Occupational Hazard Assessment And Risk Mitigation In The Gluing And Lapping Section Of A Gas Meter Manufacturing Plant

Evaluación de riesgos laborales y mitigación de riesgos en la sección de encolado y lapeado de una planta de fabricación de medidores de gas

Avaliação de riscos ocupacionais e mitigação de riscos na seção de colagem e lapidação de uma planta de fabricação de medidores de gás

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Recibido: 24/05/2025 Aceptado: 24/07/2025

Summary. - Occupational health is fundamental aspect of work force management to ensure healthy and secure working environment especially in production environments where life threatening hazards are commonplace. This study implements Hazard Identification and Risk Assessment (HIRA) within a gas meter manufacturing facility's gluing and lapping shop and compares pre-existing conditions with ISO 45001 (Occupational Health and Safety), ISO 9001 (Quality Management), and ISO 14001 (Environmental Management) standards. Hazards are systematically identified by onsite workplace inspections, incident data analysis, and employee interview and input. Evaluated risk levels are made into standardized risk matrixes and control measures are suggested in line with ISO standards to minimize risk levels. The risk mitigation strategy is developed with established hierarchy of controls, emphasizing elimination, substitution, and engineering controls before administrative measures and personal protective equipment are suggested. Parameters such as temperature, noise, and lighting in the workplace are evaluated, these environmental factors are benchmarked against ISO-defined permissible exposure limits to ensure compliance and safeguard worker well-being. The findings yield actionable recommendations aimed at improving occupational safety, operational efficiency, and regulatory conformity of the gas meter manufacturing plant's gluing and lapping shop. By addressing these challenges, the research contributes to safer and more sustainable industrial practices in gas meter manufacturing. Future works in this field should in cooperate the integration of IOT and sensors to achieve real time monitoring and IOT based controls integrating Mechatronics and IOT with Health safety.

Keywords: Occupational Health and Safety, HIRA, Risk Analysis, ISO 14001, ISO 9001, ISO 45001, Gas meter manufacturing, Mechanical Hazards, Workplace Risk Management, Hierarchy of Control.

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Memoria Investigaciones en Ingeniería, núm. 29 (2025). pp. 109-130
https://doi.org/10.36561/ING.29.8
ISSN 2301-1092 • ISSN (en línea) 2301-1106 – Universidad de Montevideo, Uruguay

Resumen. - *La salud ocupacional es un aspecto fundamental de la gestión de la fuerza laboral para garantizar un entorno de trabajo saludable y seguro, especialmente en entornos de producción donde los peligros que amenazan la vida son comunes. Este estudio implementa la Identificación de Peligros y la Evaluación de Riesgos (HIRA) dentro del taller de encolado y lapeado de una planta de fabricación de medidores de gas, y compara las condiciones preexistentes con las normas ISO 45001 (Salud y Seguridad Ocupacional), ISO 9001 (Gestión de Calidad) e ISO 14001 (Gestión Ambiental). Los peligros se identifican sistemáticamente mediante inspecciones en el lugar de trabajo, análisis de datos de incidentes y entrevistas y comentarios de los empleados. Los niveles de riesgo evaluados se convierten en matrices de riesgo estandarizadas y se sugieren medidas de control de acuerdo con las normas ISO para minimizar los niveles de riesgo. La estrategia de mitigación de riesgos se desarrolla con una jerarquía establecida de controles, enfatizando la eliminación, la sustitución y los controles de ingeniería antes de sugerir medidas administrativas y equipo de protección personal. Se evalúan parámetros como la temperatura, el ruido y la iluminación en el lugar de trabajo. Estos factores ambientales se comparan con los límites de exposición permisibles definidos por la norma ISO para garantizar el cumplimiento normativo y proteger el bienestar de los trabajadores. Los hallazgos generan recomendaciones prácticas para mejorar la seguridad laboral, la eficiencia operativa y la conformidad normativa del taller de encolado y lapeado de la planta de fabricación de medidores de gas. Al abordar estos desafíos, la investigación contribuye a prácticas industriales más seguras y sostenibles en la fabricación de medidores de gas. Los trabajos futuros en este campo deberían cooperar con la integración del Internet de las Cosas (IoT) y sensores para lograr la monitorización en tiempo real y controles basados en el IoT que integren la mecatrónica y el IoT con la seguridad sanitaria.*

