Table of Contents

List of Tables

1.0 TESTING, ADJUSTING, BALANCING & COMMISSIONING REQUIREMENTS

1.1 GENERAL

This section specifies the requirements for all testing, adjusting, balancing and commissioning (TABC) of mechanical works to be carried out under the contract. The objectives of TABC are:

i. To verify the delivered materials are as per approved specification and good physical condition.

ii. To verify the installation works are carried out in accordance to specification and good engineering practises.

iii. To verify the performance in terms of functionality, safety, maintainability and operational ability of the installed equipment/systems meet the specified design intention through series of tests and adjustments.

iv. To ensure all test results are systematically recorded and verified prior to system commissioning.

TABC works are divided into four stages as the following:

i. Final Acceptance Test.

ii. Delivery stage.

iii. Installation stage.

iv. Functional Performance Test stage.

Contractor shall submit Inspection and Testing Plan (ITP) of TABC works to be carried out in accordance to this specification for Superintending Officer's (S.O) review and approval.

1.2 INSPECTION AND TESTING PLAN (ITP)

ITP shall consist of:

i. List of All TABC Requirement

All TABC works with specific scope and boundaries shall be clearly stated at every stage of TABC works.

ii. TABC Work Schedules

TABC work schedules shall be integrated into main project schedules.

iii. Method Statements

TABC method statements shall consists of TABC procedures, responsibilities, necessary tools, measuring equipment and accuracy, consumables and acceptance criteria. Type of test required is listed in Schedule of Inspection and Testing.

Method statements and acceptance criteria for all equipment installation stage inspection and functional performance testing shall be endorsed by manufacturer or manufacturer's valid representative.

Acceptance criteria shall be stated as per Schedule of Design Requirements, technical specification or any applicable standards.

ITP shall be updated for any changes and resubmitted to the S.O/S.O's representative for approval.

Prior to the commencement of the TABC works as per approved ITP, contractor shall issue Request For Inspection and Testing (RFIT) to the S.O. During the TABC, contractor shall have his supervising foremen and mechanics available to aid the testing and to perform any adjustments as directed. The TABC works shall be carried out under the direction of experienced personnel and witnessed by S.O or S.O's representatives. No subsequent installation works shall proceed without S.O's approval of the test result.

Depending on the specific demands of individual installation, S.O's Representative may require additional or substitute testing works in regard to any elements in the installation other than those indicated in this specification.

Table 1: Sample of Inspection and Testing Plan

Stage	Inspection / Test Name	Scope and Boundaries	Responsibility	Method Statement	Test Form no	Expected Date
Final Acceptance Test	Chiller Factory Performance Test	Water cooled chiller	Manufacturer	MS-ITP-PDI-01	TF-01	17-Jan
	Switchboard Factory Test	Main Chiller Switch Board	Manufacturer	MS-ITP-PDI-02	TF-02	17-Feb
	Air Handling Unit Blower Performance Test	AHU for OT room	Contractor	MS-ITP-PDI-03	TF-03	17-Jan
	Water Pump Performance Test and Inspection	Chilled water pump	Contractor	MS-ITP-PDI-04	TF-04	17-Jan
Delivery Stage	Equipment Verification and Physical Inspection	Water cooled chiller (WCH-01)	Contractor	MS-ITP-PDI-05	TF-05	17-Mar
	Equipment Verification and Physical Inspection	Water cooled chiller (WCH-02)	Contractor	MS-ITP-PDI-06	TF-06	17-Mar
	Equipment Verification and Physical Inspection	Water cooled chiller (WCH-02)	Contractor	MS-ITP-PDI-07	TF-07	17-Mar
Installation Stage	Visual Inspection	Equipment, piping, ductwork, support & hanger	Contractor	MS-ITP-PDI-08	TF-08	17-May
	Hydrostatic Pressure Test	Chilled and condenser water pipe	Contractor	MS-ITP-PDI-09	TF-09	17-May
	Pipe Flushing and Water Treatment	Condenser water pipe	Contractor	MS-ITP-PDI-10	TF-10	17-Jun
	Duct Leak Test	High Pressure above 750 Pa only	Contractor	MS-ITP-PDI-11	TF-11	17-Jan
	Cable Continuity and Insulation Test	All Low Voltage (<1000 v) (LV) cable	Contractor	MS-ITP-PDI-12	TF-12	17-Jan
	Gradient Pipe Test	Condensate drain pipe for all FCU	Contractor	MS-ITP-PDI-13	TF-13	17-Jan
Functional Performance Stage	Chiller Start-up Test	Chiller	Manufacturer	MS-ITP-PDI-14	TF-14	18-Feb
	Chiller Plant Functional Performance Test	Chiller plant	Contractor	MS-ITP-PDI-15	TF-15	18-Feb
	AHU Performance Test	AHU and FCU	Contractor	MS-ITP-PDI-16	TF-16	18-Feb

1.2.1 Final Acceptance Test

Final Acceptance Test shall be conducted if stated in the Schedule of Inspection and Testing Requirements and Schedule of Price of this tender document. The equipment shall be witness-tested at Original Equipment Manufacturer (OEM) premises before being delivered to site by not more than three (3) government's representative to be nominated by the Pengarah Kanan Cawangan Kejuruteraan Mekanikal, Ibu Pejabat JKR Malaysia, Kuala Lumpur.

