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Ducted Air Conditioning with UV-Based Air Purification for a Cattle Rescue Center

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Abstract
Ducted Air Conditioning with UV-Based Air Purification for a Cattle Rescue Center, using a cooler-based duct system, addresses critical air-quality issues. Cattle rescue centers often face severe hygiene challenges due to the temporary storage of cattle that did not survive the rescue process outside the sheds. This leads to contaminated air entering the indoor environment. When combined with inadequate ventilation, this contamination increases the presence of Gram-negative bacteria, zoonotic pathogens, and airborne microorganisms, severely impacting both cattle and human health. Integrating a net made of thin steel wires inside the duct, which helps to restrict and eliminate mosquitoes and other insects before they enter the UV light zone. This net is placed prior to the UV light, ensuring that insects are stopped first, and then the UV light deactivates microbes, viruses, and bacteria. The proposed system aims to significantly reduce airborne bacterial concentration and enhance the health and safety of both cattle and workers. This solution offers a sustainable and economical approach for improving air quality in cattle rescue centers.

Keywords: Ducted air conditioning, UV purification, Airborne bacteria, Cattle rescue center, Sustainable, Low-cost, Environment-friendly.

1. Introduction

This study presents a cooler-based ducted air-conditioning system integrated with UV-based air purification for a cattle rescue center. Cattle rescue centers play a crucial role in saving and rehabilitating injured, abandoned, disabled, pregnant, and accident-affected cattle rescued from road accidents, fire incidents, natural calamities, and urban-rural conflict zones. These centers often accommodate animals with severe injuries, amputations, mobility limitations, and newborn calves that require a hygienic, calm, and safe indoor environment for recovery. Maintaining such an environment is a significant engineering and management challenge, especially under real-world operational and infrastructural constraints. Cattle rescue centers often face severe hygiene challenges due to the temporary storage of cattle that did not survive rescue process outside sheds. One of the most critical challenges observed is air contamination originating from such cattle temporarily placed outside the shelter. Due to cultural, legal, and logistical practices related to last rites (final rites / last journey), those cattle are often kept outside the rescue center for several hours before being taken away. During this period, biological decomposition and external exposure generate contaminated air carrying Gram-negative bacteria, zoonotic pathogens, and airborne microorganisms. This contaminated air easily enters cattle shed through openings, gaps, and ventilation paths, posing serious health risks to injured cattle, pregnant animals, calves, and human workers.

