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Optimization of The Pump Room Layout Using Ergonomic Analysis and Maintenance Accessibility in The XYZ Project

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ergonomics; REBA; anthropometry; maintenance accessibility; layout optimization.

Abstract
The pump room is one of the utility areas that plays an important role in supporting building operations. A pump room layout that does not consider ergonomic aspects and maintenance accessibility may limit operator movement, create difficulties in accessing equipment, and increase the risk of musculoskeletal disorders. This study aims to optimize the pump room layout in the XYZ Project through an ergonomic approach and maintenance accessibility assessment to improve safety, comfort, and work efficiency. The research methods include field observations, room and equipment dimension measurements, anthropometric analysis, maintenance accessibility evaluation, and work posture assessment using the Rapid Entire Body Assessment (REBA) method. The results show that the existing layout still has limited operator movement space, excessively close distances between equipment, and suboptimal maintenance access. The REBA assessment results indicate an ergonomic risk score of 11 for water tank inspection and pump strainer cleaning activities, a score of 10 for checking piping system leaks, a score of 9 for valve operation, and a score of 6 for checking the control panel. Based on the analysis results, a layout redesign was carried out by considering anthropometric data and maintenance space requirements. The redesign improved accessibility, facilitated maintenance activities, and enhanced operator working conditions. The results of the study indicate that ergonomics-based pump room layout optimization can reduce the risk level of musculoskeletal disorders, as shown by the REBA analysis, increase maintenance accessibility, and support the overall operational efficiency of the pump room.

INTRODUCTION

Development in the modern construction and building industry demands the availability of reliable, safe, and easily maintainable utility systems (Minoli et al., 2017; Salimon et al., 2025). One of the essential utility facilities is the pump room, which functions as the central distribution point for fluids, including clean water supply systems, fire protection systems, and other supporting building systems (Shammas & Wang, 2015; Sharif et al., 2019; Świętochowska & Bartkowska, 2022).

Pump room design often focuses more on technical installation aspects than on operator comfort and safety. Overly dense equipment placement, limited circulation paths, and insufficient maintenance space can force operators to work in awkward and non-ergonomic postures (Balestra, 2025; Srivani & Amsamani, 2025). These conditions may increase the risk of musculoskeletal disorders, reduce work productivity, and extend maintenance time (Alhashim et al., 2025; Greggi et al., 2024; Soares et al., 2020).

Several studies have shown that non-ergonomic work postures, such as bending, twisting, and repetitive reaching, are major factors contributing to musculoskeletal disorders. Wahyuniardi and Reyhanandar (2018) and Imron (2019) found that activities with these characteristics are generally classified as moderate to high risk based on ergonomic assessment methods such as RULA, REBA, and OWAS. This condition is exacerbated by limited workspace and inappropriate workstation design, which restrict operator movement and force the body into non-neutral postures (Ahmed et al., 2022; Hedge, 2016). These findings confirm that postural factors and spatial limitations are closely related in increasing ergonomic risks in the work environment (Wahyuniardi & Reyhanandar, 2018; Imron, 2019).

Other studies have also demonstrated that facility layout and the work environment play a significant role in ergonomic risk levels and work efficiency (Trisusanto et al., 2020). Sinambela et al. (2023) revealed that non-ergonomic layouts not only increase physical risk but also contribute to higher mental workload, fatigue, and the potential for operational errors. These findings align with those of Salsabila and Susanty (2024), who showed that limited space, obstructed access routes, and improper material placement can reduce both work safety and efficiency. Suboptimal layouts directly contribute to increased physical and mental workload (Sinambela et al., 2023; Salsabila & Susanty, 2024).

Several studies emphasize the importance of an ergonomic approach in layout redesign to reduce inefficient activities and risky work postures. Safitri et al. (2024) demonstrated that layout arrangements considering frequency of use, aisle width, and storage height can reduce excessive bending and reaching activities while improving operational efficiency. Similar findings are also supported by Tosalili et al. (2025), who stated that adjustments to working conditions based on RULA and REBA analysis results can serve as a basis for reducing ergonomic risks through improvements in the work environment. Integrating ergonomic analysis with layout design has strong potential to improve overall working conditions (Safitri et al., 2024; Tosalili et al., 2025).

