Water System with “out-of-scope” auxiliary equipment



Records

The following information should be kept for a minimum of 5 years:

- First Report, annual reports and all information used in producing the reports eg raw data and calculations[1]
- Technical specifications of chilled water system components
- All input parameters and settings for the permanent instrumentations
- Instruments' calibration certificates from accredited laboratories and/or their factory calibration certificates from manufacturers
- As-built schematic drawings of the chilled water system
- As-built drawings of the chilled water system plant room layout indicating details of instruments locations and test plugs/thermowells

[1] Information recorded and calculated in the EMS should be kept in the EMS for a minimum of 3 years

Nomenclature

CHWST	Chilled water supply temperature
CHWRT	Chilled water return temperature
CDWST	Condenser water supply temperature
CDWRT	Condenser water return temperature
CHWF	Chilled water flow
CDWF	Condenser water flow
$\mathbf{C_p}$	Heat capacity of water
$\dot{M}$	Mass flow rate
ΔT	Temperature difference of chilled water or condenser water
$\mathbf{U_i}$	Uncertainty of parameter *i*