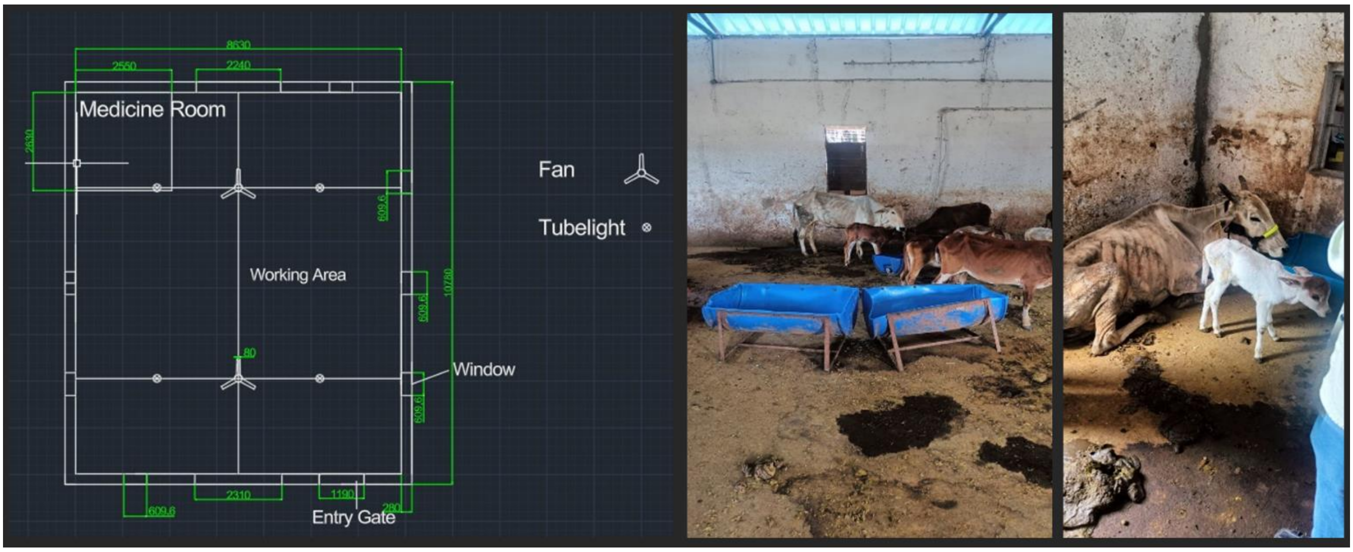

Fig. 1 The working area of the cattle rescue center.

The problem is further intensified by poor air circulation in existing sheds. Due to structural restrictions, such as the inability to break walls, enlarge windows, or modify load-bearing elements, implementing conventional high-capacity ventilation systems becomes impractical. Additionally, rescue centers usually operate under strict budget limitations, making expensive HVAC solutions infeasible. Another major constraint is the high movement of cattle inside the shed. Animals move frequently for feeding, medical treatment, and cleaning activities. Therefore, air distribution must be designed in a manner that does not obstruct movement, does not disturb animals, and delivers fresh air where cattle spend most of their time. Placing ventilation near walls or windows alone is insufficient, as it creates stagnant zones and uneven air distribution. To address these challenges, this study proposes a ducted air-conditioning and ventilation system integrated with UV-based air purification, specifically designed to work within existing structural and financial constraints. Instead of installing large-capacity ducts that would require breaking walls or windows, a low-capacity but efficiently placed ducting system is implemented.

2. Literature Review / Background

Previous studies have extensively examined ventilation, cooling, and air-quality control in livestock housing. Sharma and Sharma [1] analysed duct design in air-conditioning systems and reported that rectangular ducts, although associated with slightly higher-pressure losses than circular ducts, are widely adopted in practical installations due to space constraints. Their work demonstrated that proper duct sizing, layout optimization, and airflow balancing can achieve uniform air distribution and acceptable system performance. Thermal comfort of cattle has been shown to be a critical factor influencing animal health and productivity. Smith [2] reported that both heat and cold stress significantly affect cattle well-being, emphasizing the importance of controlled indoor environments. Similarly, Fang et al. [3] highlighted that increased air velocity through forced ventilation plays a major role in reducing heat stress in cattle sheds, even when temperature reduction is limited.

Airborne microbial contamination in cattle housing has also received considerable attention. Ton et al. [4] demonstrated that UV-based air purification can safely and effectively reduce airborne bacterial concentration in animal shelters without direct exposure to livestock. Ding et al. [5] further emphasized that high humidity and dust levels increase airborne microorganisms, including Gram-negative bacteria, posing health risks to both animals and workers [6]. This study integrates a cooler-based ducted AC with UV air purification for cattle rescue centers, addressing challenges like injured animals, limited structural flexibility, and low budgets. The system ensures safe, efficient airflow and improved air quality while being economical and easy to install [7].

3. Materials and Methods

3.1 Study Site and Layout

The rescue center shed (Cattle Rescue Center, Gorakshan Sabha, Dhantoli, Nagpur, Maharashtra 440012) was mapped into resting, feeding, and treatment zones. Figure 2 shows 2D and 3D CAD models were used to optimize duct placement and airflow within structural limits.