Palabras clave: *Salud y seguridad ocupacional, HIRA, análisis de riesgos, ISO 14001, ISO 9001, ISO 45001, fabricación de medidores de gas, riesgos mecánicos, gestión de riesgos en el lugar de trabajo, jerarquía de control.*

***Resumo*. - *A saúde ocupacional é um aspecto fundamental da gestão da força de trabalho para garantir um ambiente de trabalho saudável e seguro, especialmente em ambientes de produção onde riscos de risco à vida são comuns. Este estudo implementa a Identificação de Perigos e Avaliação de Riscos (HIRA) em uma oficina de colagem e lapidação de uma fábrica de medidores de gás e compara as condições preexistentes com as normas ISO 45001 (Saúde e Segurança Ocupacional), ISO 9001 (Gestão da Qualidade) e ISO 14001 (Gestão Ambiental). Os perigos são sistematicamente identificados por inspeções no local de trabalho, análise de dados de incidentes e entrevistas e informações com funcionários. Os níveis de risco avaliados são transformados em matrizes de risco padronizadas e medidas de controle são sugeridas em conformidade com as normas ISO para minimizar os níveis de risco. A estratégia de mitigação de riscos é desenvolvida com uma hierarquia de controles estabelecida, enfatizando a eliminação, a substituição e os controles de engenharia antes que medidas administrativas e equipamentos de proteção individual sejam sugeridos. Parâmetros como temperatura, ruído e iluminação no local de trabalho são avaliados, e esses fatores ambientais são comparados com os limites de exposição permitidos definidos pela ISO para garantir a conformidade e salvaguardar o bem-estar dos trabalhadores. Os resultados produzem recomendações práticas que visam melhorar a segurança ocupacional, a eficiência operacional e a conformidade regulatória da oficina de colagem e lapidação da fábrica de medidores de gás. Ao abordar esses desafios, a pesquisa contribui para práticas industriais mais seguras e sustentáveis na fabricação de medidores de gás. Trabalhos futuros nesta área devem cooperar com a integração de IoT e sensores para alcançar monitoramento em tempo real e controles baseados em IoT, integrando Mecatrônica e IoT com a segurança da saúde.*

Palavras-chave: *Saúde e Segurança Ocupacional, HIRA, Análise de Riscos, ISO 14001, ISO 9001, ISO 45001, Fabricação de medidores de gás, Riscos Mecânicos, Gestão de Riscos no Local de Trabalho, Hierarquia de Controle.*

1. Introduction. - Workplace safety is a critical concern, where hazards hide in plain sight and pose significant risks to employees, work operations, and the environment. This project focuses on implementing HIRA in a meter manufacturing plant, aligning our work and findings with international standards such as ISO 45001 (Occupational Health and Safety Management), ISO 9001 (Quality Management), and ISO 14001 (Environmental Management).

Gas meters are manufactured in Seven processing shops Starting with Machining shop to gluing and lapping followed by paint shop, PPM shop and Assembly finally the meters are calibrated and tested in the calibration shop than sent to packaging. Manufacturing environments, particularly those involving precision engineering and assembly, pose various risks, including mechanical hazards, chemical exposure, electrical risks, and ergonomic concerns. Gas meters play a crucial and prominent role in ensuring safe and accurate gas distribution, maintaining a safe and efficient production facility ensure the quality of meter produced and the safety of workers who produce it. A high-risk environment of the gas meter manufacturing plant is the crucial sealing step of its manufacturing process, the gluing and lapping shop.

Manufacturing plants in Pakistan have many hazards, including but not limited to machinery-related injuries, exposure to toxic chemicals, electrical risks, ergonomic issues, fires and explosion, biological hazards like dust and poor sanitation. As well as Inadequate safety training, lack of proper protective equipment, and weak enforcement of regulations further increase risks and the risks potential danger. Poor ventilation, excessive noise, and repetitive tasks contribute to long-term health issues manifesting as chronic injuries and illnesses either immediately or after long years in workers, to maintain worker safety and operational efficiency It is necessary to address these risks by implementing of strict safety regulations, proper worker training, risk assessments analysis, and protective measures.

