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Design and Development of Modular Customised Ration Storage System- 'Silo' for Service Specific Applications during Peak Winters at High Altitude Area

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ABSTRACT

Conceptualisation of design and development of modular and customised ration storage system for Army rations sustainable up to -40°C was carried out. The Indian Armed Forces operate under various climatic conditions, which are inhospitable for cooking, storing fresh/perishable food products and carrying rations for their survival during an emergency. Hence, there was an ever-existent demand for a customised, user-friendly ration storage system. Considering a number of user-friendly features, a system has been designed comprising modular unit structures with insulated wall panels containing Polyurethane Foam (PUF) sandwiched between metallic and composite material claddings. An insulated structure is required to maintain the temperature at high altitudes during extreme low-temperature conditions. The temperature and humidity are regulated and maintained using solar panels and humidly modulators. The modular structure with individual temperature and humidity control is suitable for the safe storage and preservation of fresh produce, fruits and vegetables, and milk and animal products. In case of perishable commodities of Defence supplies inclusive of leafy and tender vegetables, juicy fresh fruits, egg, chocolates, meat carcasses stored in silo are safe as its insulated structure ensures no freezing even upto -25 ° Celsius hence protects them from quality damage due to subzero temperature exposure and abuse. Therefore, the normal convention of the expected shelf life for each such commodity was extended approximately double the normal shelf life expected. An extensive design process involving CAD modelling followed by mechanical load simulation and analysis resulted in a robust and capable system. Each compartmentalised segment caters for an average one-ton material depending on the nature of the material. The system is suitable to store 3 tons of ration at a time to address the requirement of 100 individuals for 60 days in monsoon cut off and peak winter cut-off posts. Total energy consumption under fully load condition is approx. 2 KW to maintain peak temperature gradient of 45-50 °C.The outer surface of the structure can be camouflaged. The well-insulated structure ensures zero leakage and is sturdy to withstand a wind velocity of 60 km per hour and a standing snow load of 2 meters above it.

Keywords: Food storage; Modular structure; Extreme environment; Army ration; Winter trial

1. INTRODUCTION

India, owing to its long borders, faces the challenge of multiple frontiers. Hence the Armed Forces are required to be deployed in regions of varying environmental conditions. The Indian army posted in the trans-Himalayan region (particularly Ladakh) faces various challenges for ration storage which are posed by unique geo-climatic conditions characterised by extreme temperature variation (- 40°C to + 40°C), precipitation mostly in the form of snow, less oxygen availability, high wind velocity, low humidity and rugged & uneven terrain. Owing to its strategic importance of bordering two neighbouring nations, many troops are deployed in the high-altitude regions of the trans-Himalaya. The environmental factors pose a formidable challenge to the survival of the human population inhabiting the area and the perishable ration, the most important source of nutrition and energy for the troops. To meet the nutritional requirements of the Armed Forces, a large amount of ration is being supplied. Food items such as various grains, milled products of cereals, pulses, legumes, rice, whole wheat flour, semolina, besan, maida, black gram, green gram, toor dal, kabuli channa, rajma, masoor dal, salt, sugar, oil hydro, tea ration, milk and malt-based foods, various canned foods such as tinned fruits, vegetables and non-vegetarian items.

The primary issue was of the rapid deterioration of fresh and perishable produce meant a shortcoming in the availability of certain foods for the troops and, ultimately food wastage. The disruption of logistics due to snowfall and avalanches en-route and the inaccessibility to certain forward locations due to the rugged topography is another major deterrent for adequately storing rations. Some of the major drawbacks in the existing storage units for high altitude regions include; Dependence on fossil fuel for electricity and heating systems, no heating and humidity regulation and modulation as per requirement for optimum storage of service ration, absence of active heat storage

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and release mechanisms for optimal utilisation of solar energy, use of highly inflammable insulating materials leading to fire hazards, high thermal energy dissipation from the shelter, large and heavy building blocks which are not suitable for heli-transportation, faulty roof design leading to heavy snow load etc.