The Contractor shall include in the tender all costs that will be incurred for the Final Acceptance Test at Original Equipment Manufacturer (OEM) premises including food, travelling (air fare, inland transport, airport taxes, etc.) and hotel accommodation not lower than the current Malaysian Government rate for a period of not more than seven (7) working days not inclusive of travelling days.

A factory test shall be defined as any test of equipment required as stated in the contract, conducted at manufacturer's plant or at an independent and accredited test facility approved by the S.O.

Performance test method statement, test standard and acceptance criteria shall be submitted to S.O for approval prior to such testing. The manufacturer shall produce a signed test report to be submitted for S.O's approval. Manufacturer shall be responsible for any reworks and adjustment of the equipment if the test results fail to comply with the approved acceptance criteria.

1.2.1.1 Chiller Factory Performance Test

Performance rating tests of water cooled chiller unit shall be performed by the manufacturer to verify equipment performance and compliance against contract specifications.

Performance rating test of water-chilling packages using the vapour compression cycle shall comply with latest AHRI STANDARD 550/590 or MS 2449:2012 AMD.1: 2013 or any other standards specified in the technical specification.

The requirements for Full load or Part Load Performance Test (MPLV, IPLV or NPLV) or shall be stated in the Schedule of Inspection and Testing requirements.

1.2.1.2 Switchboard Factory Test

Switchboard pre-delivery acceptance test shall be carried out before delivery to site. The main circuits and the auxiliary circuits shall be tested to verify dielectric properties with power-frequency test voltage of 2500Vac for 1 minute and insulation resistance under test voltage of 1000V. Switchboard testing shall include inspection and checking of wiring,

electrical continuity, functionality of the protective circuits, connections and effectiveness of mechanical actuating elements and logic circuit interlock. Test Results or Certificate duly certified by Competent Person as in Electricity Regulations 1994 shall be issued for every switchboard supplied and installed.

Type of testing for switchboard as per categorization shall be as per Table 2 below:

Table 2: Switchboard Testing

Category	Current Rating	Registration and type of test report
I	I ≤ 600 A	Suruhanjaya Tenaga (S.T)
II	600 A ≤ I ≤ 1200 A	Suruhanjaya Tenaga (S.T) & Partial Type Test in accordance with MS IEC 60439-1 (i) Short Circuit Test (ii) Temperature Rise Test
III	I ≥ 1200 A	Suruhanjaya Tenaga (S.T) & Full Type Test in accordance with MS IEC 60439-1

1.2.2 Delivery Stage

All incoming material and equipment to site shall be inspected to verify that delivered items are complying with contract specification, as per approved materials and good physical conditions. Materials delivered to site shall be free from defects and adequately protected against harsh site conditions.

1.2.3 Installation Stage

List of inspection and testing works during installation as per Table 3.

Table 3: Test List In Installation Stage

Inspection / Test Name	System/Component	Objectives
Visual Inspection	Equipment, piping, ductwork, support and hanger, etc.)	Verify that all installation as per Technical Specification and drawings.
Hydrostatic Pressure Test	Chilled and condenser water pipe	Verify integrity of all pipe joints and fittings.
Pipe Flushing and Water Quality Test	Chilled and condenser water pipe	Verify that all pipes are internally clean and water quality is acceptable.
Duct Leak Test and Duct Flushing	Ductwork	a) Verify integrity of all duct joints and fittings. b) Verify that all ducts are internally clean.
LV Motors, Switch Gears and Cabling Insulation Test	LV Motors, Switch Gears and Cabling	Verify insulation effectiveness.
Cable Continuity Test	Electrical Cabling	Verify cable continuity effectiveness.
Pipe Gradient Test	Condensate drain pipe	Verify condensate drain pipe gradient as per specification.

1.2.3.1 Visual Inspection

All installation shall be subjected to technical specifications and drawings.

1.2.3.2 Hydrostatic Pressure Test

All pipes, valves, fitting, etc. shall be tested to the minimum of 1.5 times the working pressure or 690 kPa (100 psig), whichever is greater for period of 48 hours. During this period, pressure readings as well as the ambient temperature shall be taken at intervals of 3 hours or using chart recorder. All tests shall be done in accordance to ASME B31.9 or equivalent.

During the pressure test, all welding joints, bends, fitting and valves shall be visual checked for any leaks or deformations for the entire piping system. Expanded conditions of all piping shall be carefully studied and any necessary change in hangers, anchors or guide locations shall be made.

Prior to pressure test the contractor shall release air trapped in the pipeline system. Pressure drop for hydrostatic pressure test is not more than 5% from the tested value for the period of testing.

1.2.3.3 Pipe Flushing and Water Treatment

Contractor shall appoint water treatment specialist to carry out pipe flushing and water treatment work. Appointment of water treatment specialist must be approved by S.O. Treatment process and function is as per Table 4.

Table 4: Treatment Process and Function

Process	Function	Application
Dispersant, Descaling and Sludge Remover	To remove deposits, iron oxides, sludge and oil contamination.	Chilled and condenser water pipes
Corrosion/Scale Inhibitor & Oxygen Scavenger	To inhibit corrosion of metals in contact with condenser water upon completion of chemical flushing.	Chilled and condenser water pipes
Biocide	To control microbiological growth (algae, slime, fungi and bacteria growth on the cooling tower infill, cold water basin and hot water basin).	Condenser water pipe

Pipe flushing and treatment method statement shall be submitted to S.O for approval with the following information:

i. Scope of pipe flushing and water treatment
ii. Procedures:
    - *Cleaning procedures, flow rates, elapsed time.*
    - *Type chemicals and concentrations.*
    - *Inhibitors and concentrations.*
    - *Any specific requirements i.e. allocation of drain valves, air vent etc.*
    - *Effluent discharge method*
    - *Complete analysis of water to be used to ensure water will not damage systems or equipment.*
iii. Material Safety Data Sheet (MSDS) for the chemicals
iv. Acceptance criteria (Cleanliness level)

a. General Requirements

All water pipe systems shall be flushed according to the requirements of this specification or complying with water treatment specialist (whichever higher).

