Recent Advancements in Gun Range Design

With a focus on ammunition adaptability

October 1, 2018

1 Abstract

Indoor gun ranges require careful and methodical planning and design to meet law enforcement standards for safety and flexibility. This white paper documents an on-going effort of planning for occupant safety and flexibility as part of indoor gun range design.

Key factors that contribute to the design of an indoor gun range and opportunities to reduce cost through assessment of mechanical systems prior to construction are reviewed and presented.

Intended benefits of this paper include:

- Understanding the importance of a well-defined needs assessment to determine the use and requirements of an indoor gun range.
- Identifying how the type of ammunition can impact design decisions.
- Demonstrating the need to determine ammunition requirements so that post-construction modifications are avoided.
- Demonstrating how to utilize Computational Fluid Dynamics (CFD) as a tool to assess the design of the proposed mechanical system. This allows for virtual modification and testing of the proposed ventilation design to address potential issues prior to construction.

2 Background

In 2012, a policing agency in Western Canada commissioned an evaluation of their existing 100-metere outdoor gun range. The existing facility was an open air outdoor range surrounded by an earthen backstop and berms. It also had three rows of wooden baffles overhead to accommodate shooting from a stationary firing line. Assessing the gun range from an environmental and safety perspective were the first priorities of the initial studies.

First the lead contaminated areas were identified, followed by a soil delineation program to dispose contaminated soil. Disposal of the contaminated soil was required prior to initiating the construction of a new outdoor gun range. The Canadian policing agency needed a facility that was both safe and flexible. Working with the Firearms Skills Unit as well as the Tactical Unit, two 20-metre wide and 100-metre long bays were developed as the optimal design, one for the Firearms Skills Unit and one for the Tactical Unit.

A key components of this project was the improvement of safety features of the gun range. The preliminary design identified the need for upgrading the baffle design, installing bullet traps, and completing general berm improvements. The proposed design included a state-of-the-art steel bullet trap, new lighting system for night time shooting, and improved berms that prevent stray bullets from escaping the range. The steel trap was selected as it could be safely utilized in an outdoor environment. The armoured steel construction allowed the trap to be safely used with handguns, shotguns, and rifles.

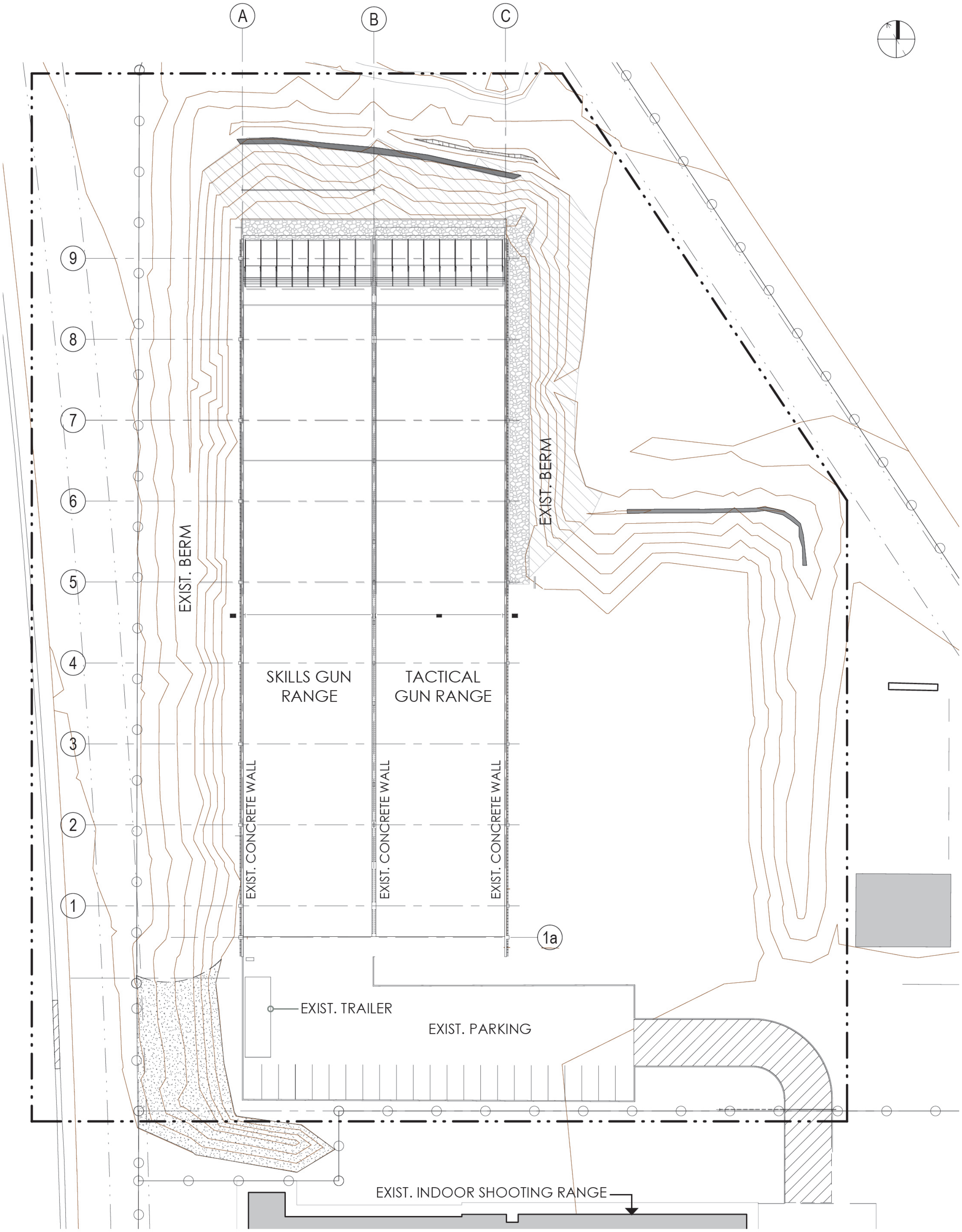


Figure 2.1 - Outdoor Gun Range Site Plan

An overhead baffle system designed to protect against ricocheting or stray bullets from exiting the gun range, and to mitigate noise impact to the surrounding. The baffles were suspended by steel trusses that were anchored to concrete walls. Each baffle was constructed of a 3/8” armored steel plate covered with plywood for protection and noise absorption.