Providing a storage structure that can maintain an amenable temperature and humidity conditions to safeguard most of the Army ration entitled during peak winters is a major challenge that requires customisation of available technologies. Hence, the concept/idea of designing non-conventional energy based modular and customised ration storage system (SILO) with self-sufficiency in energy capture and utilisation was thought of with the added advantages of flexibility of installation at any surface, including ice/snow and uneven and rugged terrain surfaces. Thus, a customised and modular silo will be a promising potential solution. The following study was undertaken with the objectives of designing a modular structure with ease of transportation, assembling/commissioning and relocation, developing a storage system that is shelf sufficient to cater for its energy requirements mainly from non-conventional sources and customised structure suitable for storing most of perishable Army Ration sensitive for freezing. The principal purpose of the developed system is to protect most of the perishable items from freezing which leads to intercellular rupture of cells and tissues due to intra and interstitial ice crystal formation in high moisture commodities, hence the focus was mainly on high moisture and fragile commodities which cannot be heated and thawed often due to quality related issues. The best amicable solution includes arresting the freezing. And the supply chain must be augmented with insulated antifreeze containers during transportation and transit form supply point to final dispatch point.

In India, silos are used for food storage mainly by the government through the Food Corporation of India and also by major players in the food processing industry. Silos are very cost-effective for the scale of application involved; especially bunker and bag silos are a lot inexpensive. However, the operation of loading and unloading the silos presents many challenges and hazards. The United States military follows a system of food safety, security, and storage that is monitored by a large network of institutions and stakeholders both inside and outside the military structure. This network monitors the food procured by the military forces from the point of origin to the point of consumption, all while retaining perfect accountability. The strategies evolved from the operation of this system have proven to be very effective such that they are being used for general logistics not only for food. Once the various types of food commodities are received, they are stored appropriately in three types of warehouses; vendor warehouse, government warehouse and individual facility warehouse. Currently, no such system is being used Defence Forces earlier to the present invention which caters for heterogeneous ration commodities.

2. METHODOLOGY

The methodology includes designing, selection of suitable material with desired characteristics, methods of on field assembly and commissioning, efficacy testing during peak winters by storing the items concerned and recoding the changes of relevant parameters.

The food commodities used for the storage studies include most of the perishable commodities of army ration includes seasonal vegetables, fruits, juices, eggs, meat, chicken chocolates etc and these loses their quality attributes significantly at sub-zero temperature storage. The best practice to store them normally at 6-8 °C with humidity of >85 %.

Components used in the silo can be broadly classified into three categories:

2.1 Conceptualisation and Designs

In accordance with India's prevalent architecture and domestic infrastructure and especially in the Ladakh region[2], an extensive literature survey was conducted to find the best suiting design. Hence, the design language with cubical enclosures and slanting roofs were adopted. The main structure is fabricated using SS SQ tubes. Computer-Aided Design (CAD) modelling of the concept considers the load capacity of 1.5 tons of static load, shear stress equivalent to 60 kmph wind velocity.[3] Also, the structure should withstand a dynamic load of 2 ambulatory personnel with the load. Every shelf in the storage system can bear a load of 100 kg. The slanted roof modules (also known as HAT modules-Top Roof Structures) hold the solar panels. The modularity in this storage system is realised in terms of the composition of a central module and two end modules (Fig. 1). The modules are attached using silicon insulating gaskets.

2.2 Structural

2.2.1 Wall Panels

These are made using Poly Urethane Foam (PUF) panels and are thermally sealed, which provides insulation against temperature. Roof panels are also made of the same materials with efficient solar panels. They are mounted with a tilt angle of 55^o, facilitating the sliding down of snow and avoiding accumulation. PUF has low thermal conductivity, is not easily ignitable and has negligible water permeability[11] (Fig. 2). SS 304(SS304 is stainless steel grade 304 which is food grade high quality steal and is resistance to rust with good strength and mechanical properties) sheet on the outside and HIPS (High intensity poly styrene) on the inside provide the cladding.[10] The SS cladding was used to provide high structural strength and HIPS to provide aesthetics and prevention for freeze shock from metal.

