Plants in field health structures

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The growing number of natural disasters and armed conflicts in the world implies a dramatic growth of humanitarian emergencies; in such contexts, it is necessary a widespread distribution of health services, in order to limit the damages to people and to reduce deaths as much as possible. The absence or the destruction of local hospitals, or their inadequacy to host many blessed people, emphasize the importance of field hospitals.

Born and developed in around 1700-1800 in military ambit, over the years they have assumed a key role in the answer to emergencies, in civil ambit too.
To bring the first aid wherever it is necessary in short times is the target of field hospitals, for which it is therefore indispensable extreme mobility in terms of transportability and modularity, feature, the latter, which allows achieving different configurations according to the territory conformation or to the military strategies, thanks to different arrangements of modules. Besides, field hospitals are expected to be quickly set up and suitable for providing assistance to several patients. They can be constituted by various types of tents or by shelters or by a combination of these elements.

Those modular solutions are used also in different contexts from those of immediate emergency; they are integrated, for instance, into traditional hospitals to replace ambulatories or surgical blocks in renovation periods or they are used as "mobile sanitary districts" to bring cares in territories without assistance or as mobile laboratories for chemical-physical analyses.
Due to the wide application ambit, we can guess the importance of equalling the efficiency and the asepsis of these structures with those of traditional ones, with a targeted upgrading of the plant engineering dedicated to them, so that we can consider them not only emergency solutions but technologically advanced modules and then suitable for being used as per-


Interior of operating room. Kindly granted by the National Alpine Associati

manent replacement of masonry premises.
The most critical room, as far as plants are concerned, is the operating room.
The state-of-the-art operating rooms in which are carried out the so-called "clean" interventions provide for the laminar flow air inlet through ceilings equipped with absolute filters in order to reach an ISO 5 particle contamination class and to reduce the number of post-surgical infections.
In the project illustrated hereafter, we have tried to compare the mobile operating room under examination to this typology of operating room, considering external climatic conditions that are typical of Middle East and paying attention to some specific criticalities of the structure
The study of the room integration into a possible layout of field surgical block made with shelters and tensile structures was focused on the optimal separation between dirty and clean paths.
To make independent in the course of the mission the surgical block and, more in general, the entire hospital concerning the supply of medical oxygen, they have assessed the economic and logistic advantage of the use of an on-site production plant based on the PSA (Pressure Swing Adsorption) technology.
Finally, they have estimated the energy consumptions of the surgical block.

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State of the art

The memory of field hospitals is contained in historical diaries, in designs and photographs. At war, the need of relying on adequate supports, easily displaced wherever necessary, to allow military physicians to take care of victims, led to the birth of the first structures made of wood and tarpaulins. They were followed by hospital trains and ships, up to reaching, in 1900, the development of shelters, metal structures characterized by structural stiffness and extreme mobility.
Their advent revolutionized the definition of field hospital that today is fully implementable with shelter modules, coupled or not with tensile structures.
To highlight characteristics, advantages and main problems of such health modules, they have examined the technological solutions existing on the national territory, paying particular attention to those proposed on the market by an international producer and to the structures currently operating. Among the latter, they have considered those adopted by the Military Health and Veterinary School and by the National Alpine Association (Ana). This has allowed taking into account several aspects of the field health, that is to say the production of modules and their use in military and civil ambit.
The hospital deployment logistics, the choice of structures and technologies is different in the three cases, sharing anyway the target of efficiency and prompt intervention in emergency contexts. The construction dates of the examined operating rooms refer to different periods. The operating room of Ana dates back to the early Eighties, the Army one to the end of the same decade, the room of the company has been in production since approximately 2008. This justifies the plant engineering differences that can be surveyed in the three cases.
Concerning the operating room of the National Alpine Association, its strong point is its wide walk-on surface (about 42 sq.m.), which allows the surgical team to move freely even in presence of two operating tables. The fact that it is constituted by more combinable shelters makes however the transport difficult and involves a delay in the starting up owing to the coupling time of modules themselves.
In this case, the plant engineering essentially shows two critical points: in the conditioning and in the distribution of medical gases.