Figure 2.2 - Existing Outdoor Gun Range Bullet Trap

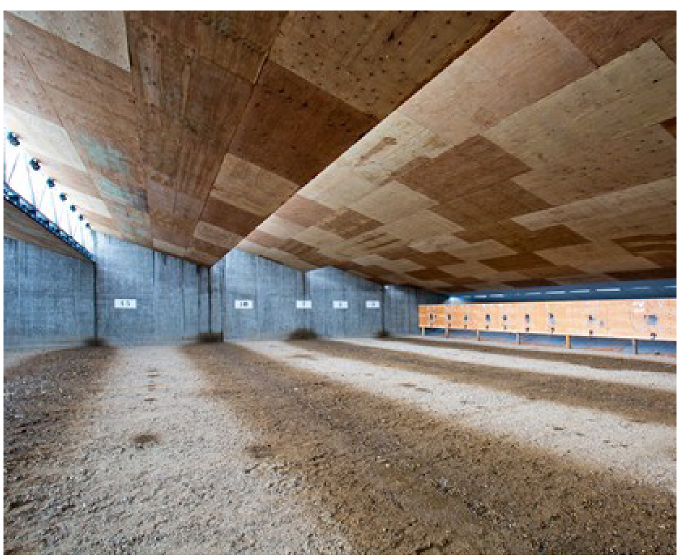


Figure 2.3 - Existing Outdoor Gun Range Overhead Baffles

3 Current Situation/Opportunity

During the design stage, the Canadian policing agency committed to the use of frangible ammunition for the outdoor gun range. However, once the range was commissioned, the agency changed their directive and started utilizing lead ammunition in the gun range. This was due to a shortage and unreliable source of supply of frangible bullets.

Use of lead ammunition resulted in poor air quality within the range and posed risks to users. Lack of control for air movement within the range meant that lead particulate could not be effectively removed from the surrounding air.

A solution was required that would improve the air quality in the range.

4 Key Challenges

Some of the challenges that were encountered while designing a solution to improve air quality in the range are identified below:

4.1 Flexibility of the Training Space

The Canadian policing agency required a training space that would present their officers with a variety of stressful situations in a simulated environment. Developing the ability to think critically and address risk is a key part of their training program. As stated previously, tactical shooting ranges are characterized by moving target lines, moving targets, and shooting positions. The tactical bay can be set up for scenario training, using a variety of visual props as well as interactive targets.

With safety being the primary mandate, the tactical bay utilized the “no blue sky” concept as the basis of design. The “no blue sky” concept relies on range rules that restricts shooters from loading their weapon until they are in an approved position where they cannot see blue sky.

To achieve the “no blue sky” concept, cast-in place concrete walls and steel trusses were designed to support a continuous overhead baffle system. This system created the “no blue sky” zones while providing a secure structure designed to protect against ricocheting and prevent stray bullets from exiting the gun range, and reduce noise impact to the surrounding neighborhood.

The combination of overhead baffles and lead ammunition creates an environment where gases and lead particulate linger around the shooters after a bullet is fired. Air movement is limited due to the presence of the continuous baffles suspended from the overhead structure. The gases and the lead particles need to be removed from the range before these particles settle on the shooter and their surroundings.

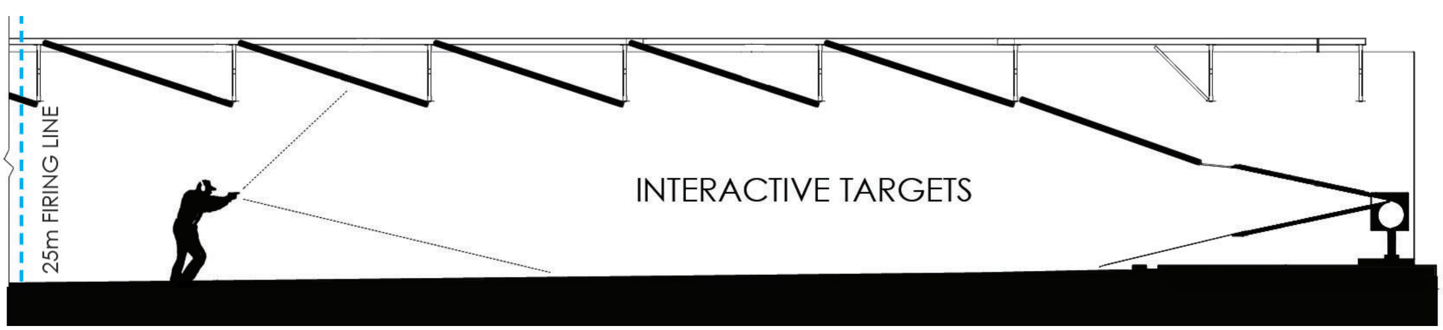


Figure 4.1 - “No Blue Sky” rule for bullet trajectory at all shooting positions

4.2 Types of Ammunition

4.2.1 Planned Ammunition (Frangible)

When the range was designed in 2013, the policing agency planned to use frangible ammunition.

Frangible ammunition replaces lead with compressed copper powder. The bullets are considered more environmentally friendly given there is little or no lead content. They also separate more easily on impact, reducing the likelihood of ricochets and contamination. Frangible ammunition, while environmentally safer, has its own limitations:

1. **Unreliable sourcing** – The client could not purchase the required quantity of ammunition required for their training purposes as it was unavailable or backordered.
2. **Higher costs** – Frangible ammunition costs are significantly higher than lead ammunition. Constrained training budgets for law enforcement agencies restricted use of this ammunition.
3. **Frangible ammunition is lighter** – When officers are training with frangible ammunition they do not experience the same recoil as with lead ammunition. This limits their real-life training experience as it would ultimately impact their point of aim. This is crucial to master as it impacts the ability of an officer to maintain steady aim when firing in rapid succession.
4. **Frangible ammunition creates dust once in contact with a steel trap** – While the dust from frangible ammunition is non-toxic, it will still produce significant quantity of dust which can be a hazard for the officers.

4.2.2 Actual Ammunition (Lead)

Given the limitations of frangible ammunition, the Canadian policing agency proposed to use lead ammunition after the gun range was designed.

This change in ammunition presented new challenges to maintain a safe breathing environment:

1. **Density** – The lead particles' high density allows it to settle quickly, coating surfaces immediately down range from the shooter with fine lead dust. This contaminates subsequent firing positions and presents an ongoing safety risk for users that crouch or go prone where lead particles are present.
2. **Inconsistent ventilation around the shooter** – Due to the impact of external wind, natural air currents in and around the range affect movement of lead particulate within the range. After each shot, the hot expanding gases from the propellant and the primer will leave the muzzle in all directions. Without a consistent down-range air current, this can result in lead particles being blown back in the breathing zone of the shooter.
3. **Inadequate range exhaust** – The presence of the baffles affect exhausting of lead particles in the air causing a health and safety concern. Elevated levels of lead content have been documented in users of the range. This needed to be addressed in the re-design of the tactical indoor gun range.

