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Multi disciplinary field Hospital design

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Abstract: Field hospitals were a great help in global pandemics and catastrophes such as earthquakes and the spread of airborne viruses. This study focused on the design of a multidisciplinary field hospital to help in different types of global emergencies. The method used in this study was depending on our expertise in field hospitals planning and the selection of biomedical devices with our own modifications, with special emphasize on finding a realistic solution for oxygen supply shortage problem which arose during the widespread of covid-19 pandemic and due to the increasing numbers of covide-19 cases. The result of this study was a field hospital design appropriate for any need.

Keywords: Field hospitals, Multidisciplinary Field Hospital, Military Hospital, Field hospitals oxygen supply

1.Introduction:

The standard definition of a hospital is “a facility whose staff provides services relating to observation, diagnosis, and treatment to cure or lessen the suffering of patients”. The meaning of observation is to study patients and perform examinations and different tests to achieve a diagnosis of the patient, A diagnosis is a medical expert’s explanation of the cause of the symptoms and acts as a result of the observation procedure which decides the plan of treatment, so the diagnosis process is the most important medical service, treatment is the series of different medical services applied on the patient to cure the medical issue which happened to him based on the diagnosis procedure. The design of any type of hospitals is centered on these three medical services so it needs to be organized according to them.

A field hospital can be defined as a mobile or fixed medical care unit which can be temporary or permanent with the sole purpose of quick emergency medical care to the wounded in case of war or disasters such as earthquakes, and in the case of a pandemic spread before sending them to a primary hospital (if needed).

The structure of field hospitals can be made of tents, inflatable tents, solid containers and already built abandoned buildings, the main aim of tents and containers structure is to be easily set up at the site of need. The site of the field hospital was agreed to be in plain sight and easily accessible.

Field hospitals can be used after the end of a war or a pandemic or any other disaster to diagnose patients to direct them to the correct hospital destination, and to treat emergency cases which don’t stand to wait until arriving to a primary hospital due to the far distance between the emergency site and the primary hospitals location, and depending on the classification of the field hospital, it may be able to operate surgical operations, thus saving lives without the need for a primary hospital. This can reduce the load on primary hospitals and saves time for decompensating patients.

1.1 History of Field Hospitals:

The first fully function field hospital in history was founded by the United States of Americas army, it was called Mobile Army Surgical Hospital (MASH) and it was considered as a fully function hospital due to the complicated surgical procedures which were done there. It was established in 1945 during the last month of World War II, and was used later in the Korean war and later wars.

The staff of the MASH unit was completely military medical staff and no civilian medical staff was allowed due to the dangerous environment in the battlefield. There is a previous stage of the treatment of wounded soldiers, a battalion aid stations were found in the battlefield with the sole intent to stabilize emergency surgeries until they can be carried to the MASH unit, and this helped to increase the rate of successful treatment and survival chances for soldiers. The MASH unit also founded the patient triage color coding system which helps to prioritize severely wounded soldiers from mild wounded ones as in the figure below (Cooper et al., 1995).

Black	Deceased or so severely wounded that there is no hope for survival.
Red	Requires immediate treatment in order to survive.
Yellow	Not in immediate danger but requires medical care. Requires observation.
Green	Wounds or injuries that aren't completely disabling. Referred to as "walking wounded."

Figure 1. Patient Triage Color Coding System

The MASH unit was deactivated in Korea 14 years later after the end of Korean War, then the MASH unit served in Vietnam war and Gulf war, then it was deactivated officially in 2006 to be converted to Combat Support Hospital (CSH). The CSH did has some improvements such as using ISO containers to provide transportable rooms with a level of sterilization as the primary hospital operating rooms, support air conditioning splitters and ICU rooms to produce surgical outcomes almost as the primary hospital in quality (Bar-On et al., 2020).

Figure 2. ISO container used in CSH

1.2 Classifications of Field Hospitals:

1.2.1 Level 1 field Hospital:

This level of hospital can be recognized as the first form of structured medical support which can be found in the field where both primary healthcare services and emergency treatment are administered. Level 1 field hospital should have the ability to ward approximately 5 patients per day, and anything more than basic injury should be transported to a higher-level field hospital or to the nearest primary hospital with the properly transportation mean and as quick as possible.

The staffing of level 1 field hospital must contain at least 2 doctors, 6 – 8 nurses and paramedics and 2 support personnel including 1 ambulance driver. The structure of the field hospital is tent-based, but containers and buildings can be used if available, in terms of infrastructure, the level 1 field hospital doesn't need electricity supply or water supply.

The capabilities of level 1 field hospital are to treat minor and common illnesses, basic wound care like dressing and changing the dressing, advanced cardiac life support like CPR and defibrillation procedures and basic surgery in case of emergency.

Figure 3. Level 1 field hospital

1.2.2 Level 2 Field Hospital:

This level of field hospitals provides more advanced medical support in the fields, it comes with larger and more wards with advanced life support, the most noticeable thing about level 2 field hospitals is that it is supported with basic dental facilities, radiology facility and laboratory unit.

The staffing of level 2 hospitals must contain at least 5-6 doctors including surgeons, internist and anesthetist, 1 dentist and 1 hygiene specialist, 12-16 nurses and paramedics and 6-10 supporting staff including ambulance drivers. The structure of level 2 field hospital can be tent-based or containers-based or both and it may have wheels to transport it from one site to another. It must have an outpatient clinic, an emergency ward with a triage room to sort patients' priorities according to their condition, several wards including isolation unit in case of receiving highly infectious patient, dental clinics to provide basic dental health services, laboratory and radiology units and hospital support and administration department.

The capabilities of level 2 field hospital lays in treatment of medical conditions and infectious diseases with emergency services, basic dental services, field laboratory and radiology services, pharmacy and hygiene control with preventive medicine. Level 2 field hospital can be upgraded to level 2+ by providing additional wards and services like adding surgical operation room with recovery ward and ICU ward.

Figure 4. Level 2 field hospital

1.2.3 Level 3 Field Hospital:

Level 3 field hospital can be equivalent to a general multidisciplinary primary hospital, because it can provide comprehensive medical care for up to 5000 population, with the ability to conduct up to 10 surgical procedures per day. The staffing of level 3 filed hospital must contain at least 15 – 20 doctors including surgeons, internist and anesthetist, 2 dentists, 1 hygiene officer, 40 – 50 nurses and paramedics, 14 – 20 supporting staff including ambulance drivers and technicians.

The structure of level 3 field hospital is a combination of tents and containers, it must have 3 – 4 consultation rooms, triage and resuscitation facility, 2 wards with ICU and isolation, surgical suite with multiple operating tables, dental clinic with surgical dental capabilities, laboratory and radiology facilities, pharmacy and medical store, administration and hospital support facility and general support facilities including running water and independent electricity. This level of field hospital needs 3 phase main power to provide the steam sterilization system with sufficient power, also for the CT scan system which is optional in level 3 field hospitals.

Level 3 field hospital must provide multidisciplinary inpatient services, emergency and elective surgery procedures, ICU medical care, laboratory and investigative radiology, full pharmaceutical support and specialist dental care including dental surgery.

Figure 5 . Level 3 field hospital

2.Literature Review: A lot of field hospitals around the world helped in providing medical services during disasters and catastrophes, these field hospitals were established by the same countries which contained the disasters, or by another country which tends to help the afflicted countries. The Hashemite kingdom of Jordan was always one of the first countries which hurries to help afflicted countries, the Hashemite kingdom of Jordan established a level 3 field hospital in Gaza during the Zionist occupation bombardment which killed hundreds of people and strayed thousands of them in 2010, the field hospital was equipped and staffed by the Jordanian Army Forces, it was established to continue providing all kinds of medical care services even after the truce with the Zionist occupation.

Gaza field hospital's structure is depending on using buildings and caravans, the building used for this field hospital is an old hospital which stopped working long ago, so the Jordanian Army Forces rented that place to equip it with new medical devices and equipment. A large section of the old hospital used for bunkers for the military medical staff, the supporting military staff, the administrative medical staff, while the remaining space of the field hospital, which was larger than the bunker-reserved area, used for providing the medical services.

The Gaza field hospital of the Jordanian structure contained two operation theaters, an ICU ward contained 6 beds, two separate wards for male and female admission and inpatient healthcare services, a radiology unit, a laboratory unit, an emergency hall with a triage room. The field hospital contained a dental unit, a pharmacy and a large store for medical support. The staffing of this field hospital was sufficient to provide a comprehensive medical service, it contained 15 doctors including one dentist, one anesthetist, one radiology doctor and 4 surgeons. The nurse staffing contained 30 nurses to support all types of healthcare services. The supporting staff of the field hospital was about 30 persons with different occupations, included radiologists, laboratory technicians, biomedical engineers, ambulance drivers, administrative staff and other hospital supporting personnel.

This field hospital was designed to provide comprehensive medical services, like emergency and elective surgery procedures, ICU medical care, laboratory and investigative radiology, full pharmaceutical support and specialist dental care including dental surgery. The staffing of this field hospital changes every two months, and in every changing procedure, a replenishment of pharmaceuticals is done. This field hospitals power is depending on on-site electricity generators, which can provide 3 phase electricity to operate the steam sterilizer used in the field hospital.

Figure 6. Gaza field hospital of the Jordanian

Another field hospital established by the Jordanian Army Forces in Jordan to fight against the pandemic Covid-19, its name is Prince Rashed bin Al Hasan field hospital in Irbid, it was established in December of 2020, this field hospital was dedicated to receive complicated cases of covid-19, thus it was equipped with the highest level of medical devices to provide the ultimate healthcare services. This field hospital is fully staffed by the Royal medical services with the best quality medical staff, this field hospital is level 3, it has the capacity of 300 beds, 48 of them are dedicated for ICU and 12 are dedicated for medium care unit which are ready to be transformed to ICU unit.

The staffing of the field hospital contained 600 persons, including doctors from all specialties, all types of nurses, medical staff personnel, radiologists, laboratory technicians, biomedical engineers, ambulance drivers and administrative staff. The field hospital structure is depending on a combination of tents and containers, the structure was good designed with good ventilation and strict preventive measures to prevent infection since Covid-19 is an air-borne virus, the field hospital has an advanced air conditioning system and good mechanical support.