This study, titled Optimization of The Pump Room Layout Using Ergonomic Analysis and Maintenance Accessibility in The XYZ Project, is expected to fill this research gap and serve as a basis for developing ergonomic, safe, and efficient pump room designs. The study contributes to the literature by providing empirical evidence on the application of REBA analysis and anthropometric principles in pump room layout optimization, an area that has received limited attention in previous research. The findings also provide practical guidance for building designers and facility managers seeking to improve safety and operational efficiency in utility spaces (Altohami et al., 2021; Islam et al., 2021; Sacks et al., 2018)

METHOD

This research was conducted in the pump room of the XYZ Project located in Badung Regency, Bali, during April to May 2026. The study area was situated in a coastal environment with generally flat topography.

The research used a quantitative descriptive approach by combining primary and secondary data. Primary data were obtained through field observations, measurements of room and equipment dimensions, documentation of existing conditions, and observation of operator work postures during operational and maintenance activities. In addition, anthropometric data based on the 5th, 50th, and 95th percentiles of the Indonesian population were collected to support the analysis. Secondary data were obtained from relevant scientific literature, ergonomic standards, the REBA method, technical standards for pump and piping systems, and occupational safety and health regulations.

Data analysis was conducted in several stages, including an evaluation of existing conditions, work posture assessment using the REBA method to determine ergonomic risk levels, and anthropometric analysis to assess the suitability of spatial dimensions and operator reach. A maintenance accessibility analysis was also performed to evaluate ease of access, mobility, and physical constraints within the workspace. The results of these analyses were then integrated to develop recommendations for optimizing the pump room layout to improve ergonomics, safety, and operational efficiency, as well as to support effective maintenance activities.

RESULTS AND DISCUSSION

Data collection on equipment dimensions and specifications was conducted to obtain technical information related to the physical size and operational characteristics of the equipment in the pump room. Data collection was conducted on the dimensions, technical specifications, and existing layout of the equipment in the pump room. Data obtained through technical documents, manufacturer catalogs, and field verification, and used as the basis for layout analysis to ensure suitability of space requirements, maintenance accessibility, and the application of ergonomic principles in the pump room.

While functionally, the equipment layout has met the needs of the plumbing system, existing conditions demonstrate that technical efficiency has not been matched by adequate work ergonomics. Limited mobility, narrow circulation paths, and the position of several components outside the ideal reach zone require operators to adapt to less-than-neutral working postures, such as bending, stooping, overreaching, and twisting. In the context of a commercial utility space, this is crucial because the pump room must not only be able to perform system functions but also allow for safe and efficient inspection, operation, and maintenance activities.

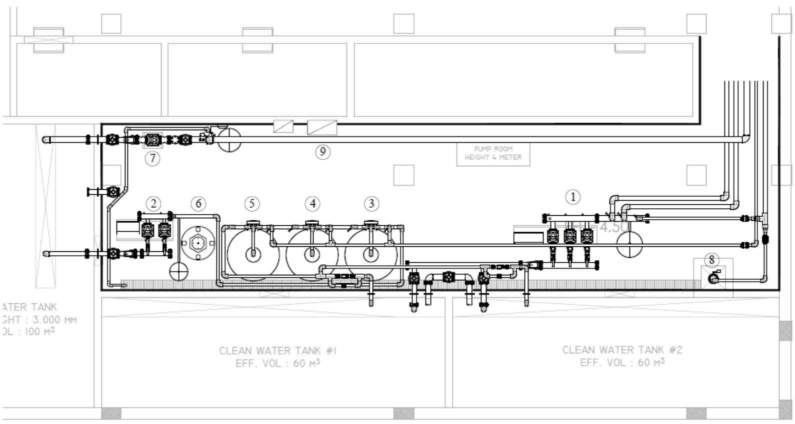

Figure 1. Pump Room Layout *Existing*

Pump room at Project XYZ has dimensions 13,900 mm x 3,400 mm with 4,000 mm high, and inside placed various equipment main such as booster pump, transfer pump, system filtration , sprinkler pump, drain pit pump, electrical panel , and sprinkler control panel. In addition In addition , the sprinkler system is also equipped component supporters in the form of a main control valve, pressure tank, and alarm bell (Plumbing Engineering Design Handbook: A Plumbing Engineer's Guide to System Design and Specifications, 2013). Combination many equipment in room with wide limited create dense and challenging configuration from side access workspace . This situation indicates a conflict between the technical requirements of the system and the ergonomic needs of the user. On the one hand, close equipment placement supports efficient fluid distribution and system integration; on the other hand, such density limits operator movement, hinders visual inspection, and increases the risk of unergonomic working postures. Thus, the main problem lies in how the equipment is arranged in a limited workspace, not in its presence.