4.3 Importance of a controlled environment

In an outdoor gun range, the influence of ambient winds cannot be predicted. Winds can direct firing emissions towards the shooters and also cause re-circulation within the range due to varying wind flow patterns. This was further validated by a wind study completed in July 2016 by RWDI which clearly demonstrated the difficulty in passively ventilating an outdoor gun range. Mechanical ventilation is essential to ensure that the air flow within the range moves away from the shooters respiratory zone keeping the shooting area safe. The ventilation system is also designed so that air is cleaned from lead dust before it is released into the atmosphere.

5 Proposed Solution

5.1 Design approach for the Tactical and Skills Bay

Our proposed solution resulted in the following approaches for the 100-metre gun range:

1. **Tactical Bay – East Side:** A tactical bay is designed to accommodate a moving target and shooter which results in ricochets in unpredictable locations. This can be addressed with the existing continuous baffle system. However, the presence of lead particles in a large variety of locations throughout the range requires the provision of a precise mechanical ventilation system. A moving firing line will require guaranteed air quality along the length of the range. A made-to-order mechanical system and ballistic safety ceiling is required to deliver this objective. The intent for the tactical bay was to transition from an 100-metre outdoor range to a fully enclosed, mechanically ventilated 100-metre indoor range.

2. **Skills Bay – West Side:** A skills bay utilizes a stationary firing line where both the shooter and targets remain still. A stationary firing line allows for better control for safety as there is only one location for the shooter. This did not require the presence of a continuous baffle system. Our proposal was to remove some of the baffles and place a few strategically in front of the firing line, to restrict and interrupt the travel of direct fired rounds. The baffles will ensure that no rounds exit the range from the firing line. The reduced number of baffles in this design minimizes operational costs as there are fewer baffles to maintain and replace. The target system can be programmed to have targets present themselves at different distances in the same course of fire so that the shooter does not have to move. The reduced number of baffles will improve natural air movement. This, supplemented with a sound lead management program, can reduce the potential of lead exposure and contamination to the users and the environment.

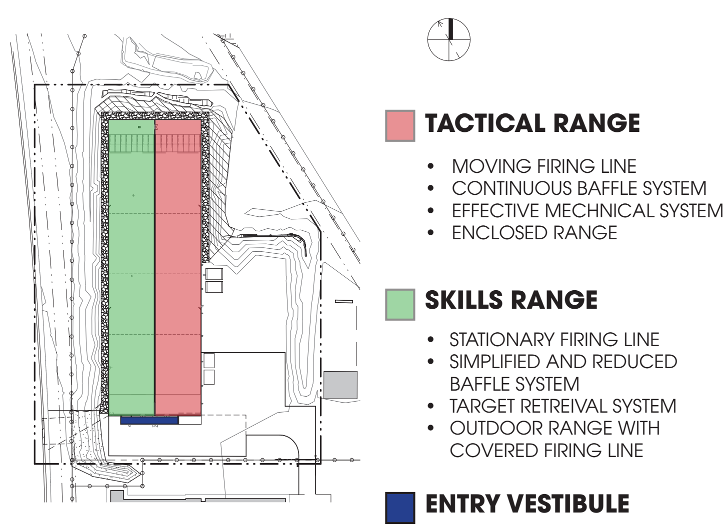


Figure 5.1 - Proposed Floor Plan

5.2 Tactical Bay Ventilation System

5.2.1 Regulatory Requirements

Based on the various design guidelines and best management practices, active ventilation is considered the most important engineering control to reduce primary lead exposure in indoor firing ranges. The recommendations from the various design guidelines for the ventilation system performance in an indoor firing range are summarized below:

1. Provide effective air movement away from the shooter stations (firing line) toward the target area (Royal Canadian Mounted Police 2014).
2. The air system should create uniform airflow across the area of the firing range, floor to ceiling and wall to wall (Royal Canadian Mounted Police 2014).
3. Introduce supply air as far up range as possible. A perforated wall plenum has been shown to provide uniform air distribution at the firing line. A minimum distance of 15 ft (4.5 m) is recommended from the wall to the firing line (NAFA Guidelines Committee 2004
4. Airflow along the firing line should be between 50 fpm (0.254 m/s) and 100 fpm (0.508 m/s) with an optimal velocity of 75 fpm (0.381 m/s). Higher airflows may create circular flows of air (eddies) starting downstream of the shooter, allowing contaminated air into the breathing zone (NAFA Guidelines Committee 2004).
5. In addition, higher velocities may create airflow that interferes with the bullet trajectory or creates vibration of the target. If it is desired to minimize fall out of gun emissions downrange of the firing line, downrange airflow should be maintained at a minimum of 30 fpm (0.152 m/s) and should be evenly distributed (Department of Health and Human Services 2009).
6. There should be no obstructions to the airflow between the supply air inlets and the firing line (Department of Health and Human Services 2009).
7. The combined exhaust airflow should be greater than the total supply airflow to ensure the firing range is maintained under negative pressure, and to prevent migration of lead-contaminated air from the firing range to the surrounding environment. The exhaust air capacity should exceed the air supply capacity by at least 10% (National Shooting Sports Foundation 2011).
8. The air should be exhausted at or behind the bullet trap (Royal Canadian Mounted Police 2014).
9. The exhaust system should be designed to provide minimum duct air velocities of 2,500–3,000 fpm (12.7–15.24 m/s) (Department of Health and Human Services 2009).