Oxygen providing is a key component in fighting covid-19 virus, thus Prince Rashed bin Al Hasan field hospital is equipped with three main oxygen tanks, each one with the capacity of 160 m^3, this oxygen is delivered to every bed inside this field hospital through a grid of pipes with a pressure of 3.5 – 4.5 bar. Prince Rashed bin Al Hasan field hospital was established around the primary hospital (Prince Rashed bin Al Hasan hospital) to continue its medical services even after the end of the pandemic.

Figure 7. Prince Rashed bin Al Hasan field hospital

Figure 8. another picture of Prince Rashed bin Al Hasan field hospital

Another field hospital dedicated for Covid-19 was inaugurated in Amman in December of 2020, it is considered the third field hospital dedicated for Covid-19 in Jordan, it was established on the grounds of Prince Hamzah hospital and was called "Amman field hospital for Covid-19", the hospital has a capacity of 408 beds including 84 ICU beds, this field hospital staffing depended on the ministry of health and volunteers (Petra AG, 2020).

A Jordanian field hospital established in Beirut, Lebanon, this hospital was dispatched in the aftermath of the 5/8/2020 Beirut port explosion. Orthopedics, burns, and general surgery were prioritized. The hospital has 50 beds, including 6 intensive care beds, two operating rooms, an emergency department, surgical department, internal department, x-ray room, dentistry clinic, laboratory, and sterilizing department.The field hospital lasted 31 days, during which time the hospital visited 2,200 patients and performed a number of surgeries on some of them.

Figure 9. Jordanian field hospital in Lebanon

Figure 10. Operation theatre in the Jordanian field hospital in Lebanon

With the unfortunate ongoing international COVID-19 outbreak, many countries and regions face hospital capacity problems, and some countries didn't have this problem such as the USA; the Army Corps of Engineers have taken actions in the U.S. by hiring private contractors to build emergency field hospitals dedicated for COVID-19 around the country, this action costed more than $660 million, but it was shocking that most Army Corps field hospitals haven't seen a single patient(Rose, J., 2020). In the next table, it is shown how many patients transported to the U.S field hospitals, and how much costed every field hospital.

FACILITY NAME	LOCATION	CONTRACTOR	TOTAL COST	MAXIMUM BEDS UNDER CONTRACT*	TOTAL PATIENTS
SUNY Stony Brook	Stony Brook, N.Y.	Turner Construction Co.	$155,500,000	1,038	0
SUNY Old Westbury	Old Westbury, N.Y.	AECOM Technical Services Inc.	$118,504,737	1,022	0
McCormick Place	Chicago	Metropolitan Pier and Exposition Authority	$65,526,533	3,000	37
Westchester County Center	White Plains, N.Y.	Haugland Energy Group LLC	$46,971,895	100	0
Colorado Convention Center	Denver	ECC Environmental LLC	$34,609,792	2,000	0
Walter Washington Convention Center	Washington, D.C.	Hensel Phelps Construction Co.	$31,793,893	443	Not yet complete
Commercial Appeal Building	Memphis, Tenn.	AECOM Technical Services Inc.	$26,134,527	40	Not yet complete
Miami Beach Convention Center	Miami Beach, Fla.	The Robins & Morton Group	$25,925,692	450	0
Sherman Hospital	Elgin, Ill.	Turner Construction Co.	$18,255,251	283	0
Westlake Hospital	Melrose Park, Ill.	Bulley & Andrews	$16,391,366	314	0
MetroSouth Medical Center	Blue Island, Ill.	Clark Construction Group LLC	$14,989,955	350	0
Wisconsin State Fair Expo Center	West Allis, Wis.	Gilbane Inc.	$14,912,326	530	0
The Ranch Events Complex	Loveland, Colo.	AECOM Technical Services Inc.	$13,331,415	1,007	Not yet complete
Suburban Collection Showplace	Novi, Mich.	Gilbane Federal	$11,754,262	1,100	6
Javits Center	New York City	New York Convention Center Operating Corporation	$11,364,953	1,900	1,095
East Orange General Hospital	East Orange, N.J.	Cutting Edge Group LLC	$10,993,404	250	Not yet complete
TCF Center	Detroit	Gilbane Inc.	$9,452,813	1,000	39

Figure 11. U.S Field hospitals utilization

It should be noted that the information in the table above was due to May, 2020, so the field hospitals which were not completed in the table was just for the month of May. The most patient-receiving field hospital in the U.S was the Javits Center field hospital, during the three weeks it was open, the Javits field hospital treated about 1,100 patients (Lopez. T., 2020).

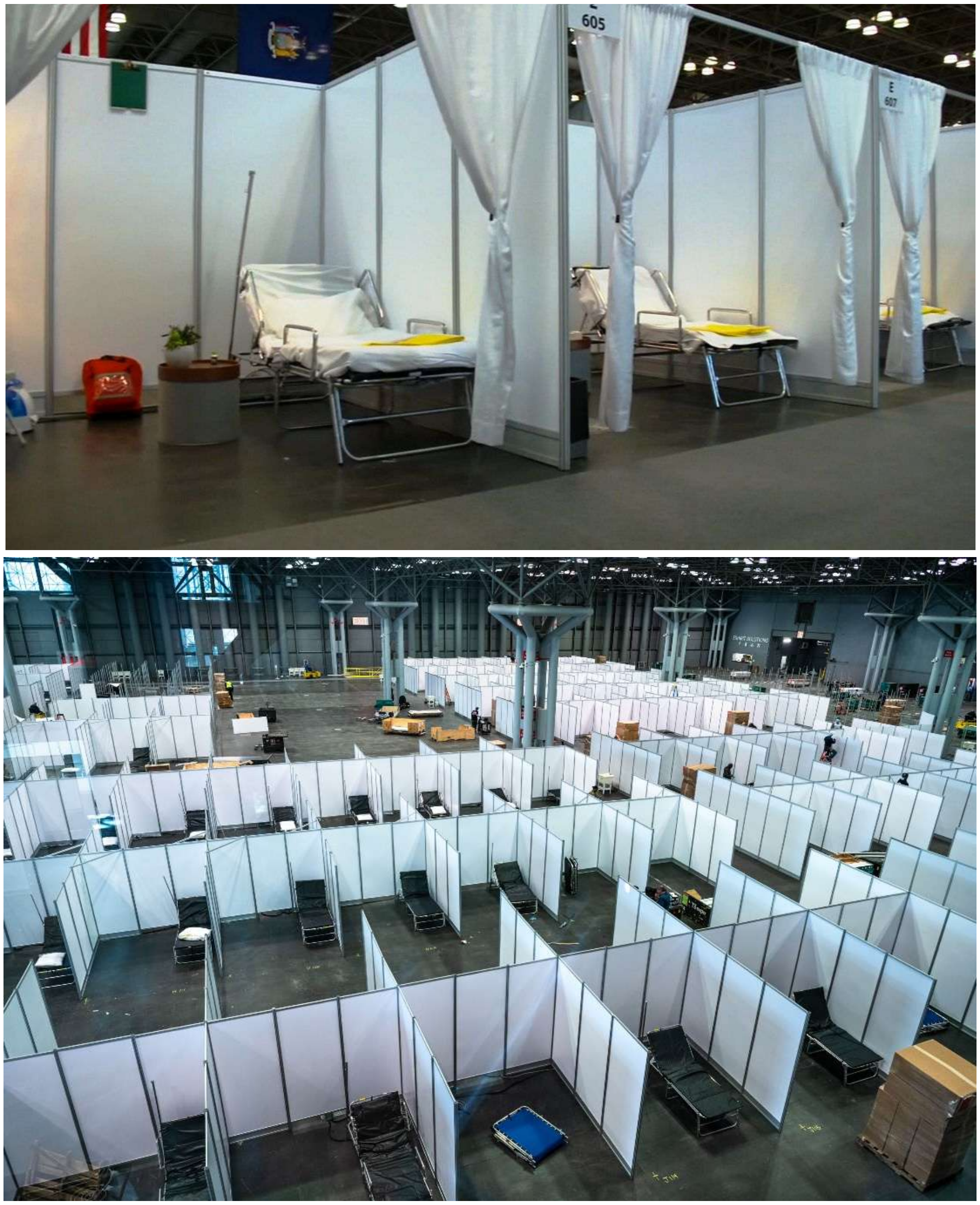


Figure 12. Javits Center Field Hospital

Baltimore Convention Center Field Hospital was the longest-running US COVID-19 field hospital opened in April 2020, and received 543 patients so far. It had 252-bed, its staff included physical therapists, occupational therapists, and social work teams to assist in patient care and discharge planning, its staff also included Rapid Response Team (RRT) and Emergency medical services (EMS) (Chaudhary, M.J., 2021).

Figure 13. Baltimore Convention Center Field Hospital

3.Methodology:

3. The Design of Multi-disciplinary Field Hospital:

A thorough design plan of a multi-disciplinary field hospital will be introduced in this chapter, based on the global standards of designing field hospitals, our long expertise in choosing the appropriate medical equipments and devices for the field hospital and our technical suggestions and improvements in the design of field hospitals and medical equipments modifications to make them fitted for a limited-source field hospital.

A multi-disciplinary field hospital is a field hospital which can be fitted for any type of use, e.g., in the case of natural catastrophes (Earthquakes, big fires, etc.), in the case of a global pandemic (spread of highly infectious airborne viruses) and in the case of war. In the normal circumstances, this multi-disciplinary field hospital can be used as outpatient specialty clinics to provide clinical medical services for people in who live in deserted areas where primary hospitals are far from there(Kim et al., 2010).

This chapter will be divided into four sections as follows:

- Infrastructure recommendations of the field hospital.
- Construction recommendations of the field hospital.
- Selecting medical equipments for the field hospital.
- Staffing recommendation of the field hospital.

3.1 Infrastructure Recommendations of the Field Hospital:

3.1.1 Field Hospital Location and Area:

Before the preparation of the infrastructure of the field hospital, it is very important to select the correct site for the field hospital to be built on. The site of the field hospital must be in a clear and plain site with a large area enough to contain all the healthcare facilities of the field hospital and the outbuildings belonging to the field hospital (Staff dorms, kitchen, etc.). from our expertise in military field hospitals, the recommended area for building a multi-disciplinary field hospital with 300 beds must be between 4500 m^2– 5000 m^2.The floor of the selected site for the field hospital must be solid flat or a hard standing floor (like concrete) to streamline the construction procedures (Vafaei&Öztayşi, 2014).