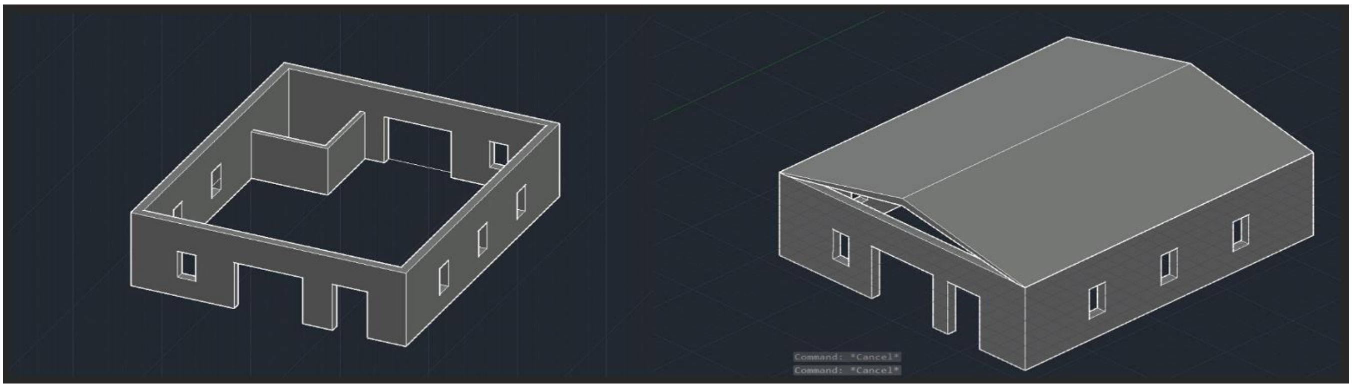

Fig. 2 The 3D model of the rescue center (CAD Model).

3.2 Heat Load and Internal Gain Estimation

Sensible heat gain through building components and internal heat loads from cattle, occupants, lighting, and equipment were estimated using standard heat-transfer and metabolic heat values.

3.3 Ventilation, Infiltration, and Total Cooling Load

Ventilation and infiltration heat gains were calculated based on outdoor air entry, and total cooling load was obtained by combining sensible and latent heat loads to determine required airflow and cooling capacity.

3.4. Airflow Requirement and Duct Design

Based on the total heat load, required airflow rate was calculated. The duct cross-sectional area and air velocity were determined to ensure uniform air distribution without causing discomfort or disturbance to cattle. With the help of duct design shows in figure 3, various friction losses within a ducting system were evaluated, and a low-capacity blower was selected to meet airflow requirements efficiently. The ducts were positioned at the center of the cattle shed to ensure uniform air delivery across high-occupancy zones.

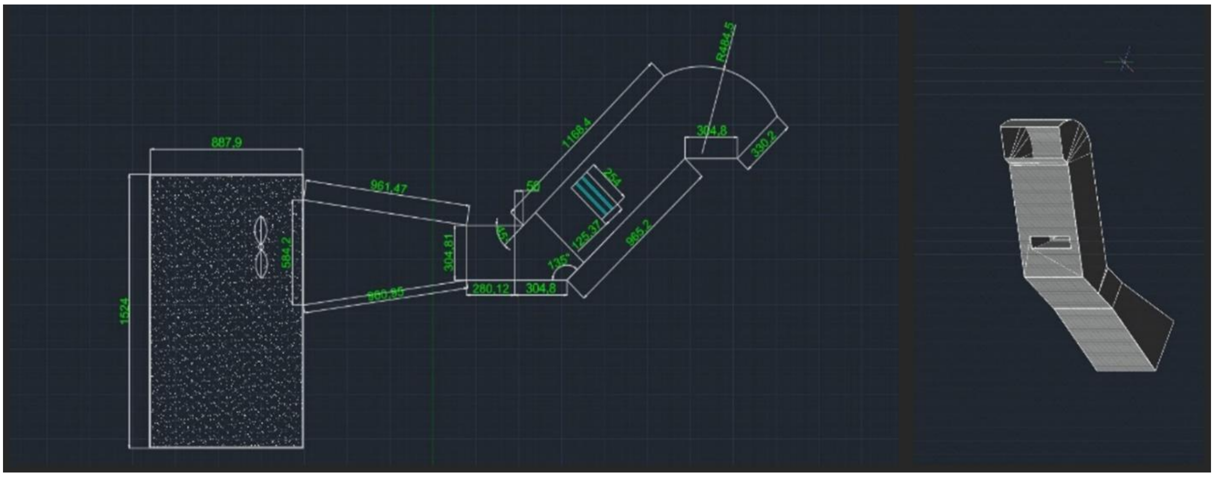

Fig. 3 The 2D and 3D Model of duct design (CAD Model).