2.2.2 Racks/Shelves

These are made of 6060T5 Aluminium alloy (anodised) sections providing high strength & rigidity, being very light in weight.[4] Three types of segments were used in

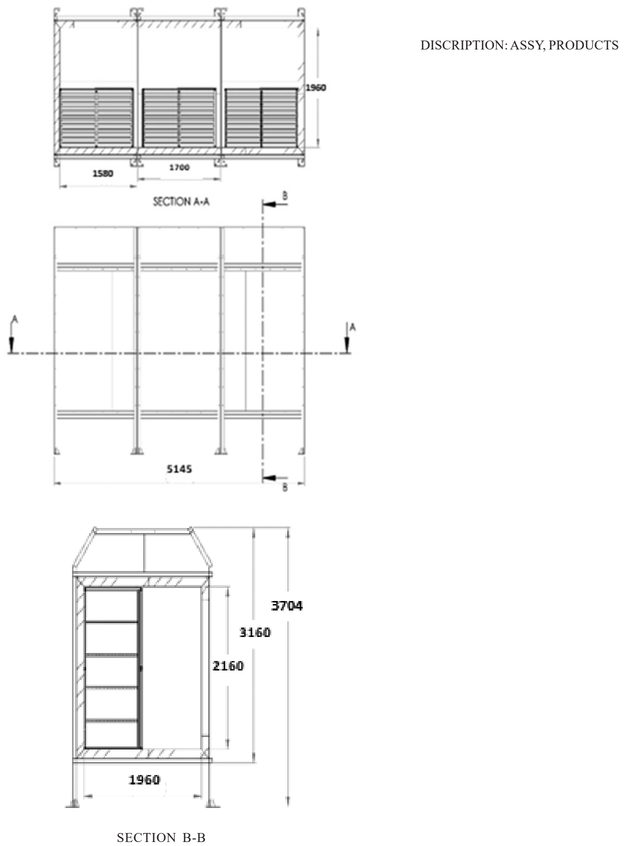

Figure 1. Sectional views of the SILO.

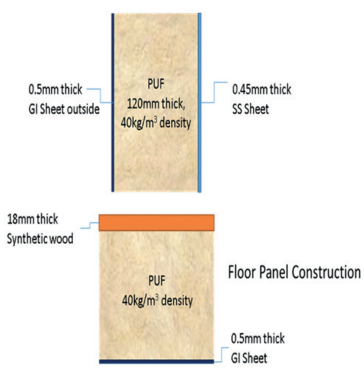

Figure 2. Cross sectional view of the sandwich panel.

rack making and each segment of 6060T5 Aluminium alloy used has sufficient strength to handle the loads.

2.2.3 Floor Panels

External cladding is made of powder-coated GI sheet 0.5mm thick, whereas the internal cladding is made of Fr grade plywood 18mm thick, which sandwiches a PUF panel 120mm thick.

2.3 Electrical

The complete system runs on a 48V system consisting of 12V and 45Ah batteries with special design considerations for solar applications, including 1000 charge cycles. It is enclosed in a marine-grade plywood box with adequate padding for battery expansion and to provide separations to batteries. As the system had to rely on alternative sources of energy, *i.e.*, solar energy, the electrical components were selected in such a way as to accommodate the uncertainties and also be compatible with emergency power sources such as diesel generators. Energy ratings of each component were also considered in the selection process.[5]

2.4 Solar

The solar charging circuit consists of four water and dustproof solar panels mounted on the slanted roofs (Fig. 3). A solar charge controller is provided with built-in indicators for solar energy availability, battery level and detection of faults.

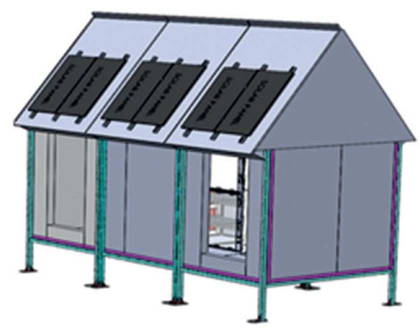

Figure 3. Computer-aided design model of the system.

2.5 Smart Features/ Functional Attributes-Sensors

As the system relies on solar energy for its needs, energy conservation plays an important role in sustaining supply and demand. Hence several smart features are included for fulfilling the purpose in this regard. A controller module and user interface are provided for end-user configuration enabling the user to control temperature, humidity and alert threshold for low oxygen inside the silo. Motion sensors provide control over automatic lights. Access control is PIN protected. A multitude of sensors are installed to provide real-time information on oxygen levels, temperature, battery level and relative humidity.