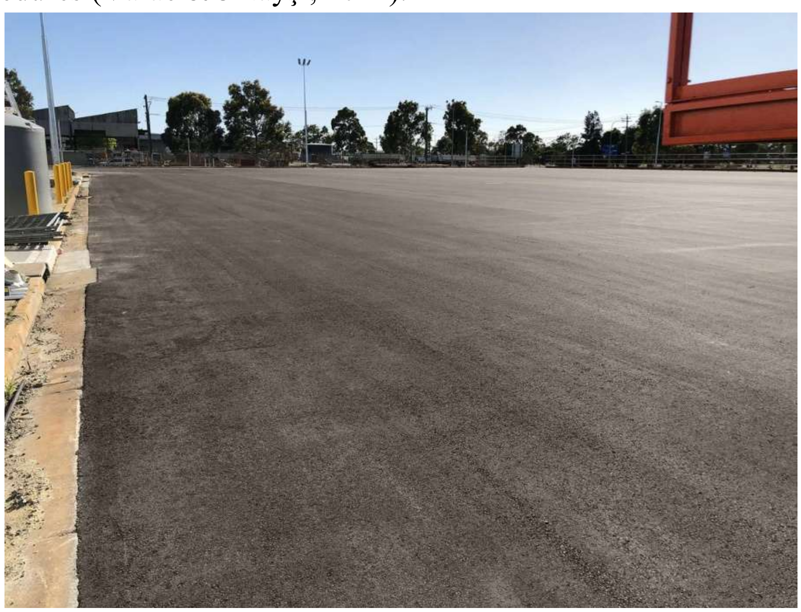


Figure 14. Hard standing land suitable to build a field hospital on it

3.1.2 Water Supply for the Field Hospital:

Hospitals -in common- requires different types of water to use inside them to provide the different medical services, these types of water are:

- Distilled water
- RO water
- Drinking water
- Other uses water (for washing and showering ... etc.)

Drinking water must be provided through two methods; first, through having a large quantity of bottled water which can be purchased through the local market, and second, through the treatment of municipal water by a drinking water purifier which can be used in homes like in the figure below.

Figure 15. Household drinking water purifier

Drinking water purifier principle of operation is based on the reverse osmosis (RO) filtration process, but it can provide low volumes of drinking water which can be sufficient for one department or dorm.

Municipal water can't be drunk due to the chemical materials added to it like chloramines, chlorine and fluoride which act as a filtration method to kill waterborne disease but it may cause other health problems, because they create toxic byproducts with the natural elements that are in the water. Hence comes the need to use an additional water filtration method such as RO so the municipal water can be used to drink in homes (Renzetti, 1999).

RO water can be used in the field hospitals to supply the laboratory unit's chemistry analyzer device, which needs the RO water along with other water processing stages like softening of water to measure the right quantities of chemical components of blood through spectrometry, if the water isn't filtered and softened enough, then the chemistry analyzer will use turbid water which will affect the spectrometry process and this results in false quantities of chemical components in blood.

RO water can also be used to clean injuries and bruises, and in sterilization departments, where it can be used in the primal washing and disinfecting of contaminated surgical and other medical services tools, and in the steam sterilizers where RO water can be used to generate steam (El-Manharawy & Hafez, 2001).

Total Dissolved Solids (TDS) meter is a handheld device which can be used to measure the amount of TDS in the filtered RO water to make sure it is in the right allowable range of TDS, which is from 0 -10 to use in chemistry analyzer, and from 50 -150 to use for drinking. The presence of multiple TDS meters is a must in a field hospital (Howard, 2002).

Figure 16. TDS meter

Water distillation is a process where water is boiled into vapor and condensed back into liquid in a separate container. Impurities in the original water that do not boil below or near the boiling point of water remain in the original container. Distilled water is used specifically in the laboratory unit where some tests require distilled water instead of RO because distilled water is left behind with no remaining impurities, including essential minerals (Saidur et al., 2011).

Figure 17. Water distiller

Water softening is an important water treatment process which aims to remove calcium, magnesium and other cations in water, this stage of filtration is necessary in the laboratory unit, because chemistry analyzers require softened water, so a water softener is a must in the field hospital (Wang & Lin, 2019).

Figure 18. Water softener

Other uses water can be supplied as the municipal water itself; it's treated in the municipal water treatment unit where chemical compounds (like chloramines, chlorine and fluoride) were added to the water to filter it and make it ready for different types of uses but not for drinking.

3.1.3 Electric Power Supply for the Field Hospital:
The main electric power required for the field hospital is a single-phase electricity for the most uses of the field hospitals, like lighting, functioning of medical devices and other important electric-dependent services. The field hospital requires 3-phase electricity also, because there are machines which require 3-phase like the CT scan system and the steam sterilization machine.

The 3-phase electricity can be supplied through two ways; first through a shore line where a near building which can supply 3-phase electricity, or from a near electricity station, the second way is through using a 3-phase generator. The 3-phase generator must be cooled diesel generator which can produce at least 40 kWh to power up the sterilization machine and the CT scan system with the cooling required for it at the same time without any interruptions (Timbus et al., 2005).

Figure 19. 40 kWh Water cooled diesel 3-phase generator

Single phase electricity can be obtained from shore line from a near building or a near electric station, from single phase or 3-phase generator where a 93.7 kWh can be used to power up the whole field hospital including the single and 3 phase requiring systems, or from a solar energy system which can be used to power up the lightings and other small necessary loads, by this way, the solar energy can act as a backup to a 93.7 kWh 3-phase generator and this can be enough to function the whole field hospital without the need to shore lines or nearby electricity stations.

The solar power system must be able to produce 30 kWh of DC voltage, which is equivalent to 3,000 to 4,000 kWh of AC voltage. The area needed for this solar power system with the specified output power is around 160 meters square, the solar power system can be used on the rooftops of various section of the field hospital to exploit the area efficiently. (Makdisi et al., 2020).

The electricity network of the field hospital must have a backup plan in case of power off either from the generator due to a malfunction in it or from the shore line where solar energy power is not enough due to a bad weather. An uninterruptible power supply (UPS) large enough to power up the whole field hospital for a limited time until the power off problem is fixed, 100kW, 480V 3-phase UPS is enough for this purpose. The UPS solution can guarantee continuity where no outages to critical life support devices can occur, it can also provide consistency where it can eliminate glitches or surges and allows time to safely shut down main systems if and when needed, it can protect against all the oddities of electricity such as surges, spikes, dips and failure because the UPS essentially senses those things and switches to alternate power before the anomalies cause damage. The UPS can act as a kind of filter by refining the power as it comes into the UPS then adjusting its output so that internal systems receive a clean, consistent supply free of abnormalities.

The UPS require a small room (at least 5 meters square) with an adequate air ventilation and air conditioning (1 ton is adequate) to function properly, it also requires a 3-phase 480V AC 50Hz frequency. The output of the UPS must be distributed according to the priorities in the field hospital, where life support devices and operation rooms with their equipments set at the top of the priorities list(Halpern et al., 2003).

Figure 20. 100 kWh 480 V UPS

3.1.4 Medical Waste Management of Field Hospital:

Medical waste management and good drain system planning is required for field hospital to maintain clean and healthy environment for patients and staff, general and medical waste may pose a great danger, where highly infectious viruses may spread due to poor medical waste management, medical waste are far more dangerous than general waste, because it contains the remains of infected patients medical servicing. Medical wastes can be sorted as follows:

1) Infectious wastes: they are wastes which contain or suspected to contain the causatives of infectious diseases (Bacteria, Viruses, Parasites and Fungicides).
2) Autopsy Wastes (Pathological): they are the wastes which are related to the body of the patient or any part of its components like tissues, sick organs which extirpated, amputated extremities and organs, dead embryos, body fluids (blood, cerebral spinal fluid, seminal fluid, other body secretions) and biopsies.
3) Sharp Wastes: they are the tools which may cause a cutting or puncturing to the human skin like syringes, scalpels, X-acto knives, the blades used in surgical procedures, nails, broken glass shatters and etc.
4) Chemical wastes: they are the solid, gaseous and liquid wastes which are produced from diagnosing processes, treatment processes and experimental processes, or from the cleaning and disinfecting procedures.
5) Pharmaceutical waste: it's the raw materials, medicines, expired pharmaceutical materials, non-conforming to specifications, not usable pharmaceutical materials and some pharmaceutical industry wastes.

6) Pressurized packages: the packages which contains pressurized gases like pesticide cans, oxygen cylinders, Ethylene-oxide cylinders and others which may be used in treatment of patients and which are explosive if prone to high pressure from inside or outside.

Medical waste collecting and sorting is a key component in managing medical wastes, medical wastes must be collected at the site of generation, patient beds, isolation rooms, operation theaters and laboratory units are the most medical waste generation sites (Klangsin & Harding, 1998). The sorting process of medical wastes lays in providing multiple wastes containers suitable for each type of medical wastes according to the ministry of health color-coding regulations regarding medical wastes sorting as in the table below:

Waste Type	Color Code	Container Type
Highly infectious waste	Red	Plastic bag or plastic container
Other infectious waste, autopsy waste and sharp waste	Yellow	Plastic bag or plastic container
Chemical waste	Brown	Plastic bag or plastic container
Chemotherapy waste	Blue	Plastic bag or plastic container
Not dangerous medical waste	Black	Plastic bag or plastic container

Table 1. Color coding for medical wastes sorting in Jordan

Sharp waste must be collected in plastic containers, these plastic containers must be made of non-halogenated burnable plastic, and they must be solid and durable and impermeable. Medical wastes need to be stored outside the field hospital temporarily before treating them with the final treatment method, the medical wastes storage site must be away from warehouses and places of food preparation and from staff residents. The storage period for waste should not exceed 48 hours in the winter and 24 hours in the summer, unless the place is cooled.

Medical wastes storage floor must be constructed of a solid, impermeable and smooth material that is easy to clean and disinfect, and it is serviced by a good sanitary drainage system. The walls should be smooth and polished at a height of not less than 1.5 meters, the storage must be provided with a water source for cleaning purposes. The possibility of closing the place to prevent the entry of non-interested persons is necessary and the prevention of entry of animals, birds and insects is necessary too (Yao et al., 2020).

Figure 21. Example on proper medical waste storage

Medical wastes need to be transported from the generation site multiple times a day to a temporary waste storage before the final treatment stage, the transportation mean (the carrier) should be clean and in good shape, the staff responsible for transporting the medical waste must check on the carriers every time they use it to prevent the chance of spilling or dropping some of the carrier contents thus prevent the risk of infection during the transportation process. The means of transport must be cleaned and disinfected daily or directly in the event of a leak or spill on the surface of the means of transport, ensure that waste bags arrive sealed and intact at the end of the transportation process. Every medical waste carrier should have a tag on it, the tag must contain the following information: The name of the healthcare facility and the section from which the waste is generated, the type of waste contained in the bag or package and the date of collection.

