A review study on specific requirements for refurbishment of military buildings in cold climates

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Abstract. In most cases there are no specific and clear design requirements defined in local building codes, the responsibility for appropriate design of military buildings therefore lies primarily on third party design service contractors that are hired upon a short term agreement, whereas government is primarily involved in financing stages and military personnel is solely involved in long term exploitation of these structures. Authors of this paper focus on analyzing and isolating specific requirements for refurbishment of military buildings with regards to their structural reliability, safety, endurance, fire and explosion-resistance, heating, ventilation and air-condition systems performance and efficiency, as well as adding energy efficiency, building performance optimization recommendations and measures in moderate and cold climate conditions.

1. Introduction
This study aims to define main parameters of military buildings to developed guidance for refurbishment of military buildings in cold climates. US army experience shows that energy efficient measures can be simply implemented also in military buildings and ensure energy reduction of almost 65% depending on climate zone [1,2] [3]. In addition, research [4] have shown that such building as military building have a strong potential to significantly reduce energy consumption. Average energy consumption of unclassified buildings in Latvia is 240 kWh/m². Some of the typical refurbishment and new construction solutions can be easily used also in some of military
buildings while such specific types of buildings as shooting ranges, ammunition storage require different solutions. In addition to final energy consumption, the more advanced energy sources should be developed for such buildings [5] [6].

By its definition, a military building is any structure designed to house functions performed by a military unit. General types include:

- Administrative Facilities;
- Ammunition Storage Facilities;
- Fortifications, Defense structures;
- Hospitals;
- Housing, Barracks;
- Training Facilities;
- Utility Structures;
- Vehicle Repair, Maintenance, & Storage Facilities;
- Weapons and Ammunition Storage and Production Facilities and etc.

Military buildings and barracks, with composite deck floors lightly built on joists and beams, rigidly fixed to the columns resist the effect of blast (and seismic and hurricane load). The sheeting can be frangible (that is, will bend, deflect, wrap around its supporting steel) but not fall to bits and fly around.

Where blast resisting glass is used it must be held in place with steel mullions and transoms fixed strongly to defense structures frames and designed to bend plastically without fracturing.

Fortifications and Defense Structures are defense contractors for blast resistant military buildings and other critical infrastructure, specializing in purpose made force protection against a variety of threats including bomb blast protection and explosion mitigation solutions.

This category also includes defensive barracks, headquarters buildings, blast walls, cover from view screens, gates, hardened hangars, mortar resistant roofs, observation posts, hangars, rocket screens, road barriers, observation posts, dangerous goods stores, vehicle checkpoints and workshops.

Force protection is an important factor in peacekeeping and peacemaking operations. Defensive structures are therefore necessary. The military buildings should provide an outstanding safety for Headquarters, Barracks, Hospitals and Weapon and Ammunition Storage Facilities.

Blast protection of these facilities and the personnel using and protecting them can be enhanced with defensive structure techniques. A Blast Wall consists of steel supporting structures and steel reinforced bolt-on concrete panels. The concrete is placed lying flat in the prefabricated panels which are then lifted into position and bolted on.
Nothing can give total safety against forced access, but strong steel blast gates can improve security. A blast gate should preferably open outwards, and close to form a V-type barrier which will jam if forced from outside. They should be fully clad to give cover from view; or clad in solid steel plate to give protection against small arms and artillery shrapnel. The blast gate (Figure 1) should be covered from an observation post on one side or both sides. It would be better if the gate can be surrounded by blast deflecting walls. It would be better still if the blast walls had a labyrinth or dual lock gate, so that in coming trucks enter, and stop surrounded by blast wall and gate. Such dual lock blast gates would be able to save many lives if methods of attack used in the past were repeated.

Defense Structures chain hedgehogs are a lightweight, transportable and effective standby gate.

![A blast wall and Lock gates with blast walls.](Image)

**Figure 1.** Blast Wall solutions.

According to Latvia rules on Cabinet Regulation No 1001 Regulations Regarding the Acquisition, Registration, Recording, Possession, Transportation, Conveyance, Carrying, Sale of Weapons and Ammunition and Possession of Collections of Weapons, the external walls of the weapons depository shall be equivalent in durability to 200 mm thick reinforced concrete walls or brick external walls the thickness of which is not less than 510 mm. This issue significantly reduced possibilities to use wood frame constructions. However Cross-laminated timber CLT wood construction can meet before mentioned requirements. Structural insulated panel also can be used in some type of military constructions. Mainly structural insulated panel can be with steel or OSB skins.