Pre-requisite

i. All fabrication, welding and non-destructive examination shall be completed and accepted before the flushing procedure.
ii. Pipe hydrostatic pressure test has been carried out and verified.
iii. All chiller, Air Handling Unit (AHU), Fan Coil Unit (FCU), heat exchangers or any other clogged prone equipment shall be isolated or temporarily removed from the system. Equipment without incoming pipe strainer shall be temporarily installed with by-pass pipes to enable water circulation.
iv. Vents and other connections that can serve as vents shall be open during filling so that all air is vented prior to the application of flushing procedure.
v. Pot Feeder complete with necessary shut off valves, drain and air release valves, and system connections shall be provided by the contractor, for introducing chemicals into system. Pot feeder shall be either insulated cast iron or insulated galvanised steel tank with funnel or large opening on top for easy chemical addition. Feeders shall be 18.9 L (five gallon) minimum capacity at 860 kPa (125 psig) minimum working pressure.

b. Stage of Flushing

i. 1st stage: Fresh Water Online Flushing (Debris Removal)

Water pipes shall be filled with fresh water from water mains and circulated in the water pipe via water pumps. Make up water valve and drain valve shall be open concurrently. Collect sample and do water analysis at interval of an hour during process until the following water condition is obtained.

pH:	7.0 – 8.0
Conductivity:	< 200 µS/cm (micro-Siemen per cm: the measure of dissolve solid concentration which has been ionized in water)
Turbidity:	< 50 NTU (nephelometric turbidity unit)
Total Iron:	< 5 ppm

When above water quality is achieved or as recommended by water treatment specialist, the water then shall be drained entirely and proceed to next process. All strainers shall be checked and cleaned before proceeding to 2nd stage flushing.

ii. 2nd stage: Chemical Flushing

Water pipes shall be refilled with fresh water before adding up dispersant, descaling and sludge remover in the required quantity and circulated for a period of 48 hrs or as per water treatment specialist recommendation whichever longer. Collect sample and do water analysis at interval of an hour until the maximum turbidity level is achieved (Maximum turbidity level is considered when turbidity level is stabilized at peak values with 3 readings). The water then shall be drained entirely and all strainers shall be cleaned.

The water shall then be refilled with fresh water and carry out online flushing. Collect sample and do water analysis at interval of an hour until the following water condition is obtained.

Conductivity < 200 µS/cm

Turbidity < 20 NTU

Total Iron < 5 ppm

When above water quality is achieved, proceed to next stage.

All chemicals shall be safe for discharge to sanitary sewer.

iii. 3rd stage: Passivation (Corrosion Control)

Water pipe passivation shall be carried out by adding chemical inhibitors as per water treatment specialist recommendation until nitrite level reach min level of 1200 ppm. These inhibitors act to form a thin protective oxide film on the metal surface. Nitrites and molybdates inhibitors may be used.

iv. 4th stage: Microbiological Control (Biocide)

Add in biocide as per water treatment specialist recommendation to control the microbiological growth. Maintain the maximum recommended biocide residual (for the specific biocide) for a period sufficient to bring the system under good biological control (residual and time varies with the biocide).

c. Test Equipment, Apparatus and Chemical Dosing Facilities

The contractor shall provide test equipment and apparatus for evaluating the water quality describe as below:

- Spectrophotometer inclusive reagents and high index sample cell.
- pH meter
- Electrical conductivity meter

- Graduated burette inclusive reagents
- Dip slide bacteria kit
- Graduated beaker, measuring cylinder and conical / volumetric flask
- Test tubes, filter paper, funnel, sampling bottles, etc.

The chemical dosing facilities used are as per below:

1) Filter vessel
2) Personnel protective equipment (PPE) for chemical handling.

d. Final Water Quality

Water quality test shall be carried out by water treatment specialist and certified by accredited lab to verify the water quality parameters are met as per Table 5. Circulation water is free from suspended solid and debris.

Table 5: Water Quality

pH	9.0-10.0
Conductivity (µS/cm)	Less than 200
Total Iron (ppm)	Less than 5
Turbidity (NTU)	Less than 20
$CaCo_3$ (ppm)	Less than 100
Nitrite as $NaNO_2$ (ppm)	Less than 1200

Suitable water treatment chemicals for chilled and condenser water shall be maintained in the pipeline after pipe flushing has been concluded.

Pipe flushing test reports shall be submitted to S.O after completion of flushing procedures. As a minimum, the test records shall contain detail of testing and the results.

1.2.3.4 Duct Leak Test and Duct Flushing

All high pressure ductwork more than 750Pa static pressure shall be subjected to duct leak test procedure and acceptance criteria in accordance with HVAC Air Duct Leakage Test Manual (ANSI/SMACNA 016-2012). All duct opening shall be sealed prior to duct leak test. Maximum system leakage shall be limited to 5% of design flow. The test result shall be approved by the S.O.