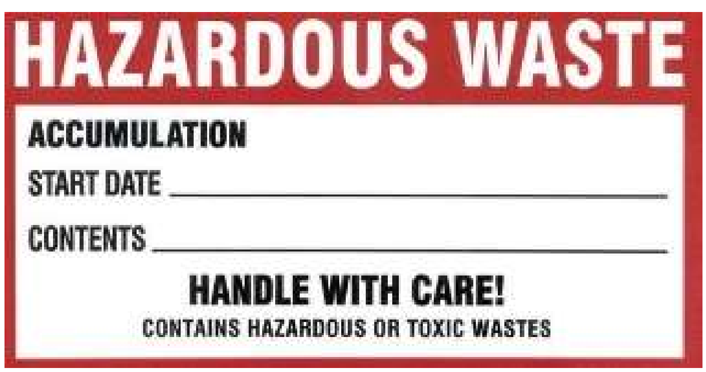


Figure 22. Example on medical waste tags

Before the final treatment of medical wastes, there is a stage called "shredding", where a machine also called "shredder" can cut the medical wastes into small pieces and reduce its volumes to be ready for the final treatment.

The treatment of medical wastes in field hospitals can be done by using nearby sanitary landfills. The sanitary landfill location must meet the following requirements:

1. Approval of the Ministry of Health and other relevant official authorities and the authority responsible for the landfill.
2. Easy access to the landfill site.
3. The presence of the necessary engineering staff and the trained manpower necessary to manage the process.
4. Provide trenches around the site to protect it from surface water.
5. Provide a final cover to protect layers of waste from the arrival of rainwater.

Figure 23. Sanitary landfill

3.1.5 Medical Wastewater Management:

Hospital wastewater are produced in field hospitals on a daily basis, it is characterized with high risk because in comparison with domestic sewage the hospital wastewater contains wide variety of toxic substances like antibiotics, radionuclide's, and disinfectants. The optimal field hospital wastewater treatment scenario includes a combination of two technologies: MBR and FP technologies.

MBR (Membrane Bioreactor) technology, a membrane is a material that allows the selective flow of certain substances, so when wastewater flow through the membrane, undesirable species will retain on the other side, so the better the membrane, the better pollutant retention. Certain types of microbes are used to do the filtration function in this technology, multiple individual membranes are located inside units called "modules", these modules combine together to form a working membrane unit. Air is an important component in the filtration process; where it works as a cleaner to the surfaces of membranes and a mixing component in the filtration process (Khan et al., 2019).

FP (Fenton Process) is dependent on the Fenton reagent, which is a solution combined of peroxides such as (H_2O_2) and iron ions to form a catalyst which is used to oxidize contaminants in wastewater. These two technologies will lower cost and decrease the amount of reagents required for field hospital wastewater treatment.

Wastewater can be used after treatment to be a water supply for the circulation pump in steam sterilizers, this circulation pump doesn't need RO water to operate, and the water supplied to this pump doesn't affect the sterilization process nor the sterilization efficiency. By using the treated wastewater to this purpose, a great reduction of main water consumption is approached, so the main water supply can be sufficient to more important uses.

3.1.6 Gases Supply for the Field Hospital and how it is improved in this study:
Medical gases are key components in all hospitals because they mainly operate in the life support services and equipments and surgical operations, these gases are oxygen, nitrous oxide and medical air.

Oxygen is important for a patient who suffers from respiratory diseases and illnesses, like pneumonia, Covid-19 and others, so there is a necessity for an oxygen outlet beside every bed in the intensive care department and recovery department. Oxygen outlets must be available in the operation theaters as well because it acts as a driving gas in the anesthetic process.

Figure 24. Oxygen outlet

During the pandemic of covid-19, there was a huge demand on oxygen supply in the medical market, which posed a challenge and contest between oxygen suppliers and providers. Some hospitals emptied their oxygen reservoirs which caused multiple deaths like what happened in the Salt Governmental hospital, and this is increasing the importance of securing great amounts of oxygen.

In our design of field hospital, oxygen is supplied through three ways to avoid any risk of empty reservoir. The main method of supplying oxygen is by huge oxygen concentrators, these huge oxygen concentrators can produce up to 1700 liters per minute (LPM) with an oxygen concentration of 95%, which can be divided to 68 beds with flow of 25 LPM and this is sufficient for respiratory uses. This huge concentrator requires a dried air inlet from a compressor with a pressure of 6.2 bar, the concentrator requires a tank to store the generated oxygen, the capacity of the tank must be 4800 liters. The concentrator also requires a well-ventilated room with a temperature degree range from 4 – 40 Celsius degrees to keep it operating normally (Graham et al., 2020).

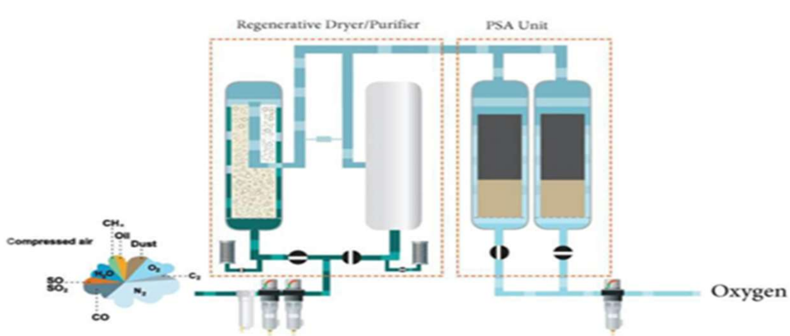
Figure 25. Large oxygen concentrator

The second method to supply oxygen is by storing it in liquid state and vaporizing it in case of need and deliver it to patient bedside through pipeline planning, oxygen is stored in liquid state to be less bulky and to reduce cost because storing oxygen in gaseous state is expensive, the tank required to store oxygen in the liquid state must has the capacity of 5000 liters to be sufficient for approximately 70 beds. The tank of liquid oxygen must be cryogenic tank, which is a tank used to store liquids at a very low temperatures, liquid oxygen has a boiling point of–183°C, by this way vaporizers uses the surrounding heat to vaporize the liquified oxygen and turn it into gas. A pressure controlling module is necessary to regulate and monitor the vaporizing process.

Figure 26.Liquid oxygen vaporizing

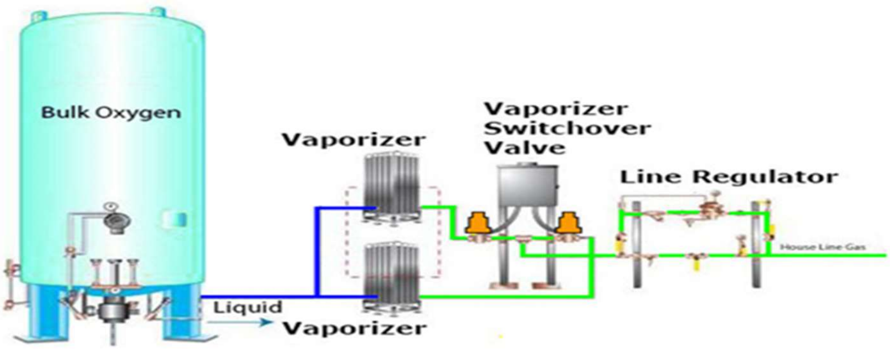
The third method of oxygen supply is through oxygen cylinders, where they must be available at the field hospital site, in sufficient quantities to avoid suffocating of patients who are connected to ventilators and oxygen masks, also to be able to operate surgical operations where oxygen is necessary for anesthesia.

Our design solved a huge problem facing field hospitals around the world in oxygen supply, we managed to use the three forementioned methods to avoid any oxygen supply interruptions, where is the outlet of the oxygen concentrator is lowered to 4.5 bar, and the outlet of the liquid oxygen vaporizer is regulated at 4.25 bar, and the outlet of the oxygen cylinders is set to 4 bars, a final one-way valve connecting the three lines of oxygen which is set to 4 bars. As the concentrator outlet is 4.5 bar, then it is the main supplier of oxygen, if there are any interruptions or decrease in the output pressure of oxygen, then the oxygen vaporizer will be the main method because it has a pressure of 4.25 bar. If there are interruptions in the concentrator and vaporizer outputs at the same time, then it will be the oxygen cylinders as the main method until the problem is solved in the other two methods.



stage A

Figure 27. Large oxygen concentrator



stage B

Figure 28. Liquid oxygen station

stage C

Figure 29. Oxygen cylinder system

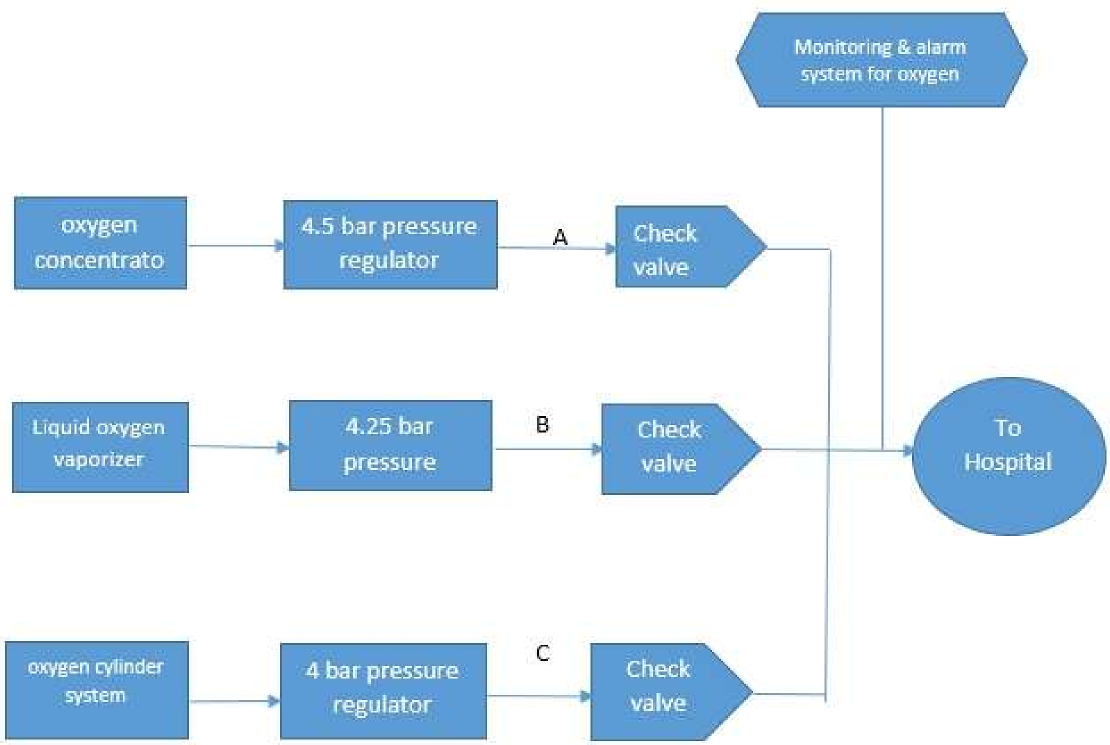


Figure 30. Our design to supply oxygen

Nitrous Oxide is necessary in field hospitals, especially in operation theaters, because nitrous oxide acts as an anesthetic agent and pain relief. Nitrous oxide can be supplied to field hospitals through cylinders and must be stored near the operation theaters to be ready whenever they are needed.