Work activities in the pump room are not homogeneous in their risk levels. Some activities, such as inspecting water tanks, checking for leaks in piping systems, cleaning pump strainers, and operating valves, require more physical involvement than simply inspecting control panels. This suggests that the pump room needs to be analyzed based on activities, not just physical objects. Within an ergonomics framework, an activity-based approach is relevant because risks stem not only from the shape of the equipment but also from the operator's interaction with the equipment within the context of a specific task. Therefore, analyzing work postures using REBA is crucial for identifying critical points requiring design intervention.

Table 1. Equipment Dimensions and Specifications

No	Type Equipment	Dimensions (mm)	Brand
1	Pump Distribution *(Booster Pump)*	1700P x 1140L x 1650T	Grundfos
2	Transfer Pump / Filter Pump	1210P x 960L x 1510T	Grundfos
3	*Sand Filter*	Ø 920 x 1830T	Pentair
4	*Multimedia Filter*	Ø 920 x 1830T	Pentair
5	*Softener Filter*	Ø 920 x 1830T	Pentair
6	*Salt Water Tank*	Ø 920 x 1830T	Pentair
7	Sprinkler Pump	260P x 260L x 1150T	Grundfos
8	Pump *Drain Pit*	450P x 450L x 450T	Grundfos
9	Electrical Panel	600P x 300L x 800T	Local
10	Sprinkler Control Panel	400P x 200L x 600T	Saka Parfima

Figure 2. Water tank inspection activity

The REBA assessment results indicate that the ergonomic risk level in the existing conditions ranges from moderate to very high. Water tank inspections received a REBA score of 11, categorized as very high risk; pump strainer cleaning also received a score of 11; piping system leak inspection received a score of 10; valve operation received a score of 9; and control panel inspection received a score of 6, or moderate risk. This pattern is important because it confirms that the activities that most frequently interact with confined space elements are actually the activities with the highest risk. This means that ergonomic issues in the pump room are not merely incidental but inherent in the existing layout, which does not provide enough space for the operator's body to move safely and neutrally.

Table 2. Results REBA assessment of each activity

No	**Activity**	**REBA Score**	**Risk Level**	**Action Repair**
1	Inspection water tank	11	Very High Risk	Need action repair quick with layout adjustments so that position ladder become more ergonomic
2	Control panel check	6	Moderate Risk	Transfer Control Panel to side wall with adjustable height .
3	Inspection leakage system piping	10	High Risk	Redesign the equipment layout to facilitate inspection access between equipment.
4	Pump strainer cleaning	11	Very High Risk Tall	Adjustment height *header* and widen *clearance* in the work area .
5	Operation *Valve*	9	High Risk	Adjustment height *header* and widen *clearance* in the work area .

High score on examination water tank shows that position operator work standing above ladder while bow and crouch create combination significant static loads and postural loads . Factors handle less stairs stable and position less than ideal work worsens condition said . In perspective ergonomics, activities kind of This trigger improvement pressure on the back bottom, neck, shoulders, and legs, especially when done repetitive in One month. Risk similar also appears in the cleaning of pump strainers, where the operator must squat, bend, and do manipulation component in a narrow area. From the angle biomechanics, posture the enlarge moment at the joint and increase burden static muscles, so that enlarge potential fatigue and disturbance musculoskeletal. With Thus, the REBA results are not only describe number risks, but also explains How configuration spatial room pump form pattern work that is not Healthy.

In activity inspection leakage system piping and valve operation, risks tall especially appear from need For reach areas that are not easy seen or accessible, while maintain balance body in limited space. Activities visual inspection around pipes and valves is also required change repetitive postures, such as looking down, looking up, or turning the body. Posture dynamic kind of This often considered light, but If done in narrow and deep space frequency high, the risk increase in a way cumulativ. In other words, the load ergonomics in space pump No only determined by weight burden physical, but also by frequency, duration, and limitations a compelling space body working outside position neutral.