Study [7] analyzed SIP panels with steel skin. This study has shown that application of steel skin thickness SIP significantly improves construction blast resistant.
OSB Structural insulated panel has a significantly lower mechanical properties in comparison to steel skin structural insulated panel. However their properties can be significantly improved by application of extra steel or fiberglass mesh. Study [8] has shown that strengthening the OSB skin SIP panel with 3 mm-thick glassfibre can increase the projectile impact resistance capacity to wind velocity 32 m/s.

2. Review of structural solutions

Explosions and blast can produce, in a very short time, an overload much greater than the design load of a building. Explosives or projectiles can cut or deform structures with chemical energy or kinetic energy. In spite of this buildings can and do survive such effects without collapse, if correctly designed to do so. On the other hand, structures which are not so designed can suffer rapid cumulative collapse. Cladding and glass can be detached and fly around, forming lethal weapons. Such debris is often the biggest cause of injury and death. Steps should be taken to maximize the distance from any attack using gates, barriers, chicanes and such like. Nothing can be guaranteed to eliminate all risks; but if the following design features were to be incorporated, many lives could be saved, and many structures and businesses would survive. In addition to blast risk, neighborhood fires can affect such buildings. In order to minimize risks of forest fires, buildings should be kept 42–43 meters from the forest fires [9].

Floors must be prevented from ‘falling off’ their supports. If pre-cast concrete planks are used they should have sufficient bearing; but they should not depend on bearing and gravity to stay in place: they should be made continuous with rebars between adjacent planks and preferably be made continuous with the supporting beams, using shear connectors. However, a more robust detail is to pour continuous concrete slabs on to composite style decking which is itself continuous over 3 or so joists; such slabs should be poured so that they encapsulate the main beam to which the joists are fixed, and around the columns. For fast erection of such type of buildings, prefabricate panel can be used. For example metal sandwich panel can insure necessary strengthens and energy efficiency [7] [10]. Also SIP panels can be adopted for these purposes [8].

Joists should be made continuous themselves, through every main beam and wherever they coincide with outer columns. The joints should exceed the plastic capacity of the joists so that, if they fail, it is by plastic hinge and not by joint failure. Where joists are attached into the webs of outer beams no moment resistance is possible but there should be sufficient bolts to make shear failure unlikely before plastic hinges form in the outer main beam.
Main beams should be continuous across the structure and should have connections to the outer columns which exceed the plastic capacity of the main beam. This means that in the case of overload the beams deform, forming hinges, absorbing energy and taking time. Blast or shock loads will diminish in a very short time.

The main outer columns should remain elastic and strong enough to carry likely loads even when main beams attached to them form plastic hinges. Care should be taken that the shear capacity of the column should not be exceeded within the moment connection zone by the moment in the beam: this almost always requires hunched beam-to-column connections. In addition load bearing metal beam should be covered by fire resistant layer [11].

The ground to first floor columns carry the heaviest loads. They are always more vulnerable to attack. These columns are almost always longer than columns on other floors. They often have less stability because of gaps between them. And they often have no continuity below, as they sit on 'pinned' feet. So special care has to be taken: they need to be stronger; to have barriers to protect them; to have continuity at footings level with ground beams or slabs.

If all this continuity is achieved, even if a column or two are cut or deformed, the grillage of beams and joists and slabs at each floor throughout the building will continue to carry the loads. They may well deform substantially, joists and beams may well bend and form plastic hinges or act as a catenary net to share loads; but it would be exceptionally difficult to demolish such a building.

3. Analysis of HVAC requirements in indoor shooting ranges

Primary purpose of ventilation is to remove contaminants created during the firing of a weapon from the respiratory zones of those occupying the range. Exploding primers containing lead stypnate and friction from the lead slug against the gun barrel create airborne lead. Carbon monoxide and other contaminants are also created during the firing of a weapon. Protecting users from the inhalation of combustion-related contaminants is the key concern when designing an indoor shooting range [12]. The American Conference of Government Industrial Hygienists recommends a minimum airflow velocity of 0.25 m/s across the firing line and away from the shooter’s breathing zone. Traditional indoor ranges use dedicated outdoor air systems utilizing 100% outside air ventilation system to provide this flow rate.