Fig. 4 Ducting setup in the cattle shed with UV light.

3.5. Integration of UV-Based Air Purification

A UV air purification unit was installed within the duct system. Lamp capacity was chosen based on airflow and microbial inactivation needs. The lamp ensured effective air exposure while avoiding direct UV contact with cattle and workers. Safety and reliability were prioritized.

3.6. Practical and Operational Constraints

Design followed real-world constraints: no wall or window modifications, minimal structural changes, low-cost implementation, easy installation, low maintenance, and energy efficiency. These factors ensure feasibility and scalability for similar cattle rescue centers.

Instead of big ducts that need breaking walls or windows, small but well-placed ducts were used, with the duct stack head oriented toward the center of the cattle shed where cattle movement is highest shown in figure 4, ensuring uniform air distribution and maximum effectiveness without structural damage. The Gorakshan Sabha provided an existing air cooler, which helped the project team maintain a low overall budget during implementation. For instance, the system was implemented successfully at a cost of around ₹12,000 due to the air cooler being provided by the rescue center, demonstrating the practicality and efficiency of the proposed solution. The UV purification unit is installed inside the ducting, ensuring that harmful microorganisms are deactivated while completely avoiding direct exposure of UV radiation to cattle and workers. In addition, a net made of thin steel wires is integrated inside the duct and placed before the UV light zone. This net helps restrict and eliminate mosquitoes and other insects, ensuring that insects are stopped first, after which the UV light deactivates microbes, viruses, and bacteria. This layered approach improves purification efficiency while maintaining safety. By improving air quality through controlled airflow, proper duct placement, insect restriction, and UV-based microbial reduction, the system helps create a calmer and healthier indoor environment. Improved air conditions directly contribute to reduced stress, faster recovery, and better overall health of injured and vulnerable cattle, while also safeguarding the health of caretakers and veterinary staff.

4. Results

Figure 5 and Figure 6 show the calculated variations of total, static, and velocity pressure for both the theoretical and practical ducting systems, which were used to evaluate duct efficiency and airflow performance. Temperature and humidity measurements obtained using sensors indicated improved thermal comfort compared to previous conditions in the shelter. Multiple engineering calculations, including total cooling load estimation, required inducer capacity, airflow rate, and duct sizing, were performed to design and validate the system and to ensure appropriate operating conditions for the rescue center.

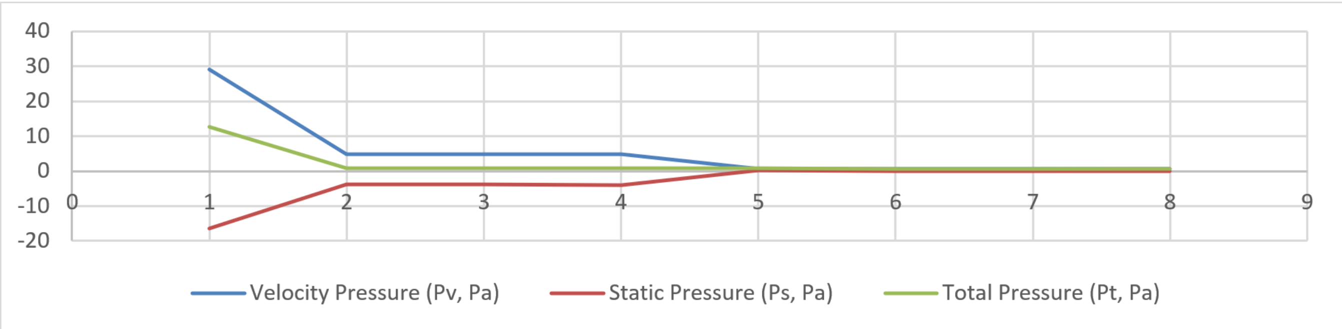

Fig. 5 Variation of Total Pressure, Static Pressure and Velocity Pressure within a Theoretical Duct