Maintenance access analysis shows that layout density directly impacts operator efficiency. Areas with limited access, such as water tanks/manholes, transfer pumps, and strainers, show that inspection, dismantling, and cleaning processes are still limited by limited workspace and physical barriers around the equipment. This condition not only reduces work comfort but also has the potential to extend maintenance time and increase the risk of work errors. In building utility systems, this is crucial because delayed maintenance can impact the continuity of water supply and the reliability of fire protection systems. Therefore, accessibility is not simply a matter of convenience, but an operational component that determines system performance.

Pump panel control area get score access highest, indicating that its placement relatively more Good compared to other areas. However thus, the height score the No automatic show that room has been optimally overall, because other areas are still own significant limitations. From a facility design perspective, this situation demonstrates an imbalance in the layout: some components meet access needs, but other critical elements still force operators to perform compensatory work. When workspaces are uneven in terms of access quality, operators tend to develop inefficient movement patterns, such as tilting, twisting in tight spaces, or working while holding certain body positions. Over the long term, these patterns increase fatigue, increase the likelihood of injury, and decrease maintenance productivity.

Limited access to the pump room also has safety implications. In the event of an emergency, such as a leak, reduced water pressure, or pump failure, operators must be able to quickly reach valves and control panels. If access is obstructed by piping or tight equipment placement, response times are lengthened and operational risks increase. This suggests that good pump room design must consider both normal and emergency scenarios simultaneously. A convenient space for routine inspections is not necessarily sufficient if it does not allow for rapid response in the event of a disruption. Therefore, the results of the accessibility analysis in this study reinforce the argument that utility room layouts should be evaluated as dynamic work systems, rather than simply as static arrangements of technical objects.

The redesign and optimization of the pump room layout was carried out to address various issues identified in the existing conditions based on an analysis of work postures and maintenance access. The redesign process aimed to create a more ergonomic, safe, comfortable, and efficient layout, thus optimally supporting operational and maintenance activities.

In its preparation, the rearrangement of equipment takes into account the operator's movement space requirements, ease of access to components, work circulation paths, anthropometric data, and work safety aspects. The layout redesign also refers to PUIL 2011 which emphasizes that panel placement must pay attention to ease of operation, safety, and maintenance access, so that all measuring instruments, buttons, and switches on the panel can be operated easily and safely from the front without the aid of a ladder or additional equipment, and still have sufficient space for service and maintenance (General Instructions for Electrical Installations, 2011). In addition, the orientation of the valve handle is arranged so that the opening and closing process can be carried out with a more natural body position without excessive body twisting, with a position close to chest or shoulder height to achieve a more neutral and ergonomic work posture (Al-Qaisi & Aghazadeh, 2018).

Using anthropometric data as a basis for redesign is a sound methodological decision because it allows the design to be objectively tailored to the user's body characteristics. In this study, the body dimensions of Indonesian operators, referenced to the 5th, 50th, and 95th percentiles, were used to determine the working reach, ideal component height, and clearance requirements between equipment. This approach is important because a good design should not only be suitable for a specific user but should also be able to accommodate the varying body dimensions of the majority of the user population. Thus, anthropometry serves as a bridge between the technical dimensions of the space and the physical capacity of the operator.

Anthropometric parameters such as standing elbow height, forward arm reach, shoulder width, hip width, and arm span length directly contribute to determining clearance and work zones. For example, valves, control panels, and inspection components must be positioned within a safe reach to prevent operators from having to reach too high or too far. Similarly, the width of circulation paths must allow the operator's body to move through the workspace without physical contact with equipment or piping. In this context, ergonomics is not only about reducing fatigue but also about ensuring that the structure of the space supports the natural movement of the human body. Because pump rooms are permanent facilities with long-term use, the application of anthropometric principles is crucial to maintaining the space's sustainable function.