All duct systems shall be flushed according to the requirement of this specification. All fabrication, jointing works and leak test shall be completed and accepted before the flushing

procedure. Duct flushing reports shall be submitted to S.O after completion of flushing procedures.

1.2.3.5 LV Motors, Switch Gears and Cabling Insulation Test

Insulation resistance test shall be performed via a megohmmeter with a voltage output of at least 500-1000 dc volts. Each conductor shall be individually test with all other conductors and shields grounded. Test duration shall be one minute and the resistance value shall be recorded.

Step 1- Conducting Time - Resistance Absorption Test Method

The successive resistance reading shall be taken at specific times and the differences in readings shall be recorded. A good insulation shows a continual increase in resistance over a period of time (in the order of 30 to 60 second).

Step 2 - Dielectric Absorption Ratio

The test shall be continuing with Dielectric Absorption Ratio reading by taking resistance value at every minute until 10 minutes to obtain the Polarization Index.

The Polarization Index is the ratio of two time-resistance readings (such as a 10-minute reading divided by a 1-minute reading)

The minimum acceptance value of Polarization Index shall be 1.4 to 1.6 for 60/30 sec Ratio and 2 to 4 for 10/1 minute ratio.

1.2.3.6 Cable Continuity Test

Cable continuity test shall be performed on each power cable by ohmmeter method. Perform an acceptance test on cables, including terminations and joints, after cable system installation and before the cable system is placed into service. In accordance with ANSI/IEEE 400, by means of direct voltage (dc) and recorded in the relevant testing form.

1.2.3.7 Pipe Gradient Test

All drain pipe carrying condensate water shall be tested to verify their ability to discharge condenser water to the drain point seamlessly without any obstruction or water stagnation.

1.2.4 Functional Performance Test

List of functional performance test are as the following. All Functional Performance Test shall commence after all inspection and testing during installation stage has been completed.

1.2.4.1 Pre-Functional Performance Test

a. Air Balancing

Air flow measurement in ducts shall be measured by either pitot tube traverse average method or vane anemometer (depending on site conditions). Balancing damper final position shall be marked on site. Final terminal air flowrate shall be balanced to within ±10% from design value or as per S.O satisfaction.

Air flow rate to each terminal shall be measured by air flowhood with digital manometer and balanced via balancing damper. Total air balancing report shall be produced and submitted to S.O.

b. Water Balancing

Water balancing shall be carried out to balance the water flow distribution in chilled water and condenser water circuit as per design water flow. Volumetric water flow rate shall be measured by flow meter or balancing valve pressure drop-flow relationship. Total water balancing report shall be produced and submitted to S.O. Final terminal flowrate shall be balanced to within ±10% from design value or as per S.O satisfaction.

For constant flow pump system, pressure-flow curve (pump curve) shall be provided via plotting minimum of 3 tested points of pressure and flow.

For variable flow pump system, variable speed drive shall be inverted to various frequencies. Pressure-flow curve (pump curve) shall be provided via plotting minimum of 3 tested points of pressure and flow at each frequency tested. The contractor shall establish 4 sets of curve at various frequency for each pump i.e. 50 Hz, 45Hz, 40 Hz, 30 Hz.

c. Accuracy Test

Before the commencement of the functional performance test, the contractor shall carry out field calibration check for the functional accuracy of the various item of measuring, regulating and similar equipment, forming part of installation including gauges, transducers, sensors and meters.

All calibration certificates of all measuring facility shall be submitted to the S.O.

1.2.4.2 Chiller Plant Test

List of inspection and test name for chiller plant are listed in Table 6. Detail method statement for testing shall be submitted conforming to the test requirements in this specification.

Table 6: Chiller Plant Inspection and Test List

Inspection / Test Name	Objectives
Chiller Plant General Inspection	Verify that all chiller plant components are installed as per approved shop drawings, approved material list (Borang Penerimaan Bahan / Mock-up), installation method statement and free from installation defects.
Chiller Plant Power Supply	Verify that power supply is adequate and phase sequence check.
Chilled and Condenser Water Flow Test	Verify that chilled and condenser water flow is as per design.
Chiller Plant Interlocking Test	Verify interlocking and operation sequence between chiller, CHWP, CWP, CT and valves.
Chiller Low Flow Protection Test	Verify chiller protection against low flow condition.
Chiller Low LCHW Protection Test	Verify chiller protection against low LCHW condition.
Chiller High ECWT Protection Test	Verify chiller protection against high ECWT condition.
Chiller Refrigerant Charge and Adequacy Inspection	Verify that chiller refrigerant charging is adequate.
Chiller Plant Noise Level Test	Verify that noise level is within permissible range.
Chiller Lead-Lag Control	Verify chiller plant sequencing control and optimization effectiveness.
Chiller Load Test	a) Verify chiller performance as per published performance data. b) Verify chiller plant ability to perform at peak and minimum anticipated load within allowable chiller operating parameters.
Cooling Tower Performance Test	Verify cooling tower performance as per published performance data.

a. Chiller Plant General Inspection

All chiller plant's components i.e. chiller, cooling tower, chilled & condenser water pumps, switchboard, pipework & fittings, ventilation ductworks, water treatment plant shall be visually inspected for any deviation from approved shop drawings, method statement, approved material and identification of any physical defects that may arise during installation works. All components shall be installed as per approved shop drawings, approved material list and free from defects.

b. Chiller Plant Power Supply

The voltage, ampere, phase sequence, overcurrent tripping setting shall be check and verify prior to chiller initial test run. In no condition should the voltage dropped in access 10% the chiller shall run.