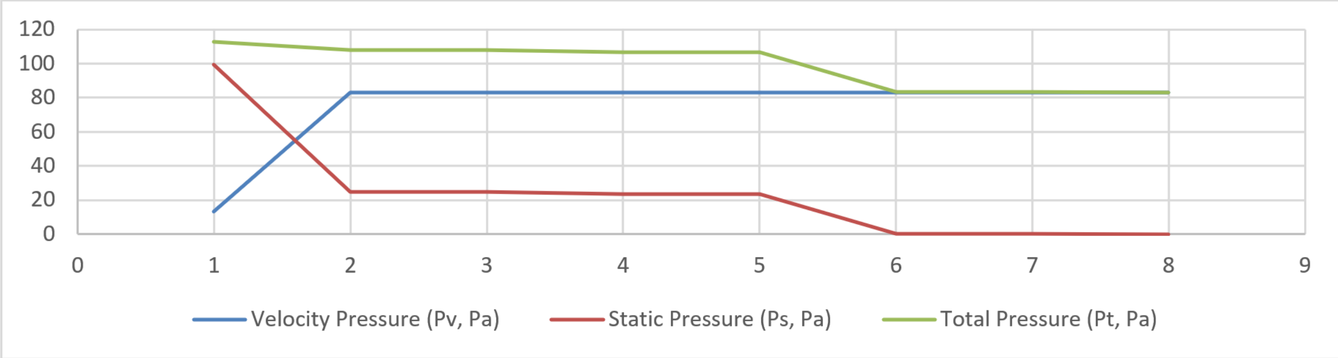

Fig. 6 Variation of Total Pressure, Static Pressure and Velocity Pressure within a Practical Duct

Figure 4 shows the installed ducted air-conditioning system with integrated UV purification at the Gorakshan Sabha cattle rescue center. The ducting is centrally oriented to provide uniform airflow, and the UV unit is installed within the duct. Temperature and humidity measurements indicate improved indoor conditions compared to previous values. The system also helps restrict insects such as mosquitoes, bees, and flies, contributing to a cleaner environment for the animals. Quantitative measurement of bacterial reduction was not performed due to the unavailability of on-site microbiological testing facilities; however, the effectiveness of UV-based air purification has been well documented in existing literature [4].

5. Discussion

The results demonstrate that the cooler-based ducted air-conditioning system with integrated UV purification effectively improves airflow, temperature, and humidity within the cattle rescue center. The measured pressure variations closely matched theoretical predictions, confirming the proper duct design and placement. Compared to typical shelters without controlled ventilation, the system provides more uniform airflow and a comfortable indoor environment for the cattle. Previous studies have shown that UV-based systems are highly effective in reducing airborne microbes in dairy housing, and by extension, our system is expected to similarly reduce microbial contamination in the rescue center. Overall, the study highlights the practical significance of combining ducted ventilation with UV-based air purification to enhance animal welfare and indoor air quality in high-risk environments.

6. Conclusions

The cooler-based ducted air-conditioning system integrated with UV-based air purification successfully improved airflow, temperature, and humidity conditions within the cattle rescue center, creating a more comfortable and safer environment for the animals. Pressure and airflow measurements confirmed the efficiency of the duct design, while the UV system is expected to reduce airborne microbial contamination. The study demonstrates that combining controlled ventilation with UV-based purification is a practical, low-cost, and effective solution for enhancing animal welfare and indoor air quality in high-risk environments.

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