Table 3. Anthropometric Dimensions (all ethnicities, male, aged 20 to 45 years)

No	Dimensions Anthropometry	Percentile	Size (cm)	Information
1	Height	P50	1 69	General reference for operator dimensions in workspace evaluation
2	Eye height stand	P50	1 58	Determine ideal position of the indicator and monitoring panel
3	Standing shoulder height	P50	1 41	Reference for placing operational components in the operator's comfort area
4	Standing elbow height	P50	106	Determine the ideal operating height of the valve and control panel
5	Reach hand to front	P5	52	Setting limits maximum operator coverage area
6	Grip height hand to on in position stand	P5	178	Determines the maximum height of components that can still be reached.

No	Dimensions Anthropometry	Percentile	Size (cm)	Information
7	Side width shoulder	P95	52	Determining needs minimum width of work and circulation areas
8	Hip width	P95	43	Determining needs operator's space for movement in narrow areas
9	Thick chest	P95	38	Reference need *clearance* when the operator is working
10	Long range hand	P95	192	Determine the work area effective maintenance

Source: (Antropometriindonesia.org, 2013)

An anthropometric-based approach also improves the quality of design in terms of generalizability. Because operators can change over time, designs that follow a single individual's body will quickly lose relevance. In contrast , designs population data based more adaptive and resilient to change personnel . In operational and technical utility spaces, this aspect is crucial because technicians do not always have the same body dimensions. Therefore, the use of anthropometry in this study not only strengthens the validity of the proposed design but also demonstrates the research's orientation toward human-centered design principles commonly used in advanced ergonomics studies.

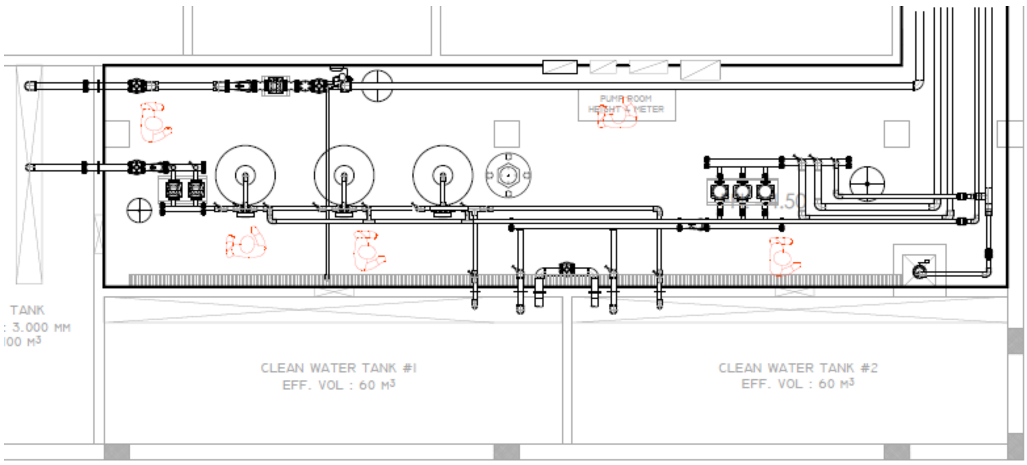

Figure 3. Pump Room Redesign Layout

In the proposed layout, the distance between equipment is made more regular so that operators have more work space when inspecting or dismantling components. The distance between booster pump and transfer pump against The water tank wall, which was originally 45 cm, was widened to 90 cm with consider dimensions anthropometry, in particular The operator's shoulder width is 52 cm. In addition that, distance The interfilter which was originally 28 cm was enlarged to 60 cm, while position of strainer, valve and pump header raised from 30 cm above floor to 1 meter to be more easy accessible and supportive posture more work good. Pipeline arranged more to middle so as not to obstruct inspection, control panel placed in a larger area centralized and easy accessible, path drainage made more easy reachable, and wide track circulation main enlarged For increase safety as well as comfort Operator mobility. Thus, the proposed layout is expected to improve maintenance accessibility, enhance work comfort, and reduce the potential for unergonomic work postures during operational and maintenance activities.

The redesign results showed that layout improvements had a direct impact on reducing ergonomic risks. Widen spacing between equipment, elevated valve and strainer positions, and rearranged control panels resulted in more neutral working conditions for operators. Reductions in REBA scores from 11 to 2 for water tank inspection, from 6 to 2 for control panel inspection, from 10 to 5 for piping leak inspection, from 11 to 5 for strainer cleaning, and from 9 to 2 for valve operation demonstrated the significant effectiveness of the design interventions. These results demonstrate that layout design has significant intervention power in changing work risks without having to fundamentally change the operational system.