Never operate the motor where the phase imbalanced greater than 2% or manufacturer recommendation.

All equipment such as chiller, pumps, fans shall be rotational check against manufacturer recommendation. Compressor unit shall be adequately heated prior running. Interlocking function between pumps, flow switches, pressure switches, actuators and compressors shall be check and verified. For detail requirement refer Table 11.

c. Chilled and Condenser Water Pump Flow Test

The test must be carried out with chiller in off mode by either flow measurement with installed flowmeter or with portable ultrasonic flowmeter/velocity meter. Differential pressure head upstream and downstream of the pump and chiller's evaporator or condenser shall be recorded. The flowmeter reading and differential head is then crosschecked with pump curve and evaporator or condenser pressure flow curve. This test shall be repeated for all possible chiller configurations and variable pressure condition.

Flowrate and differential pressure head must be on the published pump curve from the manufacturer. All pumps shall be checked for formation of cavitation and verifying that the Net Positive Suction Head Available ($NPSH_a$) is greater than Net Positive Suction Head Required ($NPSH_r$).

d. Chiller Plant Interlocking Test

Chiller interlocking test shall be carried out in two (2) modes namely starting and stopping sequence for each individual chiller.

Chiller starting and stopping sequences and time delay including chilled water pump, condenser water pump, cooling tower, AHU and motorised valve shall response according to design requirement or manufacturer's recommendation.

e. Chiller Low Flow Protection Test

Chiller ability to safety cut off in the event of low flow condition shall be demonstrated by simulating built in or field installed flowswitch/differential pressure switch activation.

Chiller shall be cut off once flowswitch is activated. Flowswitch shall be activated once chiller flow drops below minimum allowable flow.

f. Chiller Low Leaving Chilled Water (LCHW) Protection Test

Chiller ability to cut off the event of low leaving chilled water condition shall be demonstrated by increasing low LCHW set point. Chiller shall be cut off once LCHW temperature is below Low LCHW set point.

g. Chiller High Entering Condenser Water Temperature (ECWT) Protection Test

Chiller ability to cut off in the event of high entering condenser water temperature shall be demonstrated by increasing high ECWT set point. Chiller shall be cut off once ECWT temperature is higher than high ECWT set point.

h. Chiller Refrigerant Charge Adequacy Inspection

Refrigerant charge for each compressor circuit shall be checked by observing the refrigerant flow in the liquid line sightglass.

If there is a clear sightglass, and no signs of flashing, then the circuit is adequately charged subject to chiller load and expansion valve opening. Chiller manufacturer shall be consulted.

Refrigerant charge certificate shall be issued by manufacturer.

i. Chiller Plant Noise Level Test

Frequency Analyser shall be used with one-third octave band filter set meeting requirement for Class II. All measurement points are 1m from the outside plant room wall and at a height of 1.5m from the floor at 1m interval. 'A'-Weighted sound pressure level and Octave band measurement (63 through 8000 Hz Octave Band) shall be made during chiller plant operation and background noise level. Chiller plant noise level shall meet noise level requirement as specified in the technical specification.

j. Chiller Lead-Lag Control Test

Chiller sequencing control test shall be initiated by switching on all duty AHU/FCU and all duty chillers. All AHU/FCU temperature and/or humidity control shall be functional and active. Indoor air temperature/humidity shall be set at design conditions. Allow one (1) hour for chiller plant to stabilize and then initiate shutting down of AHU/FCU gradually until chiller load reach minimum allowable load. Simulate chiller load increment by switching all AHU/FCU gradually. Chiller starting and stopping sequence and the operation of chilled water plant by-pass valve to maintain constant flow to chiller shall be recorded and verified against chiller sequencing control strategy.

k. Chiller Plant Load Test

After completion of chiller lead-lag control test, chiller plant load test shall then be carried out by continuing to operate the chiller plant for 3 consecutive days at design operating hours with active sequencing control and all duty AHU/FCU switched on. Actual field performance data shall be compared with published chiller performance data from the manufacturer. Sample chiller performance data to be provided by manufacturer is shown in Table 7. In the case of variable flow system, flowrate shall be considered as variable.

All chiller plant operating parameters shall be logged at 10 minutes interval which include data as per Table 8; Chiller plant capacity turn-down ratio (ratio of minimum recorded load and rated capacity) shall be tabulated.

Full load capacity of chilled water plant may not be achieved due to non-availability of cooling load of the actual building. Recorded chilled water plant load shall be corrected to include effect of human, lighting and weather related load at design conditions in order to demonstrate chilled water plant ability to serve peak cooling load as per design.

All chiller, pump and cooling tower and switchboard operating parameters shall then be analysed by manufacturer and parameters that are beyond chiller recommended operating range shall be identified and rectified.