The conditioner is positioned inside the room, the flow is turbulent and the last filtering stages exhibit medium efficiency; this implies a level of air quality not compliant with the regulations in force and that can negatively affect the percentage of infections at patients' and personnel's charge.
The provisioning of medical gases inside the room, as well as of the other spaces of the hospital, is granted by cylinders, filled in Italy before their starting and successively refurbished by companies situated on the settlement place. The filling on the spot is almost always problematic, as it is often difficult to find in war territories or in areas devastated by natural disasters, companies that provide for the gas supply; besides, costs are often high and the purity level of the purchased gas is not granted.
The operating room of the Military Health and Veterinary School is built in a two-volume shelter, it is comfortably transported thanks to its small external sizes and it shows a wide inner surface. Before the use and starting up, it is required an assembly time that includes the necessary time for levelling by means of hydraulic pistons, for the opening of the surgical module by means of electrical mechanisms and the time needed for the connection with the service module. Besides, the use of electrical energy is provided for, because the opening of the surgical module is not possible without it.
The presence of a module dedicated to the operating room makes it independent from the rest of the hospital and this is an advantage. Another strong point of this shelter resides in the presence of three doors – two of access and one, in the "lateral box", used both as entrance with closed shelter and as escape way – for instance in case they operate a patient with unexploded bombs in the body or in case of fire. The two access doors allow connecting opportunely the modules of the operating block with the room and granting a good separation of the dirty path from the clean one. The same plant engineering criticalities described for Ana hospital are present in this case, in which the conditioner is inside the room, taking up a space that might be used differently, and the air inlet is with turbulent flow, with a F9 final air filtering stage. For the distribution of medical gases, there are terminal units that are connected with cylinder packs positioned outside the shelter, with the provisioning problems already described.
Concerning the operating room marketed by the producer considered here, it is implemented in the three-volume shelter and exhibits the advantage, like the Army's, of the best transportability, thanks to the external sizes compliant with standards. The inner surface, of 27 m^2, is close to the minimum established by the regulation (30 m^2) and it is intermediate among those of the rooms previously examined. The opening is manual. A critical point is constituted by the only door that makes the path separation problematic, increasing the risk of cross contamination, once inserted the module into an operating block; besides, no escape routes are present. The same problems that concern the other two operating rooms arise for medical gases. The conditioning system provides instead for an ATU outside the room, positioned in the technical space of the shelter; this makes the shelter independent, without reducing internal spaces nor increasing the outer ones. The air distribution is with turbulent flow.

Examination of critical aspects

- Medical gases

As pointed out, the medical oxygen is conveyed to the operating room and to the areas where it is necessary through distribution pipes supplied by cylinder positioned outside the shelters. To grant the gas provisioning, we can hypothesize two scenarios: either you bring more cylinders, with problems of costs and overall dimensions during the transport, or the exhausted cylinders are filled by local companies; the latter solution, however, might be difficult, considering that the activity of the field hospital is carried out in war zones or in presence of natural disasters, with possible problems with local authorities. The option of receiving replacement cylinders from the origin Country is expensive.

- Conditioning plant

The air distribution with turbulent flow with not absolute filtering systems increases the possible risks of infection for patients and of contamination for operators. The insertion of the conditioner inside the shelter takes up precious space, reducing the already limited working surface. The examined ATU grant the preservation of the internal microclimate up to a maximum external temperature of about + 48 °C, but use applications with higher temperatures may occur.

Targets and development of the work

They have decided to design an operating room in a shelter expandable from one to three volumes taking as reference example a field hospital Role 3 [1, 2]. The choice of this module derives from its structural characteristics; it can be transported by air, by sea and by land because it is compliant with transport standards and, once opened, it is provided with a broad working surface. The shelter includes a technical room accessible from the outside to introduce the plants inside it and to make their inspection easy. The ATU is integrated into the room to make the operating room ideally able to operate alone and to be integrated into any preexisting operating block, field type and note. The conditioning system is provided for servicing the only operating room and it is equipped with final air filtering stages at very high efficiency, as well as with a unidirectional flow distribution in the room. The plant is designed to operate in the typical external climatic conditions of Middle East (+55°C and RU=20% in summer, -5°C and RU=80% in winter), because in this territory the number of conflicts is rising and the need of field hospitals with it. To solve the provisioning problems concerning medical gases, they have evaluated from the economic and logistic point of view the use on an on site production plant of medical oxygen through a Pressure Swing Adsorption process, to satisfy the field hospital needs.