Temperature sensors are used to sense the outside, inside and shelf temperature. The relative humidity is sensed using humidity sensors. Since the system will be deployed in high-altitude areas, consideration for human oxygen demand and fresh produce's respiration is vital.[7] Hence, an oxygen sensor senses ambient oxygen levels inside the silo and is crucial for the low oxygen alert feature. A battery sensor is provided for battery level sensing and a low battery or battery fail alert feature. A motion sensor is applied in the automatic switching on/off of lights based on people's entry. The control panels also offer a master control switch with a User-Interface module for controlling silo and display of silo parameters. Ceramic heating panels are provided, capable of a maximum surface temperature of 65°C. An ultrasonic humidifier produces a cool mist without significant energy usage with a humidity controller unit.[8]

An exhaust fan is included to vent undesirable odours and bring the oxygen levels above the threshold inside the silo (Fig. 4). A cut-off system is provided to stop the unnecessary spending of energy on the heater and humidifier when the set values are reached.

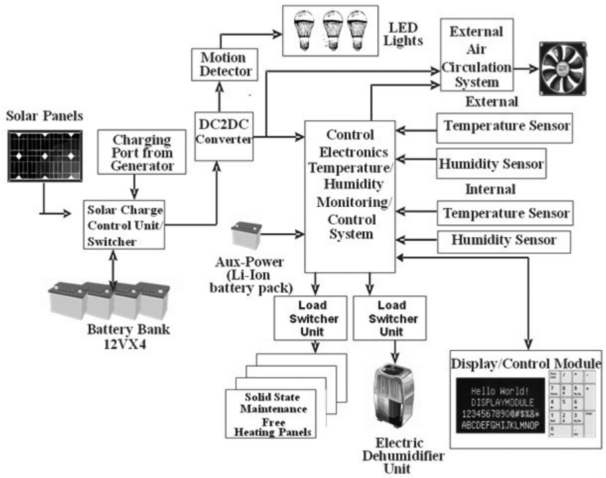

Figure 4. Electronics block diagram.

2.6 Peak Winter Trials

To evaluate and assess the performance of Modular and Customised Ration Storage System (SILO) at varying field conditions during peak winters, trials were conducted at Khalsar, Ladakh, with a few objectives under consideration. The performance was assessed regarding thermal efficiency, humidity regulation, energy harvesting from solar power, and monitoring interface display during varying field conditions and peak winters. The trials included quality assessment of stored commodities with respect to textural changes, appearance, and freshness compared to conventional storage practices. The shelf life of various stored commodities was evaluated under controlled storage conditions. Finally, the efficacy of alternate power supply in sustaining the system functioning during peak winters was quantified. The trials were carried out in the presence of scientists involved in the developmental process and the user unit's representatives.

2.7 Battery

Batteries used were high quality lead batteries and their performance was ensured optimum as these are kept inside insulated structure of silo.

3. RESULTS AND DISCUSSION

3.1 Design Criteria

In the design of the frame structure and panel, the dimensions and weight parameters are considered. The frame and floor structure comprise SS304 with insulation (PUF) panels and cladding (SS304 and HIPS).

Main Structure is made of Al6065 alloyed tubular extrusion of dimensions 60×60×1.6mm (L×W×T). HAT Structure also consists of Al6065 alloyed tubular extrusion of dimensions 30×30×2mm (L×W×T). The floor is made of Hybrid welding arrangement comprising of tubular and flat sections panels. The panels hold insulation of 2" thickness and cladding of 0.8mm thick \SS sheet OUTER and 2mm HIPS inner. The Silo has a total height of 4.2m and a footprint: 2.1m×11.7m. It has a usable volume of 2m×1.6m×2.1m.

The Frame Structure has a basic weight of 142kg, and the top HAT structure weighs 42 kg, with the panels weighing 56kg. The insulated panels made of PUF (2" thick) weighs 66kg (*density* = 60*kg/m*³) and PUF (2" thick) weighs 110kg (*density* = 100*kg/m*³). Cladding has a weight of 140kg(SS)+48kg(HIPS) (Fig. 5).

The maximum loading on the floor/platform is 2000kg (approx.), and the maximum loading on the roof structure is 200kg approx.