ANSI/ASHRAE Standard 62-2001, allows a dilution ventilation strategy to maintain clean and breathable air for users in an energy-efficient manner. Therefore, to provide sufficient ventilation and to comply with energy
efficiency strategy it is feasible to partially recirculate range air. However, this method imposes significant indoor air quality (IAQ) challenges due to high emission of lead substance from bullets. Lead may cause serious long-term health problems. Mechanical filtration effectively removes airborne lead. Study [12] suggest in their study to use three stage mechanical filtration as an optimum solution to combine good IAQ and energy efficiency in the indoor shooting ranges.

At the first stage, a pre filter is used to filter return and exhaust air at 30% efficiency. Next stage is the secondary filtration, that removes 90-95% of contaminants and particles. All recirculated air is additionally cleaned through 99.99% HEPA filters for maximum lead removal.

Carbon monoxide is the most prevalent gaseous component of combustion in all cases, and is an ideal surrogate for firing range activity. CO is a toxic gas, however, it cannot be removed by filtration, therefore it must be diluted with outside air to obtain acceptable concentration levels.

The range exhaust and outdoor air intake rates are controlled by the building automation system to ensure that carbon monoxide level is below the setpoint limit of 25 ppm (8-hours exposure limit according to OSHA/ACGIH Guidelines for CO). The carbon dioxide level is also limited in accordance with ASHRAE recommendations. If the human activity within the range increases, the variable speed exhaust fan increase the flow to extract additional gaseous concentrations and eliminate the human exposure to contaminant gases.

It is also important to note that in indoor shooting ranges a slightly negative pressure is to be maintained, or so-called underpressure of at least 5 Pa, so that the indoor air is being extracted continuously. Contaminants need to be contained in the range space. This will prevent the ingestion of these harmful particles, and also keep the non-range spaces and surfaces of the building free of contamination. This in turn will ensure the health and safety of all customers and employees. This factor is especially essential when there is a high activity in the range, as lead and carbon monoxide levels may increase significantly.

Providing negative pressure in the range is accomplished by designing more exhaust than supply air. Creating laminar air flow at the firing line will protect a shooter’s respiratory zone, but it will not keep contaminants created in the range from entering other areas of the building. The industry standard for this design is 10% greater exhaust than supply. The tighter the range area of the building is constructed, the less differential is necessary to maintain the proper pressure differential. Some ranges have been designed with the 10% differential, but the exhaust is filtered and there was no method of modulation for the exhaust based on filter loading.
If the shooting range is not a stand-alone structure the ventilation system serves more areas, therefore more precautions are applied with regards to the ventilation system. All adjacent areas that are not exposed to lead and CO emissions should be served by a conventional constant or, if necessary, variable volume ventilation system. The ventilation system serving indoor shooting range and the ventilation system serving other adjacent spaces are isolated from one another to prevent air leakage and, thus, cross contamination.

Temperatures and airflow in the shooting ranges are controlled with respect to user activity and clothing. Shooters move in various positions and are lightly active with a metabolic rate at or below 2.0 met. With respect to the temperature inside the shooting range, the temperatures should be kept in between 18-20 °C, that is somewhat cooler than lobby or classroom areas.

The temperature and the air flowrate that should be maintained in shooting ranges are not defined by local building codes in Latvia, therefore a common practice is to refer to The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Occupational Safety and Health Administration (OSHA) or National Air Filtration Association (NAFA) guidelines.

With regards to the air volume in the shooting ranges, if contamination emissions such as lead and CO cannot be accurately specified, the methodology is to use a recommended and critical airflow rates referring to NAFA recommended air velocity of 0.25 m/s during normal operation, and maximum air velocity of 0.5 m/s during critical operation.

The best method for supplying airflow to an indoor shooting range is from a full-length perforated plenum wall located behind and parallel to the firing line to ensure a steady laminar flow that both mixes with the indoor air and displaces the contaminated air. Supply air should be discharged from the ceiling, as close to the back wall as possible.