- Conditioning plant

The microclimatic parameters pursued inside the shelter and the requisites regarding the air quality are those dictated by the RPD 14/01/97, by the guidelines Ispesl 2009 and by the technical regulation Uni 10339 in the matter of operating rooms (temperature included between 20 and 24 °C, relative humidity from 40 to 60%, positive and stable pressure with closed doors towards external and neighbouring environments, hourly exchanges of external air at least equal to 15). To reach the said conditions and to keep them as much as possible constant during the day and in the various periods of the year, in conformity with the ISO 5 [6] standard, it is necessary to grant a distribution of the laminar flow air in the shelter, a terminal filtering with H14 filters and an air speed of 0.25 m/s.
The external climatic data considered are those of Kuwait City [7, 8]: altitude of 55 above sea level, latitude 29.22° N, longitude 47.98° E, maximum dry bulb temperature + 55°C, measured in summer in the shade in July at 3 p.m., minimum dry bulb temperature in winter - 5 °C, average relative humidity in summer 20%, average relative humidity in winter 80%, maximum wind speed 40 m/s, corrosive atmosphere rich in sand, maximum rain value 200 mm yearly.
For the calculation of external thermal loads, they have used the most burdensome among the three orientations of the shelters examined, in particular the one related to the north exposure of the long side, the one of the north exposure of the short side and the one concerning a 45° rotation of the previous case, corresponding to the last in the list. They have then studied three different cases of shelter exposure: all in shadow, all exposed to the sun, with the only roof shaded. Even if the total exposure of the shelter to the sun constitutes the worst case from the point of view of thermal loads, this type of field hospital deployment is presently the most frequent one. The case of complete shadow, even if it is the least demanding, is quite remote since it would involve the positioning of the shelter under a tent, increasing the space taken up on the ground. Even if not frequently accomplished until now, this hypothesis should be considered in the future by the users of shelters, as improvement of the microclimatic conditions in their inside. In view of that, it is advisable to illustrate the sizing of the ATU referring to the intermediate case, that is to say the shelter with shaded roof; the shading tent represents in fact an ameliorative strategy of partial decrease of thermal loads at zero cost, affecting neither the plant nor costs nor travel spaces, since transportable folded inside the room.
The temperature of air inlet into the room is fixed at a value lower by 5 °C ÷ 7°C, than the environmental one. A bigger temperature difference, like those generally used, would imply an excessive discomfort for occupants, owing to the small sizes of the shelter and the height of 2 m only. The massive flow rate of dry air to be introduced into the environment to compensate thermal loads is drawn from mass and energy balances and it is equal to 2122 kg/h.

Shelter of operating room and service module. Kindly granted by the Health and Veterinary School of the Italian Army

According to the regulation in force in Italy, the external air flow rate must be equal to at least 15vol/h, corresponding to 992 kg/h and the additional air quantity as to it, necessary for the load decrease, cannot be recirculated. The recirculation is on the contrary admitted by the Ashrae regulation [9]. The use of recirculated air allows notably reducing the energy consumption and the ATU size (significant parameter for the case under examination), to the detriment of the air quality. To avoid this trouble and to reduce the concentration of pollutants, the air withdrawn from the environment, before entering the mixing chamber, is adequately filtered. The ATU has been sized in relation to the following values:

- Air flow rate circulating in the plant: Mas = 2122 kg/h;
- External air flow rate: Mext = 992 kg/h;
- Recirculation air flow rate: Mrec = 1130 kg/h;
- Cold battery: Qcb = 25666 W;
- Heating battery: Qheat = 1974 W;
- Post-heating battery: Qpost-heat = 5676 W;
- Water flow rate to be disposed in summer: M_{H2O} = 0.6 kg/h;
- Water flow rate to be supplied to the humidifier in winter: M_{H2O} = 3.6 kg/h.