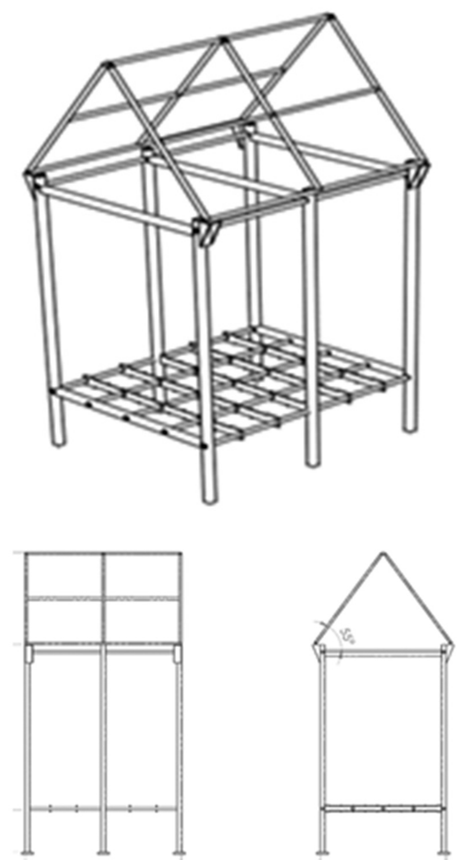

Figure 5. Frame structure.

3.2 Thermal Leakage/Efficiency

To ascertain the thermal efficiency of the storage system, the dimensional and material properties are considered and along with the operational temperatures, i.e., the required temperature (T_r) of 10 °C and atmospheric temperature (T_a) of -40 °C, heat flow through the composite wall is calculated using standard heat transfer formula[14] (Fig. 6).The internal volume of the heating chamber is 6.9 m³. The heater wattage required to maintain inner temperature is 400W under extreme conditions, i.e., 40 °C and 10 °C and 200W under nominal conditions, i.e., 20 °C and 5 °C. The system is assumed to be empty and completely enclosed with no interruptions and negligible thermal leakage. The dimensions of the chamber/module i.e., control volume are length (L) = $2m$, width (W) = $1.5m$ and height (H) = $2.2m$. Material properties are given as follows (Table 1)

Heat flow through the composite wall (Q_w) = $341W$

In an ideal condition, considering about 85 per cent heater efficiency and 2"PUF thickness, we need a 400W heater to maintain the module inner temperature[9]

Table 1. Components of the sandwich panel

Material	*Thickness*	Thermal Conductivity
HIPS	$t_h = 0.003m$	$K_h = 0.22W/mK$
SS	$t_s = 0.0008m$	$K_s = 14W/mK$
PUF	$t_p = 0.05m$	$K_p = 0.016W/mK$

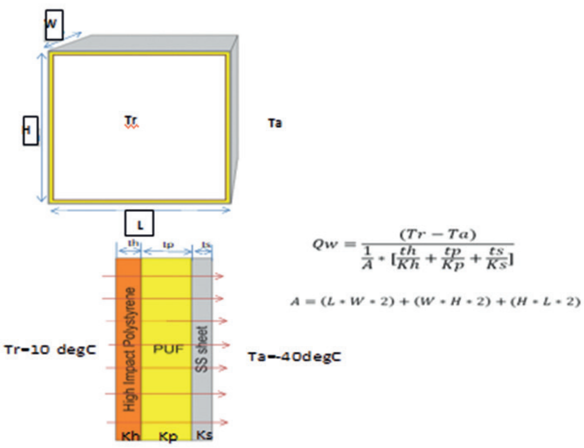

Figure 6. Heat transfer analysis.

3.3 Load Calculations/Safety Feature

As the storage system is to be installed at windy high altitudes, the effect of drag force also needs to be considered[15] (Fig. 7). The wind acts against the face of the system, having an area (A) of 4.4m^2 (2m × 2.2m). The drag coefficient (C) of air is taken as 1.05NA. The velocity of wind (V) is 60kmph, and the air density (ρ) is taken as 1.225 kg/m^3. Using the standard drag force formula i.e., $F = 0.5C\rho AV^2$

The drag is calculated to be 786.042N.

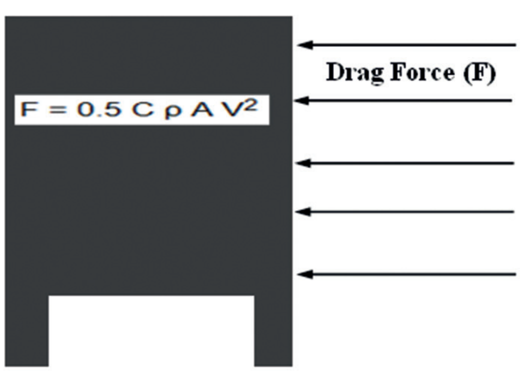

Figure 7. Drag force indication.