Table 7: Sample Performance Data

Pct Load	CAP (TR)	Pct Power	Input Power (kW)	EEFT (F)	ELFT (F)	CEFT (F)	CLFT(F)	kW/TR
15	57	25	60	45.5	44.0	87.0	88.5	1.05
20	76	29	70	46.0	44.0	87.0	89.0	0.92
30	114	38	90	47.0	44.0	87.0	89.9	0.79
40	151	46	109	48.0	44.0	87.0	90.8	0.72
50	189	55	131	49.0	44.0	87.0	91.8	0.69
60	227	62	149	50.0	44.0	87.0	92.7	0.65
70	265	70	167	51.0	44.0	87.0	93.6	0.63
80	303	79	188	52.0	44.0	87.0	94.5	0.62
90	341	88	211	53.0	44.0	87.0	95.4	0.62
100	379	100	238	54.0	44.0	87.0	96.4	0.63

Table 8: Chiller Plant Operating Variables

No	Data	Type of Measurements
1	Electrical power input of chiller, pump and cooling tower	Logged data for chiller. One-off measurement is allowed for constant load motors.
2	Chilled water flow	Logged data for variable flow system. One-off measurement is allowed for constant flow system.
3	Condenser water flow	Logged data for variable flow system. One-off measurement is allowed for constant flow system.
4	Entering condenser water temperature (CEFT)	Logged data from chiller controller or external data logger.
5	Leaving condenser water temperature (CLFT)	
6	Entering chilled water temperature (EEFT)	
7	Leaving chilled water temperature (ELFT)	
8	Outdoor air dry/wet bulb temperature	Logged data from data logger.
9	Chilled water bypass valve opening.	
10	Evaporator saturated temperature and pressure.	Logged data from chiller controller.
11	Condenser saturated temperature/pressure.	
12	Compressor %FLA or running current.	
13	IGV/ Slide valve opening percentage (screw compressor only).	
14	Subcool and superheat temperature.	
15	Compressor discharge temperature.	
16	Hot water temperature (entering cooling tower)	Logged data from data logger.
17	Cold water temperature (leaving cooling tower)	
18	Cooling tower air intake wet bulb temperature	

l. Cooling Tower Performance Test.

Cooling tower performance test shall be carried out in accordance with Cooling Tower Institute (CTI) Acceptance Test or any other relevant code approved by S.O. All data shall be recorded during chiller plant load test. Make up water tank ability to make-up cooling tower water loss shall be verified.

1.2.4.3 Air Handling Unit and Fan Coil Unit

Table 9: AHU/FCU Inspection and Test

Inspection / Test name	Objective
AHU/FCU General Inspection	Verify that equipment physical conditions are acceptable.
Fan Volumetric Air Flow Test	Verify that air flow is as per design flow.
Cooling Coil Performance Test	Verify that coil capacity is as per design.
AHU/FCU Control Test	Verify that control system function as per design control strategies.
Noise Level Test	Verify noise level within permissible limit.

a. AHU/FCU General Inspection

AHU/FCU shall be visually inspected for any deviation from approved shop drawings, approved material and identification of any physical defects that may arise during installation works.

b. Fan Volumetric Air Flow Test

Air flow measurement in ducts shall be measured by either pitot tube traverse average method or vane anemometer (depending on site conditions). Fresh air flow rate shall be measured via vane anemometer or pitot static tube (single point). All points for pitot tube insertion shall be prepared and reseal adequately after measurement. Blower motor power shall be recorded during measurement.

c. Cooling Coil Performance Test

Prior to coil capacity testing, published coil performance data at any given chilled water flow and temperature, air flow and on coil temperature/humidity shall be obtained. Coil capacity test shall coincide with chiller plant load test period.

Chilled water temperature and flowrate, control valve position, air temperature and humidity before and after cooling coil (Off/On coil) shall be spot measured and recorded at anticipated peak and lowest ambient.

Chilled water flowrate can be measured by either ultrasonic flowmeter or computed from balancing valve pressure drop-flow relationship.

Coil performance data shall then be analysed and endorsed by manufacturer. Coil performance shall be compared with manufacturer published performance data. Parameters that are beyond recommended operating range shall be identified and rectified.

d. AHU and FCU Control Test

Each Air Handling Unit (AHU) or Fan Coil Unit (FCU) control system shall be tested against their design intent as detail out in Table 10.

e. Noise Level Test

Noise level measurement shall be carried out via Sound Level Meter Type 2 / Class 2 General Purpose Grade for field use ± 1.0 dB. All measurement points are at a height of 1.5m from the floor at every enclosed space/zone. Measurement shall be made when AHU is on and another one when in off condition (background noise level).

Table 10: AHU/FCU Control Test Requirements

Type of AHU Control	Description
Temperature Control	Adjust thermostat setting above and below controlled parameter value (e.g. return air or space air temperature) and observe response in control valve action. For modulating analog type thermostat output voltage/ampere shall be measured and recorded corresponding to the sensed temperature.
Temperature and Humidity Control	Adjust thermostat and RH setting above and below controlled parameter value (e.g. supply air, return air or space air temperature & humidity) and observe response in control valve and heater action. For modulating analog type thermostat output voltage/ampere shall be measured and recorded corresponding to the sense temperature.
Air Pressure Control	Adjust pressure set point above and below controlled parameter value (e.g. supply air, return air or space air temperature & humidity) and observe response in actuator/inverter control. For modulating analog type pressure controller output voltage/ampere shall be measured and recorded corresponding to the actual operating pressure.
Duct Reheater Safety Protection	Air flow switch and overheating switch shall be tested by simulating reduce air flow scenario for flow switch and temperature set point adjustment for overheating switch.
Damper Shut Off	For motorised fresh air damper application, ensure damper is closed when AHU is shut off.
Control Valve Shut Off	Ensure control valve is closed when AHU is shut off. a) Electric heater is shut off under AHU no flow condition. b) Electric heater is shut off when supply air temperature (overheating sensor) exceeds ceiling set value.
Fire Mode Test	Test interlocking between smoke detector and AHU trip (control panel). Aerosol spray shall be used to activate smoke detectors and observe tripping of AHU.