Medical air is an important gas which must be supplied to field hospitals, it differs from the normal air we breathe in terms of dryness and level of impurities, so a medical air compressor is used to dry the normal air from any liquid molecules and filter it with an ultra-filtration process, then the output is medical air ready for use. The medical air compressor must be able to provide the whole field hospital with medical air, a central medical air plant (combined of multiple medical air compressors) is used in field hospitals which can provide medical air with pressure between 4 – 7 bars, and this is enough to be delivered for every bedside in the interested wards like recovery and I.C.U. the most important specification which must be available in the selected medical air compressor is to be oil-free, because the presence of oils in an air system is often the root of gas contamination in field hospitals.

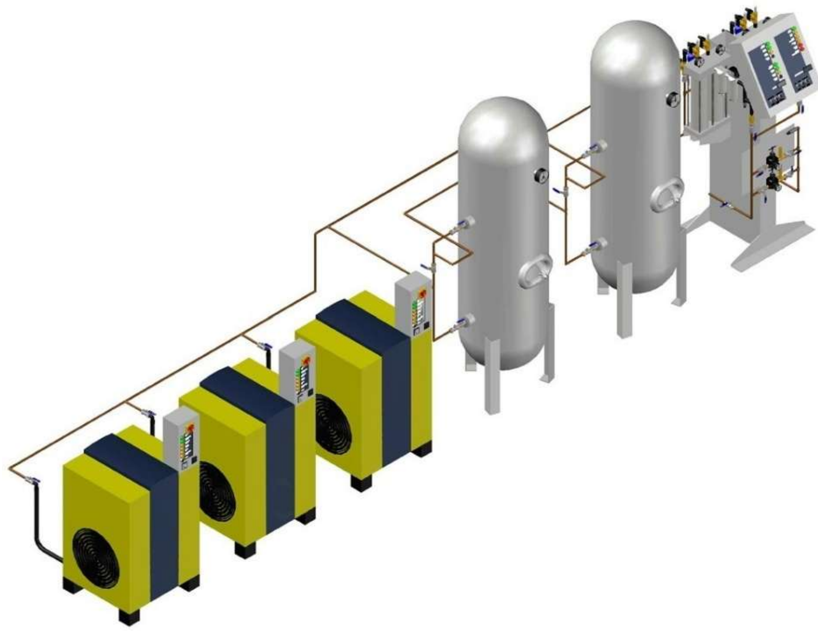


Figure 31. Medical air compression plant

3.1.7 Fire Alarm System for Field Hospital:

Field hospitals must have fire alarm system with the newest technology to prevent accidently fires from spreading and save lives, the technology which will be used in our design of field hospital is the Duct Smoke Detection, which works by using specified sensors to trigger an audible and loud alarm enough to alert all the facility staff to take action. The system recommended in our design divides the field hospital into small zones to be more accurate and precise, it must have the following sensors which should be located in the false ceiling:

- Heat sensors: this type of sensors is recording the regular temperature of the room, then if any raise in the room temperature occurs, or a sudden change of room temperature occurs, a trigger of fire alarm will be done. The principle of operation to this sensor is based on acting like a fuse; the sensor uses a eutectic alloy which is heat sensitive, when a certain temperature is reached the alloy turns from a solid to a liquid which in turn triggers the alarm.

- Smoke sensors: there are many types of smoke sensors, but the best type of smoke sensors is the Ionization smoke sensor, its principle of operation depends on having two chambers; the first is dedicated as a reference to compensate for changes in ambient temperature, humidity or pressure, the second chamber contains a radioactive source which ionizes the air passing through the chamber where a current flows between two electrodes and when smoke enters the chamber the current flow decreases, this drop in current flow is used to trigger an alarm.
- Carbon monoxide sensors: the principle of operation of this sensor relies mainly on using an electrochemical cell which is especially sensitive to carbon monoxide only, and not sensitive to smoke. Carbon monoxide is the result gas from combustion, therefore, when the CO sensor indicates CO in the air, an electronically triggering of alarm system is done.

Manual call points, which are devices covered by thin glass, must be present in a clear space where everyone can see it to trigger it in case of detecting fire before the sensors detect the fire. Fire hydrant hoses and fire extinguishers must be available everywhere and in quantities, location and specification according to the recommendations of Civil Defense department. Fire sprinklers must be available in every room, their water supply can be used by the treated waste water plant which is located in the field hospital. The communication system between sensors and the alarm system must be wireless, to avoid losing connection due to fire burning the communication cables between the sensors and alarm system.

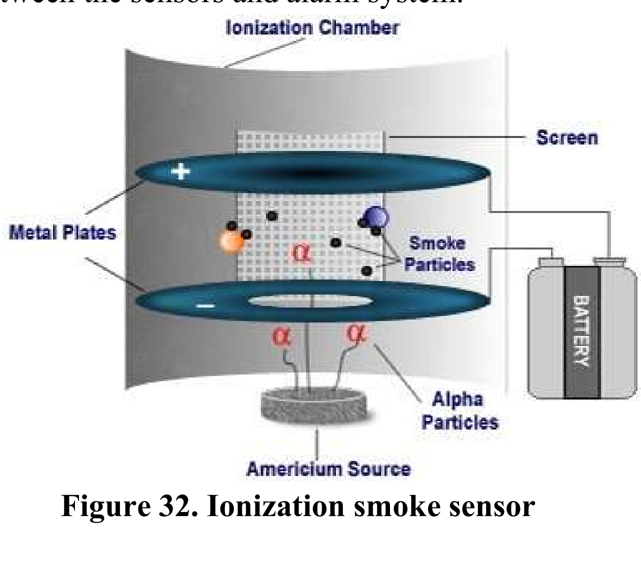


Figure 32. Ionization smoke sensor

Figure 33. Fire sprinkler

3.1.8 Heating, Ventilating and Air Conditioning (HVAC) system:

The HVAC system is responsible for maintaining good ventilation for patients who suffers from pulmonary diseases, it is responsible for cooling and heating the inside of the field hospital corresponding to the outer weather environments. The HVAC system is responsible for the negative pressure producing, which depends on large air-drawing fans, to keep the isolation sections, emergency ward and recovery ward in negative pressure to avoid the spread of infection in the field hospital.

In our design of the field hospital, the air conditioning system will be 170 tons divided into 11 units distributed around the field hospital to cover all the inside of the field hospital. The air flow inside the field hospital must pass through a galvanized-steel duct system. The negative pressure duct must be separate from the air conditioning duct, it must convey the negative pressure to the proper wards and sections in addition to the air locks compartments.

3.2 Construction Recommendation in Field Hospital:

3.2.1 Field Hospital Building Materials:

Field hospitals can be built from tents, special containers and already abandoned or dedicated buildings, in our case, field hospital will be constructed of special containers made for medical use, the recommendations of field hospital building will be as follow:

Outer walls of the containers must be sandwich panel with100 mm thickness, and they must be galvanized cold-formed steel panels and easy to clean, the inside of the sandwich panel must be rockwool to insure insulation.

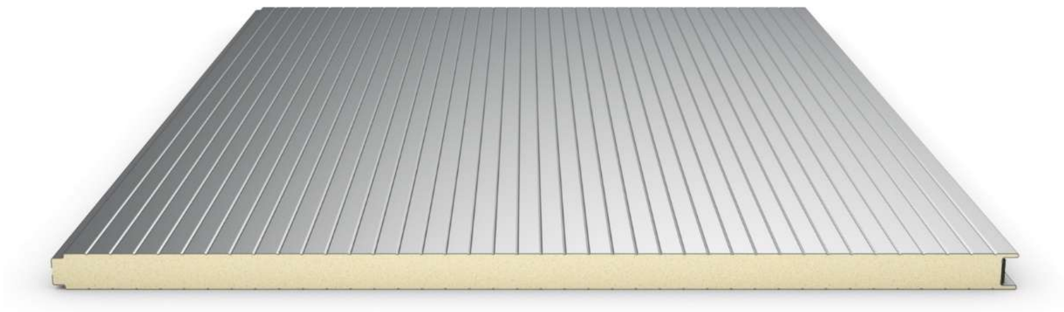


Figure 34. Sandwich panel

Inner walls must include insulation glass wool with 50 mm thickness sandwiched between two 12.5 mm thickness gypsum boards.

Figure 35. Glass wool used for insulation

The height of rooms and wards must be 5 meters, and the height of false ceiling must be 3 meters, so the 2 meters void remained as a space for pipe lines and power lines and other infrastructure uses such as ventilation ducts. The floor of the field hospital must be finished with non-slip antibacterial vinyl, it is made from PVC and it prevents the growth of fungi and bacteria, it is easy to clean with protection from slipping.

Figure 36. Antibacterial vinyl flooring

The field hospital requires air locks and air locks doors, air locks are small empty rooms located between isolation rooms, recovery rooms and other areas, it is used to prevent air from entering or exiting the isolation rooms and recovery wards. It must have two doors that are electronically interlocked so that both cannot be open at the same time, this can prevent contamination and prevent particles from outside the cleanroom from entering the cleanroom when personnel enter or exit the cleanroom. Air lock doors must be automatic sliding doors, double leaf and frameless so they open and close together, they must be made from 12 mm thickness clear tempered glass.