Similarly, the effect of drag force on the structure can be quantified based on beam bending stress calculations (Fig. 8). The drag force acting on the vertical member (F) is 786.04N as above. The length of the beam (l) is 2200mm. The outer width (B) and the tube's inner width (b) are 60mm and 56.8mm, respectively. The tube's outer depth (H) and inner depth (h) are 60mm and 56.8mm, respectively. The yield strength (σ_y) of the material (SS304) is 215 N/mm^{2,} and the modulus of elasticity (E) is 210000 N/mm^2 [12]. The moment of inertia, $I = (BH^3 - bh^3)/12$, , comes to 212614.62mm^4. The neutral axis (y) distance from the extremefibre is the greater value of B or H/2,i.e., 30mm. Section modulus $Z = I/y$ is 7087.15 mm^3. Load acting on each member, $W = F/2$ is 393.02N. Hence, using the below formula i.e. σ = W/Z, the maximum stress acting at fixed ends is 122N/mm^2. A Factor of Safety (FoS) of 1.76 is considered an added safety measure.

The system, serving the primary need of storage, has to withstand weight loads and thus, bending stress calculations are necessary (Fig. 9, 10). For platform-1, the load acting on the platform (F) is 20000N. The beam is 1500mm long. The outer width (B) and the tube's inner width (b) are 60mm and 56.8mm, respectively. The tube's outer depth (H) and inner depth (h) are 60mm and 56.8mm, respectively. The yield strength (σ_y) of the material (SS304) is 215 N/mm^2, and the modulus of elasticity (E) is 210000 N/mm^2. The moment of inertia, $I = (BH^3 - bh^3)/12$, comes to 212614.62mm^4. The distance of the neutral axis (y) from the extreme fibre is the greater value of B or H/2,i.e., 30mm. Section modulus Z = I/y is 7087.15 mm^3. Load acting on the member, $W = F/4$ is 5000N. Therefore,

Maximum stress at fixed ends, $\sigma = Wl/12Z$, is 88.19 N/mm^2 and

Maximum deflection at the center, Y = (WL^3) = (384EI) is 0.98mm.

The factor of safety (FoS) of 2.44 is considered.

For platform-2, the load acting on the platform (F) is 20000N. The beam is 2000mm long. The outer diameter (R_o) and the tube's inner diameter (R_i) is 20mm and 18mm, respectively. The yield strength (σ_y) of the material (SS304) is 215 N/mm^2, and the modulus of elasticity (E) is 210000 N/mm^2. The moment of inertia, I = $\Pi(R_0^4 - R_i^4)/4$, comes to 43221.35mm^4. The distance of the neutral axis, $y = R_o/2$, is 10mm. Section modulus $Z = 1/y$ is 4322.14 mm^3. Load acting on the member, $W = F/4$ is 5000N. Therefore,

Maximum stress at fixed ends, $\sigma = Wl/12Z$, is 192.81 N/mm^2.

The factor of safety (FoS) of 1.12 is considered.

3.4 Energy Needs/Harvesting

Since the system relies on a non-passive source, i.e., solar energy, to meet its energy requirements, the power generated from the installed solar panels can be calculated considering the area and efficiency parameters.[13] The area available for mounting a solar panel on the slanted roof

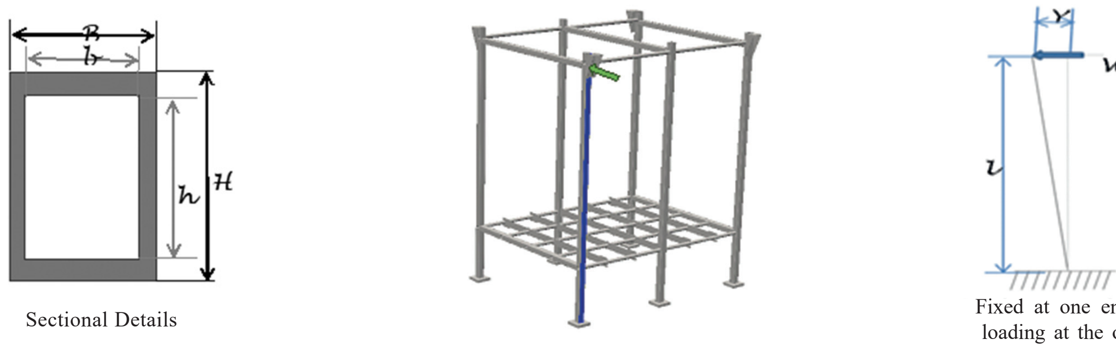

Figure 8. Frame member cross section and bending stress indication.