The most significant changes were seen in activities that previously carried very high risks. When inspecting water tanks, improving the slope of the ladder and creating a clearer space allowed operators to maintain a more stable and natural body position. When operating valves, relocating the handle to a more appropriate height allowed operators to work with a more upright posture and reduced the need for reaching or bending. When cleaning strainers, providing a more spacious access area allowed the cleaning process to be completed without having to squat for extended periods. Thus, the redesign not only improved ergonomics scores but also transformed the quality of the operator's work experience in the field.

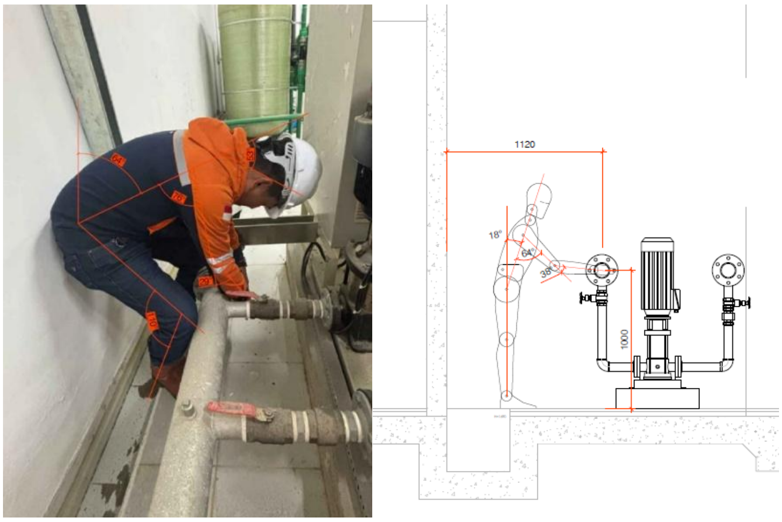

Figure 4. Activity existing strainer cleaning and redesign

In terms of maintenance access, the redesign results showed consistent improvements. All major areas achieved improved access scores, demonstrating that the reorganization of circulation paths and workspaces successfully reduced physical barriers and increased operator mobility. This improvement is crucial because maintenance in the pump room is performed not only during normal conditions but also in urgent situations. The more open space allows operators and technicians to perform inspections, dismantle, or repair damage more quickly and safely. In a facility management context, this can contribute to reduced downtime, improved system reliability, and long-term operational efficiency.

Table 4. Comparison REBA optimization score

Aspect Analysis	REBA Score Existing	REBA Score Redesign
Inspection water tank	11	2
Control panel check	6	2
Inspection leakage system piping	10	5
Pump strainer cleaning	11	5
Valve Operation	9	2

This study confirms that pump room layout optimization cannot be treated as a purely technical issue, but must be understood as an ergonomic intervention that directly impacts safety and productivity. Pump rooms, as utility facilities, are often relegated to a secondary role in building design, even though their presence is crucial to the continued functioning of water and fire protection systems. Research findings indicate that when ergonomic aspects are neglected, work posture risks increase and maintenance access is reduced. Conversely, when layouts are designed with operator anthropometry and work requirements in mind, room performance significantly improves.

CONCLUSION

Based on the research results, it can be concluded that the existing pump room layout was inadequate in terms of ergonomics and maintenance accessibility due to limited movement space, narrow distances between equipment, and inefficient circulation paths. The REBA analysis showed that several key activities, such as water tank inspection, valve operation, control panel inspection, pump strainer cleaning, and piping leak inspection, remained in the medium to very high-risk category due to non-neutral and repetitive working postures. Meanwhile, the maintenance accessibility analysis confirmed that limited space hindered inspection and dismantling activities, potentially reducing operational efficiency and workplace safety.

After the redesign, which considered anthropometric data, clearance requirements, and access needs, the ergonomic risk scores decreased significantly. The workspace became safer, easier to maintain, and more efficient in supporting the operation of the building utility systems. These findings indicate that the application of ergonomics-based design, maintainability, and accessibility principles is a feasible, relevant, and strategic approach for implementation in commercial utility buildings.

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