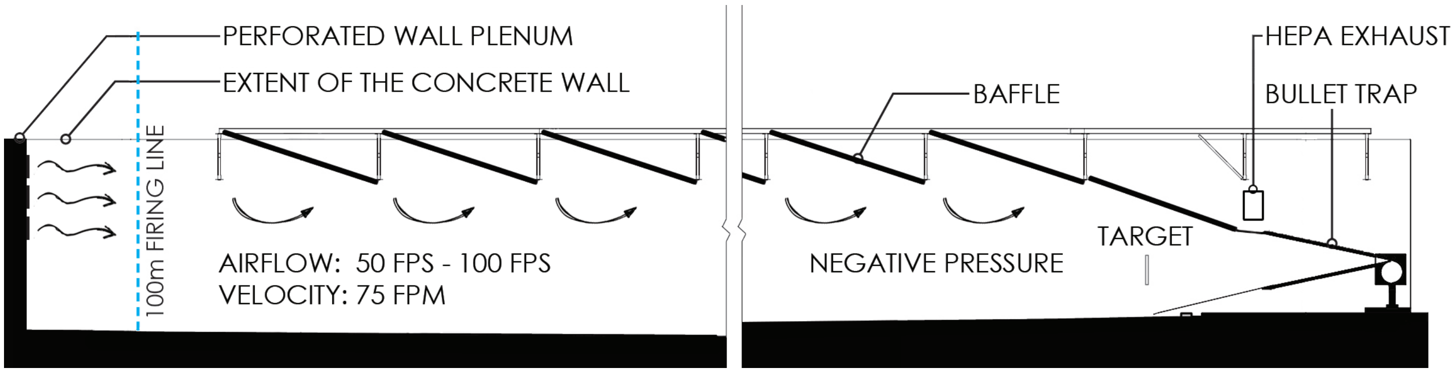


Figure 5.2 - Section Diagram

10. The ventilation system that serves the range area should be completely isolated from any other building HVAC system to prevent any potential cross contamination of non-protected areas.
11. The minimum recommended filtration of exhaust air is high-efficiency particulate air (HEPA) filtration. The HEPA filter removes lead particles from the exhaust air. The Institute of Environmental Sciences and Technology (EST) specifies that a certified HEPA filter must capture a minimum 99.97% of contaminants at 0.3 micron in size (Department of Health and Human Services 2009).
12. The NAFA Firing Range Guidelines provide two options for a ventilation design: a direct exhaust system where the system supplies 100% outside air, and a closed-loop system where the system recirculates the air in the range. The first system could be costly due to the cooling or heating of the 100% outside air. In the latter system, a certified HEPA filter is required to clean the exhaust air before it is recirculated in the range (NAFA Guidelines Committee 2004).
13. Achieve laminar airflow across the firing line in the direction of fire at 75 fpm to ensure dust from firing is swept away from users (Department of Health and Human Services 2009).
14. Negative space pressure control to limit migration of lead and other contaminants to the rest of the building (Department of Health and Human Services 2009).
15. HEPA filtration on exhaust air to reduce lead and particulate matter release to the environment to meet federal standards (Government of Canada 1999).

5.2.2 Proposed Mechanical Design

The mechanical ventilation system for the tactical bay was designed to meet the design and performance requirements identified in Section 5.2.1. The ventilation system was designed to supply 100% outside air. However, the range is not heated in order to simulate actual outdoor conditions during training. Minimal make-up heating is provided to heat the supply air to -10 °C if the outside temperature drops below -20 °C.

5.2.3 Assessment Method

The conventional method for assessing the ventilation system in indoor firing ranges is by completing a site survey during commissioning (i.e. after the ventilation system is operational). With ventilation being critical to the functionality and use of the range the use of Computational Fluid Dynamics (CFD) was proposed to assess the mechanical ventilation air flow in the tactical range and the dispersion of lead emissions from the varying firing positions.

CFD allows optimization of the ventilation system performance during the design phase, before the ventilation system is actually installed. This method provides flexibility in terms of the number of modifications that can be made to design parameters and evaluated during the design process.

5.2.4 Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) is a method of digitally simulating air with given boundary conditions by solving the equations that govern fluid flow. In contrast to a commissioning process that tests airflow after the mechanical system has been constructed, CFD utilizes the 3-dimensionsal Building Information Model (BIM) in conjunction with the proposed mechanical ventilation strategies to test mechanical design decisions in order to find the optimal solution for airflow in a space prior to construction.

The CFD model is built based on the geometry of the firing range building, the operating parameters of the supply and exhaust vents (location, dimensions and flow rates), and the possible locations of the receptors (i.e. the shooters).

The simulation generates a 3-dimensional field of airflow velocities. The airflow velocities at possible shooting positions are compared against the recommended range of airflow velocities (i.e. 50-100 fpm with optimal velocity of 75 fpm). In addition, the simulation helps identify potential areas of airflow recirculation and poor dispersion. The focus of the assessment is the airflow across the shooter's breathing zone which depends on the shooting position (i.e. standing, kneeling, or prone) and is generally accepted to be 0 to 2 metres from the floor.

The tactical firing range can be used as both, a static (i.e. fixed firing lines or firing boots) and a dynamic range (i.e. the shooters can move and shoot freely within the range). The tactical firing range has four fixed firing lines which are the shooters' positions during static training: at 100 m, 75 m, 50 m and 25 m from the target.

During dynamic training, shooting can occur from any location in the firing range and therefore, the airflow velocities along the full length of the firing range are compared to the recommended range of velocities.

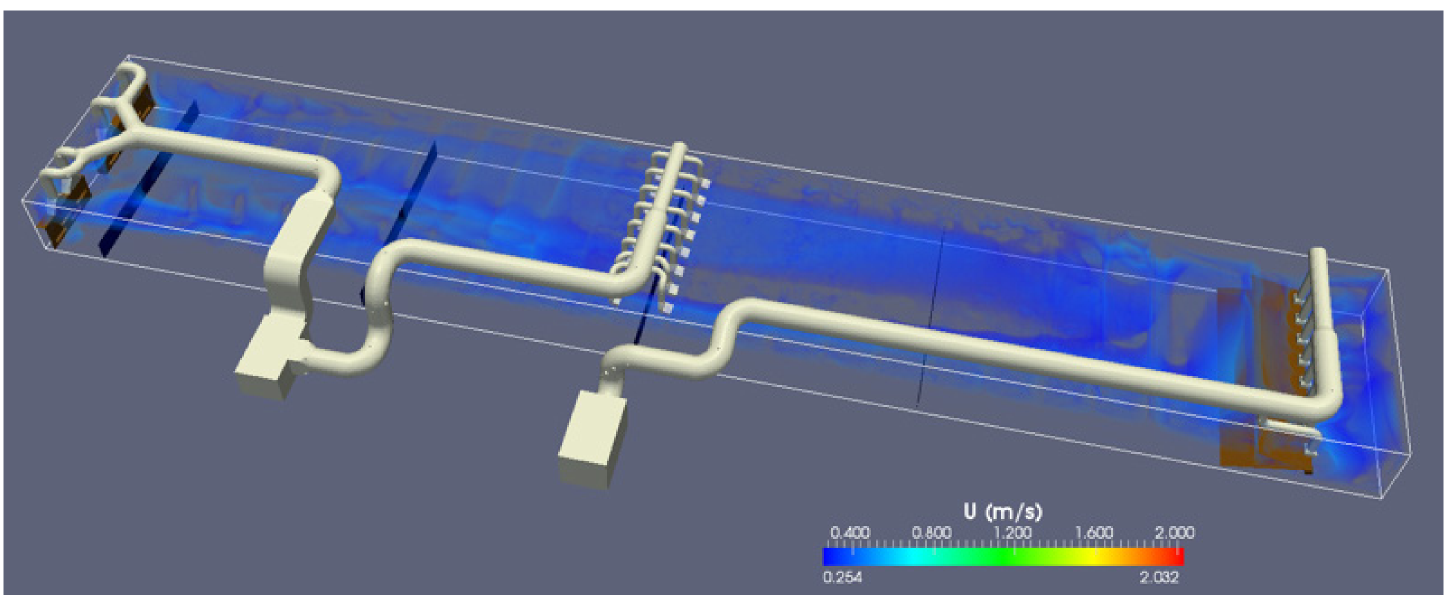


Figure 5.3 - Predicted Extent of Air Flow in the Range of 50 to 100 fpm

5.2.5 Design Options

The ventilation design was evaluated using an iterative approach starting with the initial design. Based on the CFD simulation results, modifications were made to the design and a new model simulation was generated. This iterative assessment was repeated until the model simulation showed that the performance of the ventilation system was within acceptable criteria.