The exhaust grilles are to be located on the opposite end in the target zone, however there are more aspects possible with regards to the placement of the exhaust grilles. In all cases air flow pattern should be maintained in the direction of the target zone. In most of the existing shooting ranges in Latvia exhaust grilles are placed either on the ceiling or side wall in the target zone. However, during high activity shooting practices and trainings high smoke contamination may occur even if the fans operate at full or critical speed (which in shooting range is defined as 30%-50% higher air velocity and flowrate above normal operation mode). Therefore, it is recommended to locate exhaust line approximately 5 m away from shooting positions. In shooting ranges that are above 50 m in length (distance between
the end walls) there might be several shooting positions, at 25 m and 50 m
distance from the target, therefore additional exhaust grilles are
recommended to be located along those two positions.

The principle of combined air exchange model proposed by National Air
Filtration Association (NAFA) guidelines.

4. Energy efficiency solutions
In order to set guidelines for comfort levels and optimal energy consumption
passive house criteria can be used as a threshold. Due to the required
strength and other above mentioned criteria related to building envelopes,
good and very good energy consumption criteria can be achieved. Table 1
sets out passive house certification criteria and a basic evaluation of the
importance of such criteria for unclassified military buildings. Such a basic
evaluation is applicable to most unclassified building types. When looking
for a more detailed evaluation on the criteria, specific building types must be
assessed separately.

Table 1. Passive house criteria.

| Criteria                | Result to be achieved | Importance level |
|-------------------------|-----------------------|------------------|
| Space heating energy demand | max 15 kWh/m2         | medium           |
| Primary energy demand    | max 60 kWh/m2         | high to medium   |
| Airtightness             | max 0.6 l/h (50 Pa)   | high             |
| Thermal comfort          | max 10 hours of indoor air temperature above 25°C | high to low |

Space heating energy demand is rated as medium due to the possible
struggles within cold climates to reach such low energy efficiency and
considering the specific other requirements for building structures and
protection elements that can directly relate to thermal bridges and therefore
harden the potential for achieving such a low energy efficiency. Aiming for
15 kWh energy demand is much more important than achieving it.

Primary energy efficiency can be highly important for specific cases
where no conventional heating methods can be used, and no network
electricity supply is available. In such areas, firstly, it is crucial to minimize
the energy demand and secondly renewable energy technologies can be used
to meet the demand. Study [13] has shown importance of different building
systems integration in order to achieve better level of energy efficiency.
However it is not visible that in nearest future military buildings can be self-
sufficient with application of existing technologies [14].
Airtightness is important criteria not only in terms of energy efficiency, but also other measures, therefore importance of airtightness is rated as high. For example, airtightness relates to resilience of structures as well as acoustic requirements and comfort.

5. Conclusions

Shooting ranges and army training facilities require a separate ventilation system, if they are not situated in standalone structures, that complies with strict health and safety requirements. Air exchange is ensured by mechanical ventilation system only with three stage filtering, if part of exhaust is recirculated. Underpressure should be maintained in shooting ranges in order to maintain adjacent spaces contaminant-free. Typically supply air should account for 90% of exhaust air.

It is important to maintain laminar air flow and avoid turbulent air flow pattern to ensure that contaminated air plume is not flowing backwards. The optimum air velocity range for shooting ranges is between 0.25 m/s in normal operation mode and 0.5 m/s in critical operation mode, when intense shooting trainings take place. With regards to the temperature, no specific requirements are defined, as the shooting range is a space where a person typically spends less than 2 hours. However, authors suggest that the temperature is kept at a level between 18 C and 20 C. During intense shooting training sessions the indoor temperature might be lower.

As military structure stock in Latvia is relatively outdated and a lot of existing structures need renovation and refurbishment, it is essential to define solid roadmap along with the guidelines when it comes to structural issues, energy efficiency measures and healthy indoor climate within those buildings. Another driving factor to define such guidelines is the fact that Latvian military buildings stock will be expanding in the coming years. In many cases basic requirements can be used in tenders for such buildings, outlining the quality criteria for design & build tenders, this way ensuring a single responsible party for achieving quality results.

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