

Appendix A  
Table A1. Maintenance issues in MGPSs and their possible causes.

System Component	SN	Defect	Possible Causes
Area Alarms/ AVSU	1	Fire cases response late	Lack of linkage with Building Management System (BMS) connection which helps to discover such cases by facility management
	2	Inaccessibility to the panel	Improper layout design which doesn't consider sufficiently the nature of healthcare operations which lead to obstructions
Bulk Systems	3	Gas leaks/Fire risk	The use of copper commercial pipe that is not medically certified could lead to leak cases. This increases the risk of fire.
	4	Pandemic quick response failure	The absence of external connection to the central oxygen piping system which is used to latch on to an oxygen tanker truck to provide emergency oxygen for the entire institution
	5	Alternate tanks unavailability	Only one tank is installed which does not provide an alternative when an emergency occurs
	6	Dirt or debris	Poor accessibility resulting in inadequate cleaning operations in the bulk system yard
	7	Water ponds	Poor drainage design in the foundation and walking areas, considering obstacles that might be introduced to the bulk system yard
	8	Poor access for maintenance	Insufficient area specified to ingress and egress mechanical rooms which presents challenges if a repair, replace, or checkup is needed
	9	Poor lighting	Inadequate lamp life or poor illuminance conditions in the design
	10	Corrosion of metal parts	Frequent cleaning with pressurized water or the existence of galvanized elements that get corroded, especially for evaporator freezing cases.
Manifolds Room	11	Fire risk	The design does not provide fire protection systems to avoid oxygen leaks OR Lack of linkage between fire alarm and BMS
	12	Copper pipes damage	Low height of copper pipes in manifold rooms make them prone to damage by maintenance crews and their activities especially if other systems' components are adjacent
	13	Dirt or debris	Poor accessibility to all around the manifold rooms or the existence of other obstacles
	14	Noise from maintenance	Poor selection of the location which requires crew movement across the facility OR Inadequate or inexistence of acoustical insulation in the manifold room in cases of inside-facility manifolds room
	15	Pandemic quick response failure	The design does not account for the possibility of accommodating a pandemic demand surge, such as COVID-19
	16	Excessive heat/Improper ventilation	The proximity of vacuum pumps or other machines to cylinders OR Poor location selection, such as basements
Master Alarms	17	Delayed response to pressure drop	Lack of linkage with BMS connection which helps to discover such cases
	18	Delayed response to humidity increase	Lack of linkage with BMS connection which helps to discover such cases
	19	Delayed response to electricity outage	Lack of linkage with BMS connection which helps to discover such cases

Table A1. Cont.

System Component	SN	Defect	Possible Causes
Medical Air Treatment Systems	20	Failure to provide alternative	Some facilities have compressors without manifolds rooms, which prove an alternative source for medical air in cases of failure or electricity outages
	21	Dirt and dusts	Poor design consideration for maintenance accessibility that affects cleaning activities
	22	Noise	Unavailable sound acoustical system
	23	System underperformance	Insufficient compressor capacity that affects flow rate at high demand due to the designer underestimating the factor of safety in design calculation
	24	Pandemic quick response failure	The design setting does not allow for tying in extra machines in cases of pandemics, such as COVID-19
	25	Oil contamination	Using oil-based compressors may introduce oil into the system in cases of failures which can be avoided by using oil-free ones
	26	Poor airflow	The machines are under-sized that respond to requirements due to underestimating the required airflow, or concurrent operations
Outlets and Inlets (terminal units)	27	Poor access for maintenance	Reduced area specified to ingress and egress mechanical rooms which allow free space of movement to repair, replace, or check-up
	28	Gas leaks	Improper selection of materials used for outlets and their seals that do not provide durability for heavy-duty use
	29	Inconsistent inlets and outlets	Mixing of standards adopted for outlets, especially in the absence of knowledge of healthcare medical devices' compatibility
	30	Pandemic quick response failure	The design does not account for the possibility of accommodating a pandemic demand response, such as COVID-19, by allowing extra emergency outlets or rapid expansion
Piping Network	31	Future expansion challenges	When outlets are added to accommodate demand surges, the required flow rate for gas outlets as per HTM or NFPA99 cannot be achieved successfully
	32	Multiple cutting-outs when upgrading	The design has not accounted for upgrading the network using dedicated fittings. This maximizes outages which present hazards.
	33	Electricity shorts	Insufficient earthing when pipes enter the facility
	34	Intersections with cable routes	Medical gas pipes and cable tray routes were not sufficiently coordinated. Construction crews may improvise which leads to improper adjacency.
	35	Pressure drop	Piping design use of excessive elbows
	36	Mixing gases by pipes' cross-connection	Design drawing omissions that the construction crew blindly follows
	37	Pandemic quick response failure	The design does not account for the possibility of accommodating a pandemic demand response, such as COVID-19, and allowing for rapid expansion
	38	Damage to other systems when performing maintenance	Reduced service space in the ceiling voids which limits accessibility and increases MEP systems' complexity
	39	Difficulties in carrying out maintenance	Reduced service space in the ceiling voids which limits accessibility and increases MEP systems' complexity
	40	Increased challenges to change or upgrade the system	Reduced service space in the ceiling voids which limits accessibility and increases MEP systems' complexity
	41	Poor airflow	Undersized pipes diameter

Table A1. Cont.

System Component	SN	Defect	Possible Causes
Vacuum Pumps	42	Poor vacuum	Vacuum equipment under sizing
	43	Clogs	Lack of flask
	44	Dirty and dusty area	Poor accessibility resulting in inadequate cleaning in the mechanical room
	45	Machine damage	Lack of anti-bacterial filter
	46	Faulty control panel	Poor accessibility for maintenance or cleaning
Valves	47	Maintenance shutdowns require major operation suspension	Insufficient zone and service valves to provide isolation for intervention in only the needed areas
	48	Fire risk	Oxygen valves are distant from outlets which prevents quick closure in cases of fire
	49	Noise	The need for maintenance to access isolation valves through main and secondary corridors
	50	Infection/Contamination	The frequency of maintenance visits to isolation valves that are critically situated near patient wards and operation theaters
	51	Pandemic quick response failure	The design does not account for the possibility of accommodating a pandemic demand response, such as COVID-19
	52	Damage to other systems when performing maintenance	Reduced service space in the ceiling voids may lead to poor selection of isolation valve's location