The initial ventilation design included two air inlets: one behind the first 100m firing line and one at mid-range with an alternating volumetric flow rate of 32.21 m³/s, and an air exhaust behind the bullet trap with a volumetric flow rate of 32.21 m³/s. The front and middle air inlets are alternating to allow use of only the front range firing lines (100 m, 75 m and 50 m) or only the back range 25 m firing line. The iterative assessment approach included CFD model simulations for five design options. In this document we will outline the assessment of the initial design and the final design for the front air inlets of the laminar wall.

5.2.6 Comparison of Initial Design to Final Design

Design Option 1 (Initial Design):

Two plenum walls on either side of the entrance way, 5 m behind the 100 m firing line with a series of openings to distribute the airflow across the firing range, and 2 rows of 8 supply vents along the ceiling at midrange; alternating volumetric flow rate of 32.21 m³/s between the front and midrange vents; exhaust vents above the bullet trap with volumetric flow rate of 32.21 m²/s.

Assessment Notes:

Numerical simulation is conducted for inlet airflow from front vents only and from middle vents only since the design intent is to manually alternate the inlet flow between the front and middle vents for different training settings.

Legend

Flow of lead contaminated air towards the shooter
Flow of lead contaminated air away from the shooter
1 Front air inlet and plenum wall
2 Middle air inlet at 50 m firing line
3 Overhead baffles
4 Bullet trap
5 Mechanical exhaust

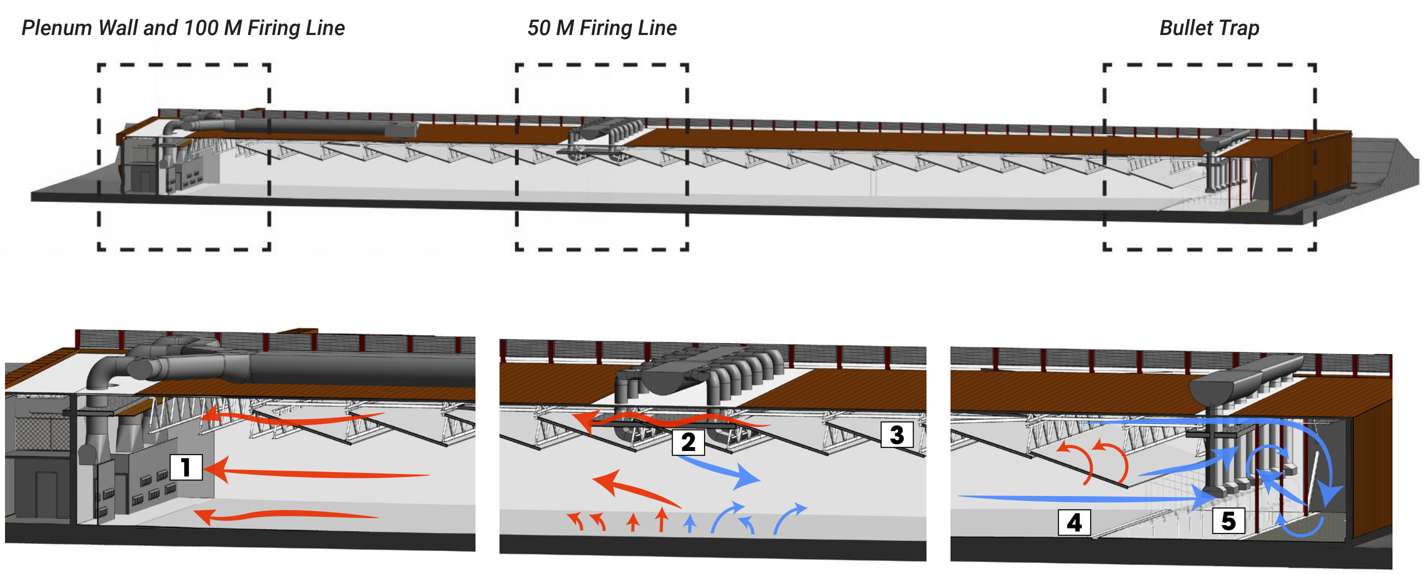


Figure 5.4 - Design Option 1 (Initial Design)

Inlet Airflow from Front Vents Only
(Refer to Figure 5.4 and 5.5)

Based on the numerical simulation, the following findings are observed for the inlet airflow from front vents only:

- Airflow velocities close to the range walls are much higher than in the interior.
- The airflow velocities at the right and left range walls are unbalanced: the velocities along the right range wall are higher than the velocities along the left range wall.
- The airflow velocities at the 100 m and 75 m firing line breathing zone is much higher than the recommended velocity range (50-100 fpm).
- The airflow velocities at the 50 m and 25 m firing line breathing zone are slightly higher (between 100 and 200 fpm) than the recommended velocity range (50-100 fpm).
- There is a horizontal recirculation zone from the left and right plenum walls towards the entry way.
- There are vertical recirculation zones above the left and right plenum walls above the 100 m firing line but these zones are approximately 2 m above the breathing zone and would not directly impact the breathing zone.
- There is reversed airflow at the vertical cross section at the centre of the range entry way.