1.2.4.4 Switchboard and Power Supply

List of Switchboard and power supply inspection and test name are listed in Table 11. Detail method statement for testing shall be submitted conforming to the test requirements in this specification. Only Competent Person as in Electricity Regulations 1994 shall conduct the switchboard testing.

Table 11: Switchboard and Power Supply Inspection and Test Requirements

Inspection / Test name	Description
Switchboard General Inspection	• Verify physical switchboard components are as per specification. • Check for tripping setting and system trip. • Check for wiring, motor insulation and record data. • Check for cable terminal tightness. • Check for equipment and panel grounding connection. • Check for any sign for cable heating. Cable temperature shall be measured and verify against IEEE standards for temperature rise during full load. • Check for voltmeter, and ammeter function and accuracy record running voltage and ampere. • Check for control circuit function as intended. • Check for contractors, relays, ACB, MCCB, MCB, type, size and ratings as per specification.
Power Supply Test	• Verify that power supply parameters are within permissible range, safety protections are in place and physical condition of switch board and cabling works are acceptable as per specification and approved shop drawings. • Verify rotation of equipment/phase sequencing according to manufacturer recommendation. • Verify phase protection relay installation and function.
Overcurrent and Earth Fault Protection	• Circuit breaker and Earth Fault Protection calibration and discrimination shall be conducted and coordinated between electrical contactors. • Circuit breaker and Earth Fault Protection shall be tested against simulated leakage current. • IDMT tripping delay shall be selected/programmed suitable for equipment starting overloading preventing nuisance tripping during starting.

1.2.4.5 Air Distribution

List of Air Distribution system inspection and test name are listed in Table 12:

Table 12: Air Distribution System Inspection and Test Name

Inspection / Test name	Objective
Room Condition	Verify temperature, humidity and air velocity is within specification.
Pressurisation Test	Verify operating space differential pressure is within specification.
Duct Condensation Inspection	Verify insulation performance to prevent duct condensation.

a. Room Condition

Space temperature and relative humidity shall be recorded either by temperature and humidity data logger or spot measurements using sling psychrometer as per S.O instruction. Time of measurement shall coincide with chiller plant load test period.

Temperature and humidity data logger shall be used to measure temperature and humidity at these locations:

- Location where occupants are known to spend most of their time.
- Furthest zone and high heat load area.
- Critical areas such as OT room, ICU/CCU/NICU room, Medical Record, High Dependency Ward (HDW), Isolation Room, Central Sterile Supply Department (CSSD), Laboratory, Medical store, Server room as decided by S.O.

For all other areas, spot measurements using sling psychrometer shall be used during anticipated peak and minimum cooling load period as per S.O instructions. Air velocity in spaces shall be measured using hot wire anemometer.

Building operation and weather conditions during testing such as outdoor air temperature and humidity, internal load factors i.e. population, lighting and equipment data shall be recorded.

Indoor air condition test report shall be submitted consisting of the descriptive statistic of the measured data i.e. mean, max, min, range, frequency bin analysis, their respective location and building operation and weather conditions data during testing.

b. Pressurisation Test

In zone where differential pressure requirements are specified, pressurisation test shall be performed via pressure differential meter and verified by smoke test.

c. Duct Condensation Inspection

Visual inspection shall be carried out to determine any traces of condensation on duct surfaces during chiller load test. Any traces of condensation shall be reported.

1.2.4.6 Infiltration Test

Any path for infiltration of outside air or untreated air to the air conditioned space shall be identified visually and reported.

1.2.4.7 Wall Insulation and Sprayed PU Foam Insulation Effectiveness Test

Visual check on trace of condensation at all wall or slab surfaces shall be carried out and reported.

1.2.4.8 Mechanical Ventilation Test

List of mechanical ventilation system inspection and test name are listed in Table 13:

Table 13: Mechanical Ventilation System Inspection and Test Name

Inspection / Test name	Objective
Fan General Inspection	Verify that equipment physical conditions are acceptable.
Fan Volumetric Air Flow Test	Verify that air flow is as per design flow.
Fan Control Test	Verify that control system function as per design control strategies.
Noise Level Test	Verify noise level within permissible limit.

a. Fan General Inspection

Fan shall be visually inspected for any deviation from approved shop drawings, approved material and identification of any physical defects that may arise during installation works.

b. Fan Volumetric Air Flow Test

Air flow measurement in ducts shall be measured by either pitot tube traverse average method or vane anemometer (depending on site conditions). All points for pitot tube insertion shall be prepared and reseal adequately after measurement. For ductless fan, vane anemometer shall be used. Blower motor power shall be recorded during measurement.

c. Fan Control Test

Fan control test shall be carried out as per Table 14:

Table 14: Fan Control Test List

Type of Fan Control	Method
Temperature Control	Adjust thermostat setting above and below controlled parameter value and observe response in fan operation. Temperature reading of the served space shall be recorded via temperature data logger for 24 hrs fan operation.
Schedule Operation	Adjust timer schedule and observe response in fan operation.
CO_2 Control	Adjust CO_2 sensor set point above and below controlled design value and observe response in fan operation. CO_2 reading of the served space shall be recorded via CO_2 meter (one off measurement).

d. Noise Level Test

Noise level measurement shall be carried out via Sound Level Meter Type 2 / Class 2 General Purpose Grade for field use ± 1.0 dB. All measurement points are at a height of 1.5m from the floor at every enclosed space/zone. Measurement shall be made when fan is on and another one when in off condition (background noise level).