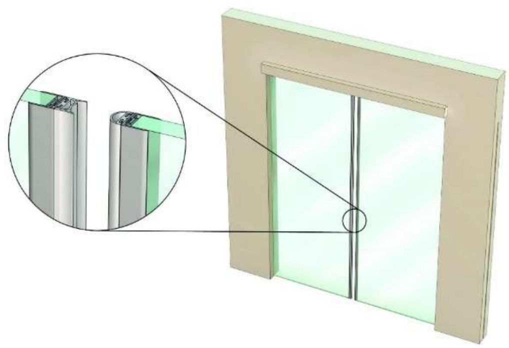


Figure 37. Airlock door

The field hospital must have a number of emergency doors according to the recommendations of Civil Defense department, the emergency doors must be aluminum framed with hinged single leaf, the emergency door must also have a panic push bar. The width of the emergency door must be 70 cm, and 5 cm thickness.

Figure 38. Panic push bar

The field hospital must have adequate number of toilets sufficient for staff and patients, every toilet room called a pod, the toilet pods must be well ventilated, drained and plumped. The doors of the toilet pods must be aluminum framed single leaf hinged door, it must be sandwich panel too.

The windows of the field hospital must be fixed so the patients can't open them to prevent entering infectious air molecules to the room, also because the inside of the field hospital is an air-controlled environment in terms of air cleanliness and temperature. The glass of the windows must be 6 mm thick clear tempered glass.

3.2.2 Distribution of Field Hospital Sections:

Our design for field hospital must include 320 beds, 50 I.C.U beds and 250 different wards beds including 20 isolation beds and 30 recovery beds, and 20 emergency ward beds. The field hospital must include 20 toilet pods for each isolation bed, 15 toilet pods for other beds and wards, 10 toilet pods for the staff (Luo et al., 2020). The flow of patients through the field hospital is unidirectional, which means that patient or the visitor access the sections of the field hospital in arrangement that doesn't require him to go back for a necessary step according to the European model of field hospitals (Bakowski J., 2016).

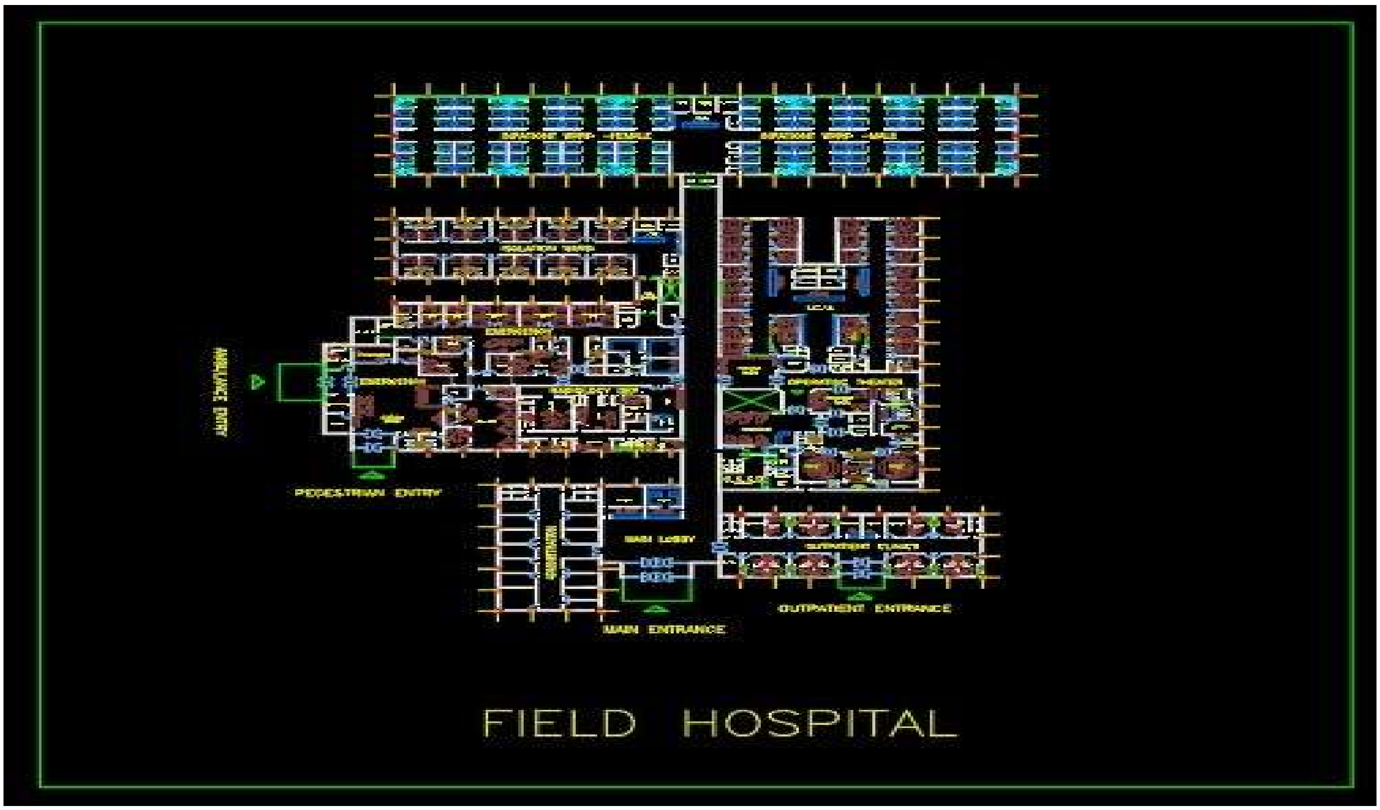


Figure 39. Blueprint of the field hospital

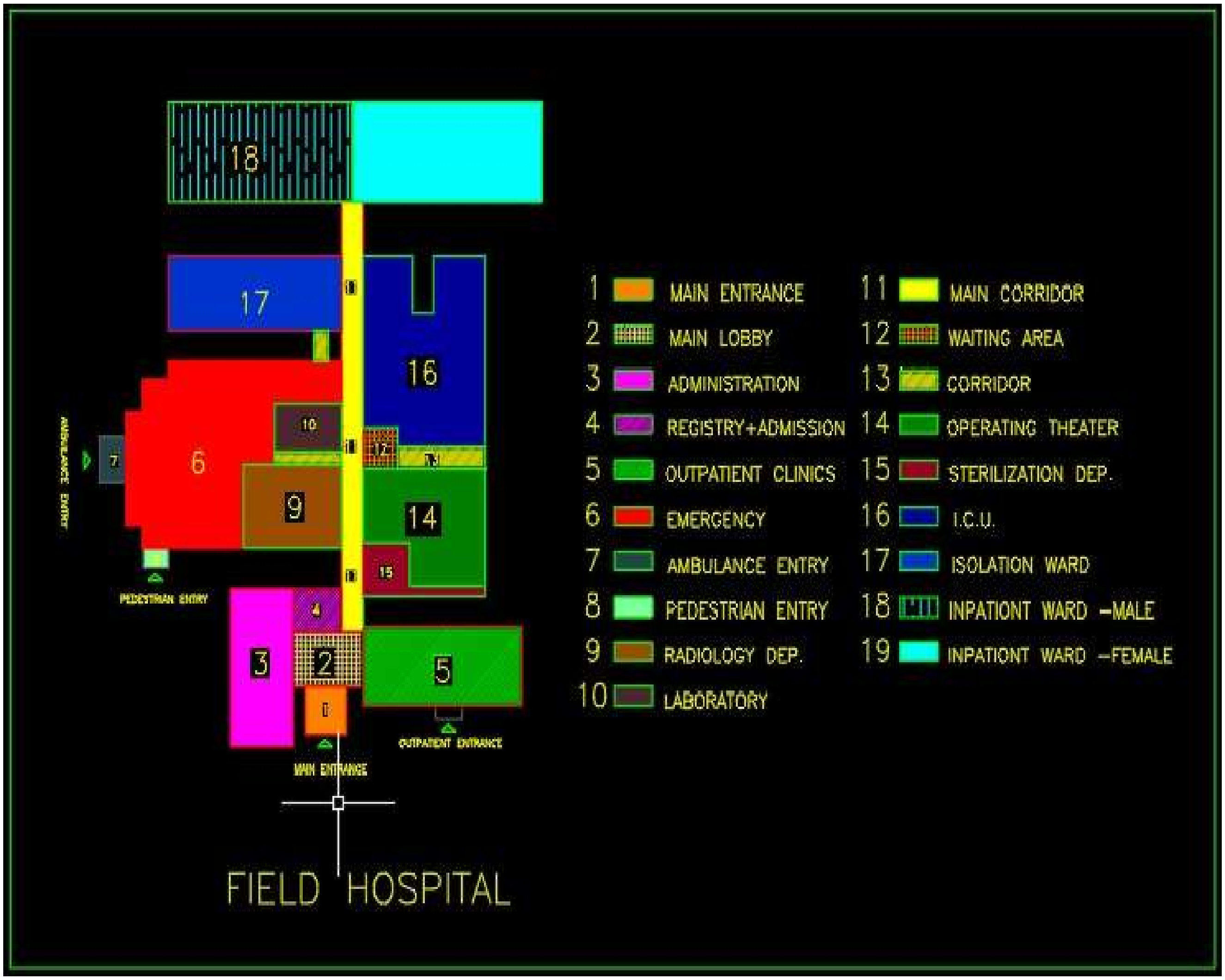


Figure 40. Blueprint of the distribution of field hospital

The field hospital must have the following sections:

- Administration department: the administration department must be located in the forefront of the field hospital; it should contain the offices of the director of the field hospital and logistics services offices. The administration department must also include the log/record section where the patients' information is taken and recorded before they get administered to the hospital, and to get the necessary papers before the patients exit the hospital.
- Outpatient ward or clinics: the field hospital is designed to serve multiple disciplines, so it can be used to treat patients who don't need admission, so a number of specialty clinics must be available, including surgical, internal, ophthalmology, gynecology, pediatric, dermatology and urology. The area of clinics must be in the forefront of the field hospital, because a lot of patients will aim to them, therefore, the traffic will be high and make it away from other remaining sections is a wise decision.
- Emergency ward: emergency ward must be divided into five main sections; the first section must be the triage section, where patients come to in the first place to be sorted

into the specified specialty, then, the specialty doctor assess the patient's case and determine whether he needs admission or not, in the triage section, the nurses measure the temperature of the patient and his blood pressure so the emergency doctor can assess their cases quickly. The second section is the observation wards of emergency, where patient beds are located, and the wards are divided into surgical ward, internal ward and I.C.U ward, where the assessment of patients takes place. The third section of the emergency ward is dedicated for the emergency medical services (EMS), which is a requirement in field hospitals and its function to transport patients to another hospitals in case the patients case worsen and need advanced medical services. The fourth section is reserved for trauma (resuscitation), where the rapid response team (RRT) are located. The fifth section is the treatment section; more like an operation theatre. The distribution of these sections is according to the European model, where the patients' flow is unidirectional (Bakowski J., 2016). The entrance of the emergency ward must be away from the main entrance of the field hospital, to avoid any blockings due to traffic in case of emergency deliverance to the field hospital.