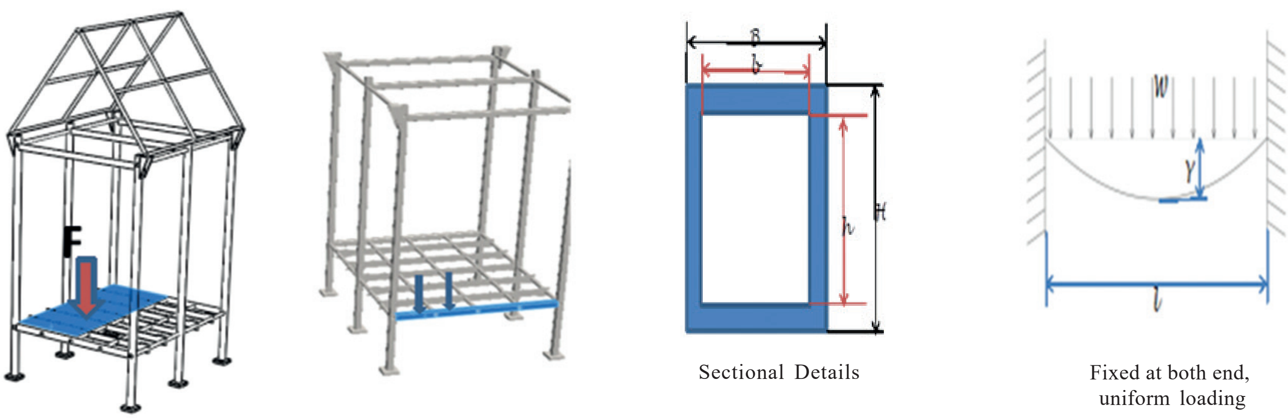

Figure 9. Weight loads and deflection indication for square cross-section members.

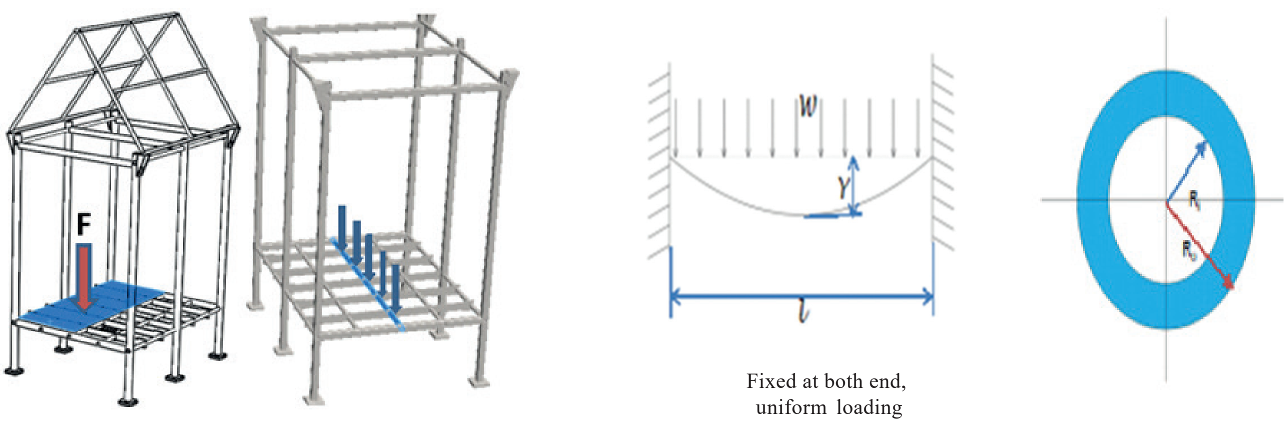

Figure 10. Weight loads and deflection indication for circular cross-section members.

is $6m^2$ per module (Fig. 11). The tilt angle of the roof is 55° to the horizontal axis. The power generated by solar panels per sq.meter on an average day (considering the efficiency* of solar panels as 15 %) is 150W. The total power generated per module is 900 W. Thus, the total power generated from all three modules is 2700W.