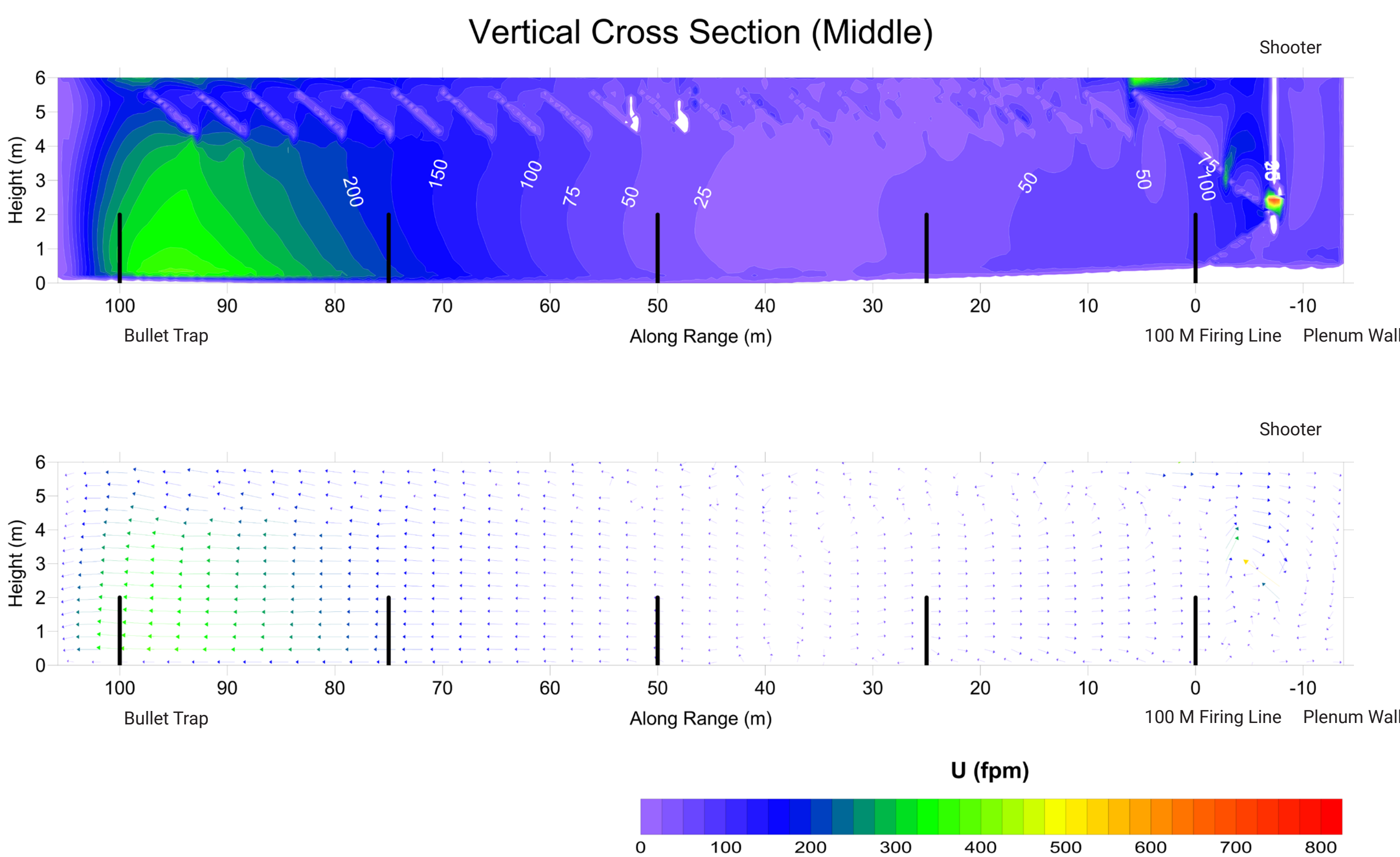


Figure 5.5 - Design Option 1 (Initial Design) - Contour and Vector Plots of Air Flow at a Vertical Cross Section between Left and Right Plenum Walls

Design Option 5 (Final Design):

Three rows of discrete front inlet vents above the entry way: lower row on angle, middle and upper row horizontal. The inlet flow rate of 32.21 m³/s is distributed between the upper, middle and lower row in the ratio: 20%, 40% and 40%, respectively. No midrange inlet vents.

Assessment Notes:

In Design Option 5, the inlet flow rate is distributed more evenly between the 3 discrete front vents. The intent of Design Option 5 is to reduce the vertical recirculation zone above the 100 m firing line or move it upwards further away from the breathing zone.

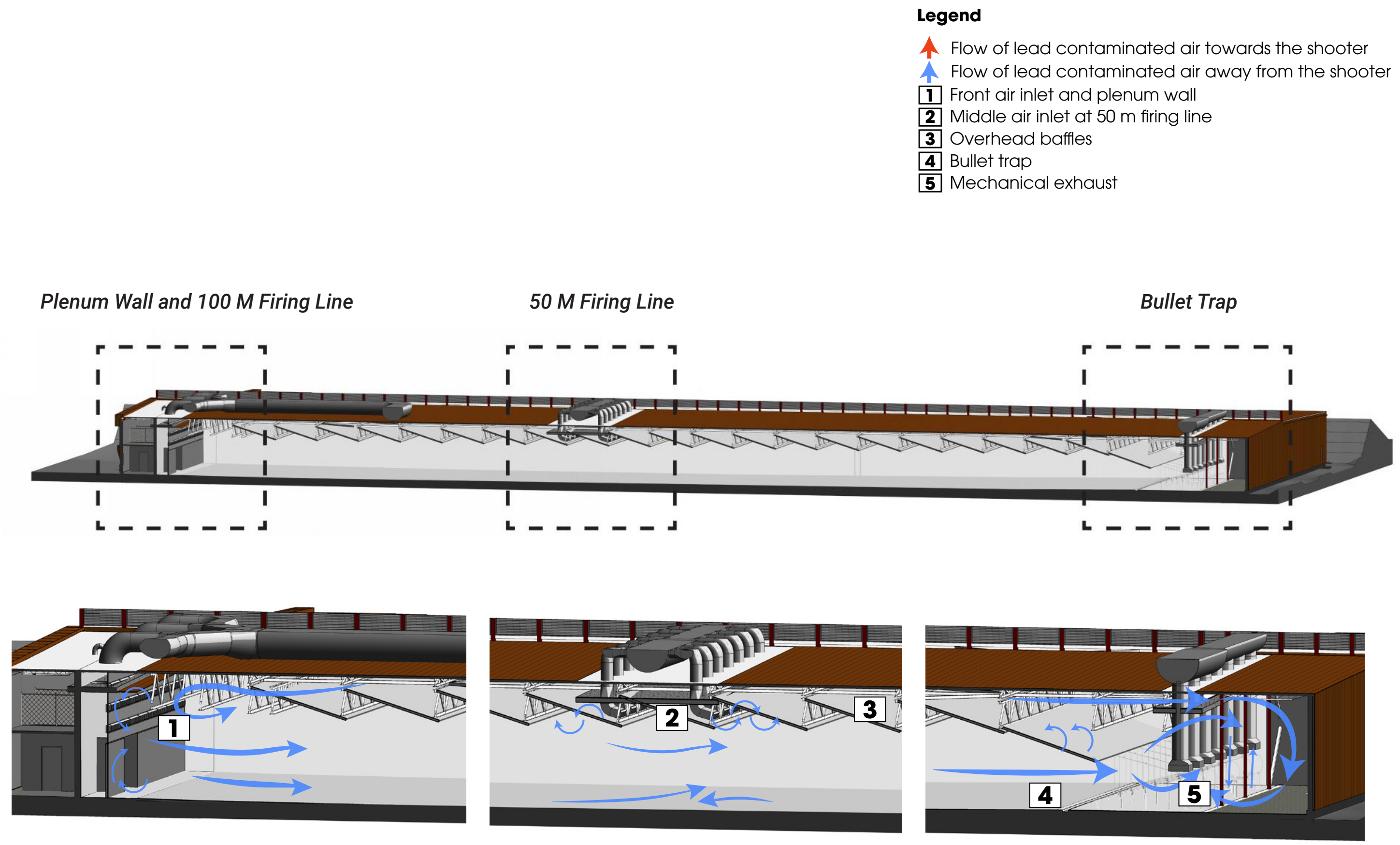


Figure 5.6 - Design Option 5 (Final Design)