1.3 COMMISSIONING

Commissioning includes achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets defined objectives and criteria.

All completed test forms and test summary shall be submitted to S.O representative for final review and approval. Having satisfied that all appropriate tests have been conducted and the performance of the installation meet the design objectives; S.O representative will issue or recommends to the S.O for the issuance of Certificate of Practical Completion (CPC).

1.3.1 Handing Over Documents

After issuance of Certificate of Practical Completion, contractor shall submit all related project handing over documents as the following:

a) Test Report complete with fully verified Inspection checklist and Test Forms.
b) Air Balancing and Water Balancing Report.
c) Defects List
d) Operation and Maintenance Manual which includes
    - *Manual/Standard Operating Procedures*
    - *Preventive Maintenance Schedule and Manual*
    - *Equipment/Product Engineering Data.*
    - *Operation set point (temperature, relative humidity, pressure etc.)*
    - *Switchboard overload setting and set points*
    - *Control valve setting*
    - *Contractor and manufacturer contact details*
    - *Circuit Diagrams*
    - *Inventory List*
e) As-Built drawings
f) Schedule of System Familiarisation Program to end users.

1.3.2 System Familiarisation Program

In-class and practical System Familiarisation Program shall be conducted to the personnel nominated by the S.O within one (1) month of issuance of Certificate of Practical Completion. The program shall focus on:

- Overview of design concept and objectives
- Operation instruction & competency requirement
- Maintenance procedures
- Critical operating parameters monitoring and
- Emergency response & safety procedures.
- Environmental protection procedures.

Contractor shall submit program modules and materials to the S.O for approval prior to commencement of training. Particulars of trainee shall be recorded and send to the S.O for records.

2.0 POST OCCUPANCY EVALUATION

Post Occupancy Evaluation shall be performed by the contractor one (1) month before the end of defect liability period.

Space temperature and relative humidity shall be measured at all respective temperature zone. Temperature, relative humidity and air speed shall be within specification. Any adjustment to the system are required if the data deviate from the specification.

A survey shall be carried out to evaluate user experiences with the air conditioning and ventilation system from comfort, operation ability or any other related problems. Survey form as in Table 15 shall be used. All survey form shall be submitted to the S.O for references.

Table 15: Post Occupancy Evaluation Form

Block			
Floor			
Space			
AHU/FCU no			
Indoor Air Conditions			
Parameters	*Measured value*		*Comment*
Dry Bulb Temperature		*^oC*	
Relative Humidity		*%*	
User Survey			
1) Any difficulty in operating the system? If Yes, please state the details.			
2) Any specific problem system? If Yes, please state the details.			

3.0 TESTING INSTRUMENTS & ACCESSORIES

All permanent sensors and gauges use for measurement of temperature, pressure and flow shall be factory calibrated and all calibration certificates shall be submitted to the S.O prior to testing works.

The contractor shall provide all necessary testing, calibrating instruments and labour required for the testing, adjusting, balancing and commissioning of the air-conditioning and mechanical ventilation system installed under the contract.

The contractor shall also allow for any necessary replacement of parts in order to achieve the conditions specified in the drawings and specification. Provisional sum for that purpose is provided in Schedule of Price.

Testing instruments specification shall be as but not limited to Table 16.

Table 16: Testing Instruments

Measurement	Type	Accuracy
Dry bulb and humidity (logging)	Temperature and Relative Humidity data logger	*Temperature measurement accuracy: ± 0.5 °C (0°C<T<30°C) and 1.5% of reading at 30°C<T<70°C). Humidity measurement accuracy: ± 2%RH (from 15°C to 25°C, from 5 to 95%RH)*
Dry bulb and humidity (One off)	Sling Psychrometer	*± 0.5°C*
Duct air velocity	Pitot Tube and digital manometer	*± 0.7 m/s (from 2 to 5 m/s)*
Free air velocity	Vane anemometer	*± 3% of reading ± 0.1 m/s (from 0.3 to 3 m/s)*
Room air velocity	Hot wire anemometer	*± 3% of reading ± 0.05 m/s (from 0.15 to 3 m/s)*
Duct thickness	Vernier caliper	*± 0.01 mm*
Ampere	Clampmeter (instantaneous)	*2.0% ± 5 digits (45-65Hz)*
	Power/Energy logger (continuous)	*± (1% of reading + 0.02% of full scale)*
Voltage	Clampmeter (instantaneous)	*1.5% ± 5 digits*
	Power/Energy logger (continuous)	*± (0.2% of reading + 0.01% of full scale)*
Combined power, ampere, voltage, power factor and Energy	Power/Energy logger (continuous)	*Active Power: ±(1.2% of reading + 0.005% of range) (For PF≥0.99); ±(1.2% of reading + 7 x (1-PF) + 0.005% of range) (from 0.6 PF to 0.98PF)*
Air volumetric flowrate	Air flowhood with digital manometer	*Supply and Exhaust: ± 3% of reading*
Noise (Full spectrum)	Sound Level Meter Class 1	*Class 1 as per IEC 61672-1:2002*
Noise (Average)	Sound Level Meter Class 2	*Class 1 as per IEC 61672-1:2002*
Vibration	Vibration Analyser	*± 5% of reading (from 0.01 g to 50 g); where "g" in meter per second square.*
Surface temperature	Infrared thermometer	*Display accuracy ±1.0°C*
Water volumetric flowrate	Ultrasonic flowmeter	*Not more than 5% of reading typical*