This study aims to identify potential hazards within the gluing and lapping shop of this plant, assessing their impact on workers and production processes, and propose strategies that are in line with industry practices and occupational health and safety regulations to maximize safety and production. The findings will help improve workplace safety, reduce the likelihood of accidents, and enhance overall operational efficiency.

A systematic process crucial for ensuring workplace safety, operational efficiency, and regulatory compliance is Hazard Identification and Risk Assessment (HIRA), particularly in high-risk industries like gas meter manufacturing [1]. Hazards such as chemical exposure and mechanical injuries are mostly common, making it an essential tool for proactive risk management [2]. The process involves identifying, assessing, and prioritizing hazards to implement targeted controls, thereby minimizing risks to employees, assets, and the environment [3]. For this instance, in gas meter manufacturing, mechanical hazards from presses and cutting machines, can be mitigated through engineering solutions and personal protective equipment (PPE) [4].

The application of HIRA in gas meter manufacturing is identical to other industries with high-risk, including foundries and power plants, proving to be highly productive [5]. Risks posed by flammable materials can be overcome by use of Chemical and fire safety measures, including proper ventilation and fire suppression systems [6]. Use of the hierarchy of controls comprises of substituting hazardous chemicals with safer alternatives [7], while mechanical injuries are minimized by drafting and adopting machine guarding procedures [8]. Environmental controls for airborne contaminants include dust extraction systems and waste management protocols that help adhere to environmental regulations [10].

It's incorporation with ISO standards—9001, 14001, and 45001—allows the developing of an enhanced safety and operational efficiency-based framework [11]. ISO 9001 encourages the enhancement of product reliability and process efficiency through risk-based thinking [12]. Meanwhile, ISO 14001 focuses on the negative aspects of the environment, such as harmful chemical spills or emissions, and works to reduce them [13]. In the same manner, ISO 45001 requires HIRA to be part of the system, thus ensuring active worker involvement and legal aspects of occupational safety and health [14]. Compliance with these standards allows gas meter producers to balance safety, quality, and environmental objectives, thereby facilitating compliance and strengthening resilience [15].

Various methodologies and tools including risk matrices for prioritizing hazards are available for gas meter manufacturing plants, based on severity and likelihood [16], process failures including leaks in meter calibration systems can be identified using Process Failure Modes and Effects Analysis (PFMEA [17]. Thermal and noise safety measures, such as Thermal Work Limit (TWL) indices for assessing heat stress and noise monitoring systems for protecting workers from permanent hearing loss which enhance workplace safety [18]. Lemmens et al. (2022) [12] came up with a risk matrix approach as a tool based on decision-making for checking probability and impact when preventive and diagnostic interventions are implemented. This Research aims for quantitative risk assessment methodologies, Karanikas et al. (2022) [13] examined ISO 45001:2018 [17] while identifying new features of systems in occupational health and safety management, which strengthened the structured approaches of earlier HIRA methodologies.

It's evolution alongside risk assessment methodologies demonstrates a gradual shift between qualitative hazard identification and structured, standardized approaches incorporating risk matrices and management frameworks. The integration of ISO standards and industry-based applications highlight the ongoing development of risk assessment strategies for improvising workplace safety and operational efficiency.[15][16][17]

Yousefinezhadi et al. (2015) conducted a systematic review examining how quality management systems particularly ISO 9001 and the EFQM (European Foundation for Quality Management) model [9] affect hospital performance. From a HIRA (Hazard Identification and Risk Assessment) perspective, the study shows that these structured frameworks help healthcare organizations systematically identify operational hazards, evaluate risks, and implement ongoing improvements. [9]

It studies within textile industries mark out factors such as noise, dust, heat, chemicals and unguarded machinery as extreme high priority hazards [21]. Qualitative data from interviews and focus groups most hazard identification was informal and reactive, and use of PPE has been limited with minimal training. The study by Hussain and T. Jamali in 2019 highlights vulnerability among workers especially young workers new to the industry and women in the field. They also identify specific hazards such as heat stress, fire risks, and mechanical injuries, and points to the absence of structured risk evaluations or preventive strategies. This study done in Pakistan highlights the emerging need for HIRA protocols within the countries growing industrial sector for it to develop and prosper. [21]