- Dental clinics: there can be two dental clinics in the field hospital, and this is sufficient, dental clinics can be useful for basic conservative services, and not for advanced surgical dental procedures. The location of the dental clinics must be adjacent to the outpatient clinics, as they are there for the same reason.
- Radiology unit: the radiology unit and the laboratory unit must be adjacent to each other, because both of them are diagnostic units, and both of them need to be between the emergency ward and other wards, to streamline the access to them by patients whether they are from the emergency department or inpatients from other wards. The radiology unit must have the proper healthy measures as recommended by the Energy & Minerals Regulatory Commission (EMRC), in terms of putting the lead in the walls of the examination rooms where X-ray is used, like in the digital x-ray system or in the CT scan room. The radiology unit must have the following sections; digital x-ray room, CT scan room, images viewing and reports writing room, ultrasound room and reception room where patients' data is entered, and where the cassette reader is present.
- Laboratory unit: as mentioned earlier, laboratory unit must be adjacent to radiology unit, the laboratory unit must have the following sections: water filtering room, blood bank room where blood bank refrigerators and blood donor chairs are located and blood aspirating room. The blood bank room must have a back door to serve people who came to donate blood. it is preferred for the laboratory unit where biosafety cabinets and other devices which dedicated for infectious viruses'tests to be in a negative-pressure controlled environment, to prevent spreading infectious diseases in case of anything goes wrong.
- Operation theaters: the location of operation theaters must be away from the entrance of the field hospital, two operation rooms are sufficient for a field hospital, where emergency surgical operations and intermediate surgical cases can be done. A preparation room must be available inside the operations department, where patients are clothed with the proper clothing, and they get their blood pressure and heart rate measured. There must

be an air-lock at the entrance of the operation theaters to avoid transporting infectious viruses to the operation theaters.

- Recovery ward: this ward must be adjacent to the operation theatre, so the patients who have their operation done, are transported to the recovery ward, so they get taken care of until they appear in a state where they can be sent to other wards.an air-lock must be available at the entrance of the recovery ward.
- I.C.U ward: this ward is dedicated for patients who get in very bad health situation, so an advanced and serious healthcare must be provided more than the healthcare provided in inpatient wards. The location of the I.C.U ward must be between inpatient wards and recovery ward, and an air-lock chamber is needed at the entrance of it.
- Isolation ward: this ward is dedicated for patients with highly and dangerous infectious diseases, like covid-19. Every patient must be put in a separate pod (small room) which can have the capacity to contain a bed, toilet pod, T.V and room for biomedical equipment. Main air-lock must be available at the entrance of the isolation ward, the passage to every patient pod must be in air-locking system, and the whole isolation ward must be in negative - pressure controlled environment. The location of the isolation ward must be at the end of the field hospital, to keep non-isolated patients, people and other staff away from it to avoid infection.
- Inpatient wards: inpatient wards can be divided into male ward and female ward; each ward can contain internal and surgical cases.
- Sterilization department: this department must be close to the operation theaters, to streamline the transport process of sterilized tools which are used in surgical operations. The sterilization department must be divided into three sections: the first section is the dirty zone, where the materials and tools need to be sterilized are received, washed and disinfected to be prepared for the sterilization process, the second section is the sterilization zone, where the sterilization machines are located. The third section is the clean zone, where the sterilized tools and materials are stored to be ready for use in operation theaters and dressing procedures. The sterilization department must have two doors, one for the dirty zone, and the other for the clean zone, the door of the clean zone must be near the operation theaters, and if possible, a direct door between the clean zone and operation theatre can be very useful to save time in transferring sterile tools during the operation, and to minimize the chance of catching infectious disease on the way.
- Medical waste storage: as mentioned earlier, the medical waste storage must be a building with specifications according to the recommendation of ministry of health, the location of medical waste storage must be outside the field hospital, to keep the inside of the field hospital clean and sterile.
- Medical store: the medical store must be located adjacent to the pharmacy, to streamline the transporting process between the store and the pharmacy. The store must have two doors, one is direct to the pharmacy and the other is to the outside of the field hospital. The door which is directed to the outside must be large and double-leaf hinged door, to streamline the supply process of bulky drugs and other pharmaceuticals materials to inside the store.

- Pharmacy: the pharmacy location must be close to the emergency ward, to keep the outpatients away from other wards like the isolation ward. The window of disbursement of treatment must be directed to the outside of the field hospital, to avoid the accumulations of people in front of the field hospital, and this helps to keep the field hospital calm and sterile.
- Mortuary: the location of the mortuary must be at the end of the field hospital, and it must have two doors, one to receive dead bodies from wards inside the field hospital, and the other is to the outside of the field hospital, to transfer the dead bodies to their graveyards.
- Biomedical workshop: the location of the biomedical workshop must be in the middle of the field hospital, to be close to almost every ward and unit, at the same time, the biomedical workshop must have a door directed to the outside of the field hospital, because the biomedical staff need to do some cleaning procedures of biomedical devices in an open area, like clean air filters from the inside of ventilator devices. The biomedical workshop must have pipelines of compressed medical air, oxygen and RO water to test and fix the different biomedical devices which need those supplies.
- Kitchen: the kitchen must be located away from all wards, to keep smells away from the inside of the field hospital. The kitchen must have two large double-leaf hinged doors, one in the inside of field hospital, and the other to the outside of the field hospital, to receive the food items and supplies.
- Supplies for field hospital: outside the field hospital, there must be separate containers dedicated for each of: the wastewater treatment plant, power generation and UPS, medical air compressors, oxygen concentrators and liquid oxygen tanks and vaporizers and central Heating, Ventilation, and Air Conditioning (HVAC). Each one of these mentioned, must be in a separate container and adjacent to the body of the field hospital.
- Transportation center: a separate container outside the field hospital with a small garage around it, the container is dedicated for the drivers of the ambulances and other vehicles, a small workshop must be inside the container to maintain the ambulances and other vehicles.

3.2.3 Selection of Biomedical Devices:

The biomedical devices selected for a field hospital are somewhat different from primary hospitals biomedical devices, each section of the field hospital will have the biomedical devices as follows:

- **Radiology unit:** this unit is considered the main diagnostic tool for doctors, it has the most expensive devices amongst the rest of biomedical devices, the main device of the radiology unit is the Computed Tomography Scanner (CT scan), it is not common to have a CT scanner in a field hospital, but in our design, it is a chance to level up the field hospital to LV3+, with the ability to house the CT scanner inside a lead-walls container, designed specifically for CT scanner. The idea of CT-specified container is not new to Jordan, where is there an installed one in the military field hospital of Zarqa.

  As mentioned earlier in this project, the power generator and the main UPS must be sufficient to power up a CT scan container, which includes the CT scanner itself, the computers attached to the CT scanner, the air conditioners installed inside the container in addition to the lightings. In case the main power generator isn't sufficient for the CT scanner and its peripherals, then a separate smaller power generator can be purchased to power up the CT scanner container.

It is better to have the CT scanner inside a specified container in a place outside the construction of the field hospital but inside the campus of it, and this is to avoid any x-ray leakage through the walls of the inside of the field hospital and to decrease the chance rate of any traffic inside the radiology unit. There are many containers structure manufacturers who can cooperate with the desired CT scan manufacturer to design the ultimate CT scan container. The CT scanner selected for our field hospital is 64 slice scanners, which is adequate to achieve images for a wide range of disciplines, such as bones images, abdominal diseases and illness, respiratory illnesses like Covid-19, brain diagnostics for headaches and etc.

Figure 41. CT scan inside a container

The second radiology device is the digital x-ray system, which consists of x-ray generator, x-ray tube and its ceiling suspension system, table and wall stand to house the flat panel detector, the digital x-ray system is more advanced than the conventional x-ray system, there is no need to process x-ray films after imaging, because the digital x-ray system displays the x-ray image in the same time as exposing the patient to x-ray. The presence of the table and wall stand is to make the digital x-ray system suitable for the majority of x-ray studies. The thickness of lead in the walls of x-ray room must be 1.5 mm to protect the x-ray technician and people outside the examination room since the x-ray can penetrate walls.

Figure 42. Digital x-ray system

A C-arm x-ray machine must be available at the field hospital, in the operation theater specifically, because C-arm are used during surgery operations of bones, vascular, neurosurgical procedures and etc. one C-arm is adequate for a field hospital.

Figure 43. C-arm

Mobile x-ray machines are necessary for field hospitals to diagnose inpatients who can can't move from their beds, mobile x-ray machines must be self-propelled type, where there is no need to use force to move the mobile x-ray and this provide more accuracy in movement to avoid collisions with people, objects and to save the mobile x-ray itself from damage. The mobile x-ray must be digital not analog, which means it must use a flat panel detector to view the x-ray image instantly without the need to use x-ray image processor, the digital technology saves time. The flat panel detector must be wireless to avoid problems of cutting the wire from inside or the wire get tangled. The number of mobile x-ray machines required for a field hospital is two, one is used between wards and emergency ward, the other will be located inside the isolation ward, to use it specifically for isolated patients.

Figure 44. Digital mobile x-ray machine

- **Laboratory unit:** The first laboratory device is the Complete Blood cell Count (CBC), a 3-part differential type of this device is adequate for the field hospital, which is able to measure and calculate the quantity of main cell types of blood, such as red blood cells, white blood cells, platelets and hemoglobin. One CBC device is adequate for the field hospital.

Figure 45. 3-part differential CBC device

A centrifuge is a necessity in the laboratory of the field hospital, to prepare the blood samples for the next tests, like chemistry test. The centrifuge needed for the filed hospital must be a low range bench-top type, which have the maximum rotation per minute (RPM) of 5000. Two centrifuges are required for the field hospital where one of them is a backup centrifuge in case the main one is defective.