*Conversion efficiency of a polycrystalline module is considered to be 15 %.

3.5 Sensing System & Control System

The system was operated at full capability during trials with most features, including the smart technology enabled in set temperature and humidity values. The electronic system comprising several sensors, display unit, heater, and humidifier was functioning satisfactorily. The temperature and humidity values were observed to be in line with the set values that translate into safe storage of most perishable /freeze sensitive items stored inside the system.

3.6 Ration Storage & Trials

The trials conducted for performance and quality assessment pointed out a few observations. There was clear scope for incorporating military-grade ruggedised components to prevent frequent maintenance and replacement. Inherent integral power source from solar panels needs to be augmented without any generator sets being provided with the system. A set of additional spares is required to be scaled at the interval of each quarter in a year to enable continued, uninterrupted working of the system. The option of modifying the system to beheli-portable, inflatable and collapsible should be considered for further iterations. The silo system is installed at Khalsar J&K (Fig. 12), the on-ground testing was carried out during peak winter in 2019 and R&D level trial was carried out at DFRL Mysore for thermal leakage of the system.

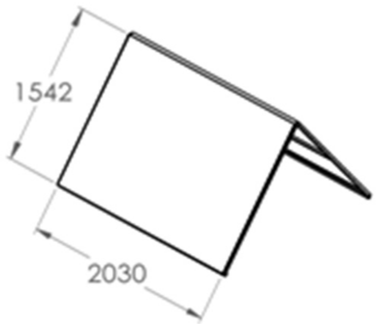

Figure 11. Solar panel area indication.

Figure 12. Completed and installed SILO at Khalsar, Ladakh.

TABLES: Temperature and humidity measurements during trial

11 February 2019									
	First module			**Middle module**			**End module**		
	At 1000 h								
	Inside	**Outside**	**Shelf**	**Inside**	**Outside**	**Shelf**	**Inside**	**Outside**	**Shelf**
Temperature °C	9.6	8.8	7.2	9.7	NA	7.5	9.9	8.0	7.8
Humidity %	46.7	46.0	49.4	46.5	NA	52.0	46.1	45.4	63.1
	At 1700 h								
Temperature °C	5.9	1.2	5.8	5.7	NA	6.0	5.9	1.1	5.8
Humidity %	41.7	41.0	37.3	42.0	NA	41.5	41.7	40.9	37.3

12 February 2019									
	First module			**Middle module**			**End module**		
	At 1000h								
	Inside	**Outside**	**Shelf**	**Inside**	**Outside**	**Shelf**	**Inside**	**Outside**	**Shelf**
Temperature °C	2.0	3.3	2.8	2.1	NA	2.5	1.8	3.3	2.8
Humidity %	44.2	40.6	35.6	43.8	NA	45.2	41.5	40.6	35.0
	At 1700h								
Temperature °C	5.2	3.2	6.2	5.1	NA	6.0	5.1	3.3	6.1
Humidity %	48.2	33.4	60.2	48.1	NA	59.4	46.3	34.5	58.3

13 February 2019									
	First module			**Middle module**			**End module**		
	At 1000h								
	Inside	Outside	Shelf	Inside	Outside	Shelf	Inside	Outside	Shelf
Temperature °C	5.6	4.4	6.5	5.5	4.3	6.2	5.4	4.4	6.0
Humidity %	45.5	46.4	47.2	44.9	46.2	46.8	45.6	46.1	47.0
	At 1700h								
Temperature °C	6.0	2.1	7.4	6.1	2.2	7.0	5.9	2.2	6.8
Humidity %	49.2	30.3	48.4	48.3	33.3	50.2	50.0	31.0	48.2

4. CONCLUSION

India is a land of varying weather, terrain and operational conditions. A standardised modern, and customizable storage system will be a boon for ensuring round the year availability of perishable rations, thus ensuring the nutritional requirements of the Armed Forces and eliminating climate-imposed food wastage. The application of existing products, systems, and processes in an optimal way will result in solutions to the challenges faced today. There is growing scope for advancement and inquisition. 'Project Pratinava' takes the vital initial step towards this direction by providing technical solutions, paving the way for further research and development in this domain. The use of military-grade components would result in a drastic increase in durability and reliability measures. As this was for terrestrial requirements, especially for high altitude areas characterised by peak winter temperatures, it is similarly envisaged to work on innovative design and functional solutions for various naval vessels.

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