The ATU components have been chosen and arranged in such a way as to consider the dimensional binds of the technical room (L×P×H = 2.3 m × 0.97 m × 2.1 m). This unusual arrangement will be verified through tests on the prototype. The filtering stages requested for the operating room are three in sequence: medium-efficiency filter, high-efficiency filter and absolute filter (with very high efficiency). Some anti-sand filters are provided at the air inlet in the ATU. For the steam humidification, they have chosen an autonomous humidifier with immersed electrodes, with a launcher with reduced absorption distance. The launcher is inserted into the ATU while the cylinder containing the electrodes is positioned below it. The selected cold battery has ten rows and it is programmed to function as pre-heating battery in winter. The battery is fed by cold water in summer and by hot water in winter, produced by heat pump. After the steam launcher, an electrical resistance battery is positioned for the summer and winter post-heating. In addition to the cylinders for the steam production, the collection tank of the condensate from the cold battery and the drop separator is placed under the ATU.

The recirculation air is transported to the return fan along fabric channels that are inserted at the shelter opening time (from return grills to the technical room). Concerning the air inlet with unidirectional flow into the operating room, this cannot be obtained through the usual ceilings used in standard rooms because, in transport arrangement, the shelter provides for the closing of “lateral boxes” among which no sufficient space is left for the ceiling and channels. It is therefore possible to insert, with a hole in the room adjacent to the technical space, an angular ceiling, bent by 45°, with H14 integrated filters. The ceiling is mounted when the shelter opens and is dismounted for transport. The air motion is unidirectional and the return occurs through fabric channels, they too arranged at the commissioning time. An alternative for the inlet is represented by fabric channels with particular micro-holes that grant unidirectionality to the airflow, both in conditioning and heating. Channels are washable and mounted on the ceiling. In that case, the terminal filter is mounted upstream the channel, at the ATU outlet.

• Medical gas plant

The medical gases used in a field hospital Role 3 are the same used in a standard hospital. Obviously, the consumption is inferior because in an emergency structure the provided number of beds and departments is lower. The state of the art, described in chapter 1, shows how large part of field hospitals uses for the gas provisioning cylinders that are filled or replaced when needed. This can be problematic if the hospital remains in a place for prolonged periods, in the order of months, or if gas demands are bigger than expected. Oxygen is the most used medical gas and the production on site can be considered a valid solution for it, with 95% purity, by means of a plant based on PSA (Pressure Swing Adsorption) technology, thanks to which it is possible to fill on demand the cylinders packs serving departments. At present, the PSA system is prevailingly used for the oxygen production on small and medium scale and this induces to think of a possible advantage in the use in field realities, due to the reduced consumptions in comparison with standard structures. Evaluating the oxygen flow rate delivered to the terminal units in the surgical block and considering 25 inpatient beds, they have obtained an average need of 10.8 m3/h. According to that requested quantity, they have sized a PSA plant for the on-site production and they have estimated fixed and variable costs.

The assessments carried out highlight that the use of a PSA for the on-site production of the medical oxygen needed by a field hospital Role 3 is advantageous in logistic terms, since it allows autonomy in time. Even if the plant (with the cylinder packs to be filled) implies perhaps bigger initial transport dimensions, since it must be moved with a container apart, it avoids long travels after the hospital commissioning (both long-haul for the arrival of replacement cylinders and short-haul for the filling of exhausted ones). From the economic point of view, considering plant, operation and maintenance costs, they proved to be much lower than the purchase of medical oxygen (considering national prices). Hypothesizing a continuative functioning of six months, the order of magnitude of self-production costs is 28,000 Euros per year, against 130,000 Euros estimated for the external supply.

• Estimate of energy consumptions

• Considering the electrical consumptions for the operation and the conditioning of the room and of the operating block, as well as for the production of hot health water, they estimate the necessary supply of 200 kW power. They provide for two generator groups, 130 kW each, to grant the continuity of the essential services in case of failure of one of the two. The oxygen production plant has a dedicated 45kW generator group.

Conclusions

They have evaluated the critical aspects of plants servicing field health structures. The layout of the operating area, constituted by shelters and tensile structures, grants the separation of paths and it is integrated into a field hospital Role 3. The conditioning plant dedicated to the operating room, introduced into a 3-volume expandable shelter, is tropicalized. Choice and arrangement of the components are dictated by the overall dimensions permitted in the technical room. A prototype of the plant will be verified experimentally. The introduction of an on-site medical oxygen production plant turned out to be both a logistic and economic improvement.

Thanks

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