Figure 46. Low range centrifuge

Chemistry analyzer must be available in the laboratory of field hospital, it is used to measure the level of chemical components in the blood through spectrophotometry principle, where the light which passes through the blood serum sample is measured to determine the light absorption and calculate the quantity of chemical components, such as blood sugar, cholesterol, triglycerides and etc. one device is sufficient, and the chemistry analyzer must be equipped with its own UPS and water filtration system.

Figure 47. Chemistry analyzer

Urine analyzer must be available, to detect urinary tracts inflammations and sedimentations, one urine analyzer is sufficient. Arterial blood gas analyzer (ABG) must be available in the field hospital, to measure the levels of partial pressure of dissolved gases in blood, like oxygen and carbon dioxide, in addition to blood acidity (pH) through Ion Selective Electrodes (ISE). There must be two ABGs in the field hospital, one inside the I.C.U ward, and the other inside the isolation ward, to avoid the mix of isolated patient with non-infectious patients' blood.

Figure 48. Urine analyzer

Figure 49. Blood gas analyzer

Coagulation analyzer must be available in field hospitals to measure the level of coagulation of blood (the time for blood to clot), one coagulation analyzer is sufficient for field hospital.

Figure 50. Coagulation analyzer

- **Operation theatre:** the main device of operation theatre is the anesthesia machine, which is used to deliver the anesthetic agents to the patient with the help of a driving gas (which is oxygen). There must be two anesthesia machines (one for each room)**.**

Figure 51. Anesthesia machine

Electrosurgery device (ESU) or cautery device is used to cut skin and inner body parts and coagulates bleeding cuttings inside the body through applying high frequency of current to the tip of the needle-like handle of the device. Two ESUs are required for the field hospital, one for each room.

Figure 52. ESU device

Operation table is the main component of the operation theatre, it must have hydraulic and electric motorized movement, with adjustable height to be able to use the c-arm during the operation. Two operation tables are sufficient for field hospital.

Figure 53. operation table

Surgical light is also necessary for the field hospital, two operation lights required for each operation theatre, operation light must have LED technology not halogen lamp.

Figure 54. Operation light

A patient monitor is necessary in the operation theatre, to display the vital signs for patient, such as heart rate and electrocardiogram wave. Two patient monitors are sufficient for the field hospital, one for each room. Infusion pump must be available in the operation theatre to deliver the necessary fluids to the patient through his veins, two infusion pumps are adequate for the operation theatre.

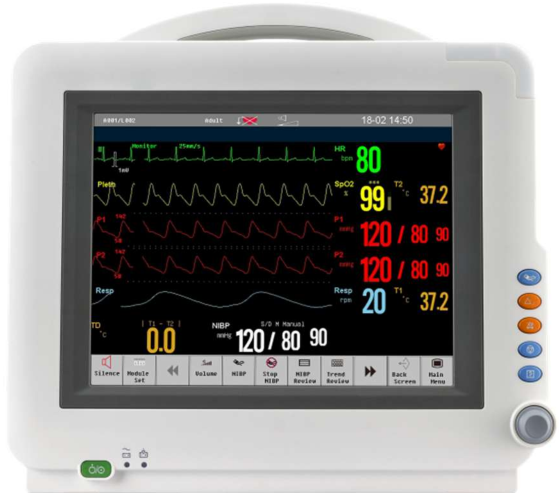


Figure 55. Patient monitor

Figure 56. Infusion pump

A defibrillator is an elemental device in the operation theatre, it is used when the left ventricle of the heart fibrillates (vibrates), so the device delivers a DC voltage shock to the heart to stop fibrillating and return back to normal, two defibrillators are required for the field hospital, one for each room.

Figure 57. Defibrillator

A suction machine is required in the operation theatre to evacuate the solutions and blood generated during the operation, it is also required to have a central vacuum system for the whole field hospital, but this suction machine acts as a backup for the central vacuum. Two suction machines are required, one for each room.

Figure 58. Suction machine

- **I.C.U:** the devices of the intensive care unit are as follows; 52 patient monitors (50 for each bed and two as a backup), 52 infusion pumps (50 for each bed and two as a backup), 10 suction machines as backup in case the central vacuum system is down, one defibrillator. 50 transport ventilator type must be available for each bed and 10 oxygen concentrators as a backup in case the central oxygen supply is defective. The patient bed selected for the whole field hospital must have a combination of electric and hydraulic movement, 50 patient beds are required for the I.C.U ward.

Figure 59. Transport ventilator

Figure 60. Oxygen Concentrator

Figure 61. Electric patient bed

- **Recovery ward:** 32 patient monitors are required for the recovery ward (30 for each bed and two as a backup), 32 infusion pumps ((30 for each bed and two as a backup), 5 suction machines as backup in case the central vacuum system is down, one defibrillator. 30transport ventilator type must be available for each bed and 5 oxygen concentrators as a backup in case the central oxygen supply is defective, and 30 electric patient beds.
- **Isolation ward:**20 patient monitors are required for the isolation ward, 20 infusion pumps, 4 suction machines as backup in case the central vacuum system is down, one defibrillator. 20transport ventilator type must be available for each bed and 4 oxygen concentrators as a backup in case the central oxygen supply is defective, and 20 electric patient beds.
- **Emergency ward:**5 patient monitors are required for the emergency ward, 5 infusion pumps, 2 suction machines as backup in case the central vacuum system is down, 4 defibrillators and 20 electric patient beds.
- **Inpatient wards:** 180 electric patient beds are required for inpatient wards (both the male and female wards), 180 infusion pumps (one for each bed) and two defibrillators.

- **Dental clinics:** two dental chairs with their handpieces and tools are sufficient for the dental clinics (one for each clinic), one panoramic x ray machine for both clinics for further dental diagnostics and one handpiece sterilizer for both clinics.

Figure 62. Dental chair

Figure 63. panoramic X ray machine

Figure 64. Handpiece sterilizer

- **Sterilization department:** the main device of the sterilization department is the steam sterilizer, which depends on steam to sterilize micro particles like spore which can't be killed except with steam. The steam sterilizer must be double door type, a door opens for the dirty area and the other for the clean area, one steam sterilizer is sufficient for the field hospital.
-

Figure 65. Double door steam sterilizer

Washer disinfector machine is a device which is used to clean dirty tools as a first step before introducing them to steam sterilizing, one washer disinfector machine is adequate for the field hospital.

Figure 66. Washer disinfector machine

3.2.4 Staffing of the Field Hospital:

The staff of the field hospital must have the following: 6 surgical doctors, 6 internist doctors, 2 dentists, 2 Orthopedic doctors, one gynecologist, 2 Radiologists, 2 lab doctors, 2 Anesthetists, 2 Respiratory doctors and one pediatrician. The field hospital must have 20 registered nurses, 40 practical nurses and 4 paramedics, one healthcare officer and one nutrition specialist.

The field hospital must have 4 laboratory technicians, 6 radiology technicians, 3 biomedical engineers, 4 pharmacists, 4 sterilization technicians, 3 stockistsand 20 cleaning staff personnel. it must also have 6 drivers, 2 mortuary specialists, 4 kitchen workers like chefs, 4 general maintenance staff and 10 administrative staff members.

4.Results and Discussion:

4.1 Quantities of Medical Devices:

The total quantity of required medical devices to function the field hospital is as follows:

Medical Device Name	Quantity Needed	Medical Device Name	Quantity Needed
CT Scan	1	Surgical Light	2
C-Arm	1	Patient Monitor	111
Digital X-Ray System	1	Infusion Pump	291
Mobile Digital X-Ray	2	Defibrillator	11
CBC	1	Suction Machine	23
Centrifuge	2	Transport Ventilator	100
Chemistry Analyzer	1	Oxygen Concentrator	19
Urine Analyzer	1	Electric Patient Bed	300
ABG	2	Dental Chair	2
Coagulation Analyzer	1	Panoramic X-Ray Machine	1
Anesthesia Machine	2	Handpiece Sterilizer	1
Electrosurgery Unit	2	Double Door Steam Sterilizer	1
Operation Table	2	Washer Disinfector Machine	1

Table 2. Total quantities of required medical devices

The selected medical devices for our design of field hospital fulfill our goal to achieve the multidisciplinary approach, this makes the field hospital suitable for any type of emergency or non-emergency situation. The principle of backup devices reduces the downtime of them and to avoid any accidently death occurrences which are caused by defective medical devices.

It is noteworthy to mention that medical devices must be purchased from manufacturers who have the required specifications, such as the country of manufacturing, where is the preferred countries are U.S.A, England, Japan and Europe, and this is due to previous experiences with devices from other countries which were inconvenient in terms of durability and accuracy.

4.2 Quantity of Staff Members:

The total quantity of required medical staff members to function the field hospital is as follows:

Staff Type	Quantity
Medical Doctors	26
Nurses	60
Paramedics	4
Healthcare Officer	1
Nutrition Specialist	1
Laboratory Technician	4
Radiology Technician	6
Biomedical Engineer	3
Pharmacist	4
Sterilization Technician	4
Stockiest	3
Cleaning Staff	20
Driver	6
Mortuary Specialists	2
Kitchen Workers	4
General Maintenance Staff	4
Administrative Staff Members	10

Table 3. Total quantity of required staff

The total number of required staff is 162 members, and this is sufficient to function the whole field hospital without any intermittence in work.

4.3 Problems Solved:

The main problem solved in this study is the design of oxygen supply system, which contained three methods to supply oxygen; Large oxygen concentrator, large liquid oxygen vaporizers and oxygen cylinders system. Our method was to combine the three methods into one to avoid any interruptions of oxygen in the field hospital.

Another problem was solved which is the supply of electric power to the field hospital, where our design suggested using solar power system and exploit the rooftops of the field hospital as an adequate area to install the solar power panels.

5.Future work

As field hospitals design always focus on using economic sources in the different supplies, we look forward to reduce the consuming of electric power in field hospitals through eliminating the need for electric power to lighten up the field hospital during the daylight, a "solatube" is a tube which can be implemented in the ceiling, which can pass the sunlight to the inside of field hospital rooms, which will cut the cost of electric power.

Another approach will be held in the future to make use of the large oxygen concentrator and liquid oxygen vaporizer to fill up the oxygen cylinders inside the field hospital itself, which will reduce the cost of re-filling the cylinders with oxygen.

Figure 67. Solatube

Figure 68. Oxygen Re-filling diagram

Figure 69. Oxygen refilling

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