Based on the numerical simulation, the following findings are observed for the inlet airflow from the front vents:

- The airflow velocities at the 100 m firing line breathing zone are slightly higher (between 50 and 150 fpm) than the recommended velocity range (50-100 fpm) but slightly lower than the airflow velocities for Design Option 3.
- The airflow velocities at the 75 m, 50 m, and 25 m firing lines breathing zone are within the recommended velocity range (50-100 fpm).
- The horizontal airflow at breathing zone height (1.5 m from floor) along and downrange of the 100 m firing line is uniform.
- There is a vertical recirculation zone above the 100 m firing line , approximately 2.5 m above the breathing zone. This recirculation zone would not directly impact the breathing zone.

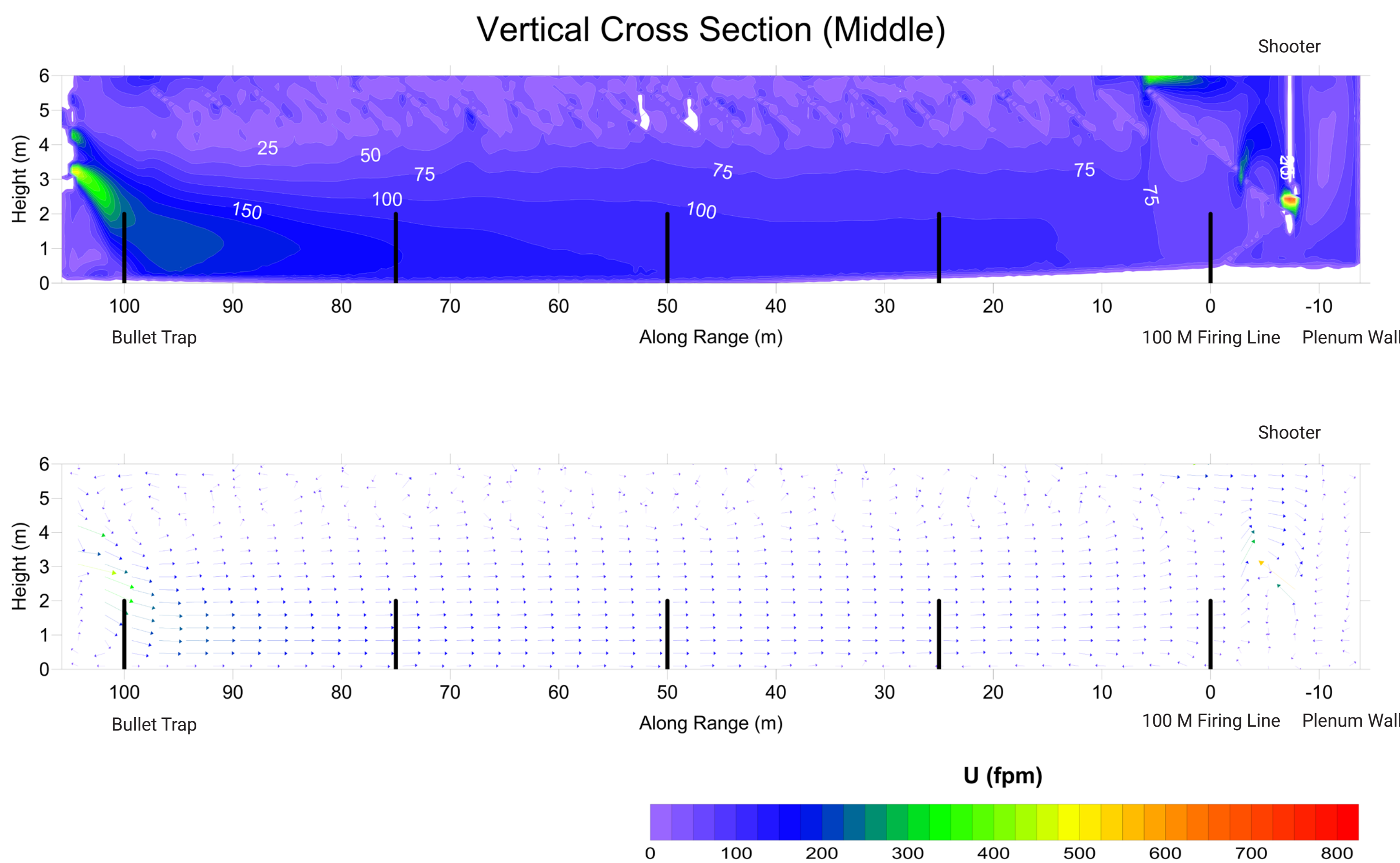


Figure 5.7 - Design Option 4 (Final Design) - Contour and Vector Plots of Air Flow at a Vertical Cross Section at Range Door

Summary of Design Options 1 and 5

Initial Design:

- The initial design includes front inlet airflow from 2 plenum walls on both sides of the entry way.
- The main deficiency of this design is the discontinued airflow at the centre of the firing range due to the position of the entry way between the left and right plenum walls.
- As a result, there is a horizontal recirculation zone from the left and right plenum walls towards the entry way, and a reverse airflow at the centre of the firing range.

Legend

Flow of lead contaminated air towards the shooter
Flow of lead contaminated air away from the shooter
1 Front air inlet and plenum wall
2 Middle air inlet at 50 m firing line
3 Overhead baffles
4 Bullet trap
5 Mechanical exhaust

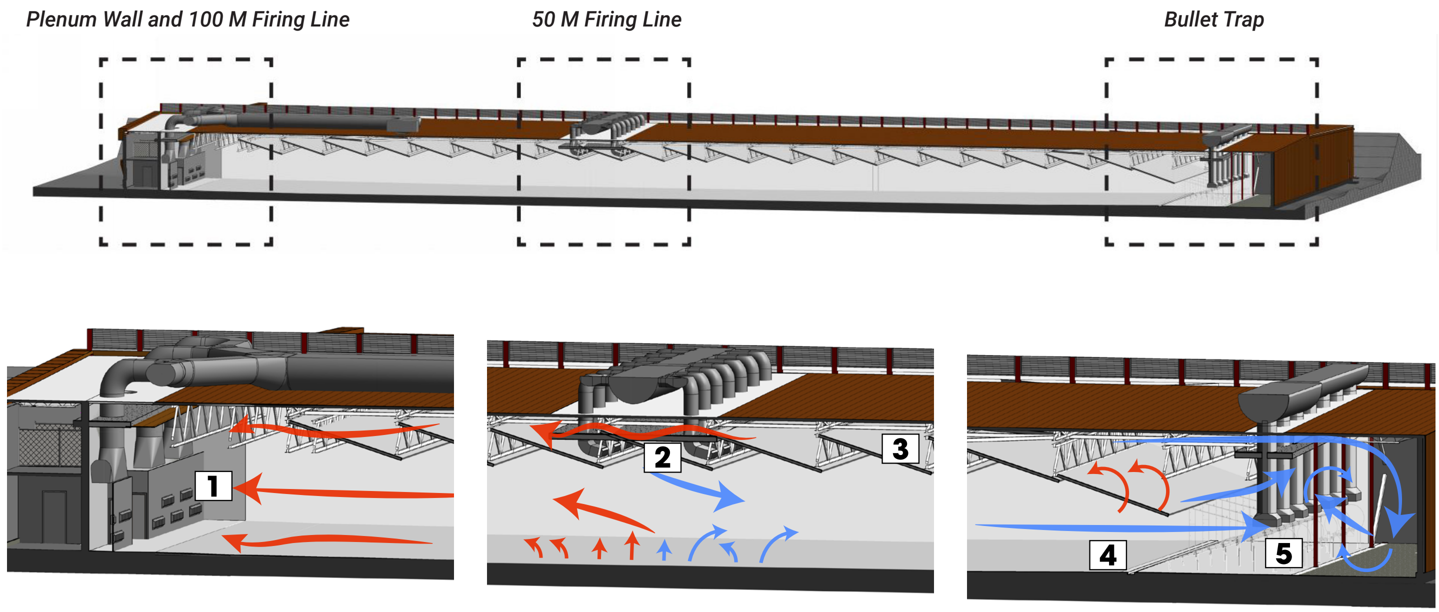
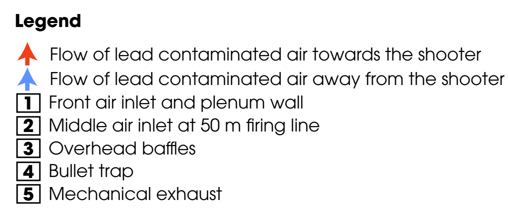


Figure 5.4 - Design Option 1 (Initial Design)

Final Design:

- Final design resolves the deficiency of the initial design by placing the front inlet vents at 3 rows above the entry way.
- This creates a uniform horizontal airflow at the breathing zone height and the airflow velocities at all firing lines breathing zones are within the recommended velocity range (50-100 fpm, with optimal velocity of 75 fpm).
- There is a vertical recirculation zone above the 100 m firing line that is located approximately 2.5 m above the breathing zone; however, this recirculation zone would not directly impact the breathing zone.



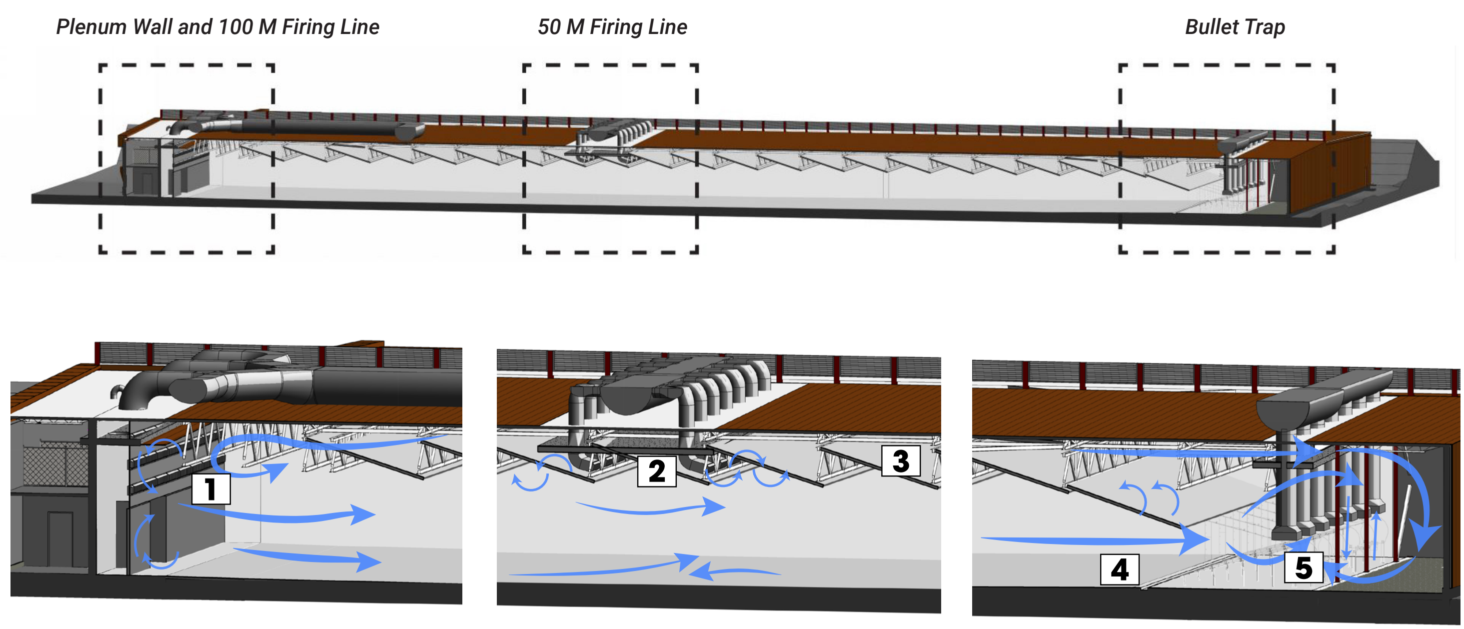


Figure 5.6 - Design Option 5 (Final Design)

6 Conclusion

Our goal was to provide the Canadian policing agency with a safe and efficient indoor gun range design. Using Computational Fluid Dynamics (CFD), we were able to test our proposed mechanical design options prior to construction quickly and cost-efficiently.

Gun ranges across the country share a common goal, to ensure the safety of the users in the space. CFD allows for law enforcement organizations to evaluate their existing gun range mechanical systems with minimal cost. CFD helps determine if the current conditions are safe for users and empowers organizations to confidently move forward with renovations to their existing gun ranges.

7 References

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