The study by Ho and Tenkate (2024) highlights significant challenges in the readability and suitability of Safety Data Sheets (SDSs) as hazard communication tools. Even after modifications to address comprehensibility, SDSs still fell short of being adequate. Key issues included dense technical jargon, inconsistency between sections, and a lack of clarity in hazard communication. These findings underscore the need for SDSs to be simplified and standardized to ensure they are accessible to workers with varying literacy levels, thereby improving workplace safety. [22]

Necessary HIRA for Workshops Environmental Features: Thermal risks in industrial settings effect both worker safety and productivity as well as morale. The Thermal Work Limit (TWL) and other heat stress indices help evaluate sustainable work rates in extreme heat. [3]

Thermal Work Limit (TWL) determines the maximum sustainable work rate by considering Dry Bulb Temperature (DBT), Wet Bulb Temperature (WBT), Globe Temperature (GT) and Atmospheric Pressure (AP). Unlike WBGT, TWL accounts for hydration, acclimatization, and skin area effect of clothing, making it a more precise heat stress predictor. [3]
TWL is widely used in mining, construction, and workshops for heat management and work-rest cycle planning. [4]
TWL in HIRA for Workshops is essential for workplace safety by:

- Identifying heat stress hazards. [3]
- Setting safe work-rest schedules. [3]
- Implementing engineering controls (ventilation, cooling stations). [3]
- Enforcing administrative controls (hydration programs, shift rotations).[3]

Lighting Safety in HIRA

Proper lighting is essential for workplace safety, Lighting safety in workshops is evaluated through:

- Illuminance (Lux) Calculations: Ensuring compliance with standards (e.g., 300–500 lux for general workshops, 750 lux for detailed tasks). [5]
- Light Distribution and Shadow Control: Optimizing uniformity to prevent vision-related hazards. [5]

Noise Safety in HIRA

- Excessive noise exposure can lead to hearing loss and decreased concentration. Noise safety assessments involve:
- Decibel (dB) Level Monitoring: OSHA recommends an exposure limit of 85 dB over an 8-hour shift. [7]
- Noise Dose Calculation: Evaluating cumulative exposure using Time-Weighted Average (TWA) measurements. [7]
- Engineering Controls: Implementing noise barriers, dampening materials, and silent machinery. [7]
- Personal Protective Equipment (PPE): Using earplugs or earmuffs for workers exposed to high noise levels. [3]

Based on the conducted literature review, it is evident that a significant research gap exists in the application of Hazard Identification and Risk Assessment (HIRA) within gas meter manufacturing plants. Although HIRA methodologies have been widely utilized across various industrial sectors including chemical, petroleum, and general manufacturing, there is a notable absence of focused studies that address the distinct risks and operational hazards inherent to gas meter production. This gap underscores the need for a specialized analysis that accounts for the specific materials, processes, and safety challenges unique to this sector. The present study seeks to address this gap by performing a comprehensive HIRA tailored to the gas meter manufacturing's gluing and lapping shop. By systematically identifying hazards and evaluating associated risks, this research aims to offer practical recommendations for improving workplace safety, mitigating operational risks, and contributing valuable insights to the broader field of industrial risk management.

2. Research Methodology. - Here is the outline of the systematic approach applied for this research to identify hazard, identify risks, and propose control measures for the gas meter manufacturing plant in alignment with ISO Standards. The process is divided into the following parts:

- Hazard Identification
- Risk Assessment
- Risk Evaluation
- Recommendation of Control Measures
- Compliance with ISO Standards

Each stage is executed systematically across the gluing and lapping of the meter manufacturing plant and utmost importance, and focus is implemented in ensuring that the process is in alignment with the principles of ISO standards.

2.1 Hazard Identification. - The first step involves identifying potential hazards in various departments. This step combines observational and analytical techniques and information from relevant research articles. The following methods are employed:

- Site Surveys and Inspections
- Analysis of Historical Data
- Employee Interviews and Feedback

2.1.1 Risk Assessment. - After identifying hazards, risks associated with each hazard are quantified using various approach including the risk matrix method.

2.1.2 Risk Evaluation. - Risk evaluation is the process of analyzing and prioritizing potential hazards based on their likelihood of occurrence and the severity of their consequences. This systematic approach helps in determining the level of risk associated with various activities and guides decision-making to mitigate or eliminate hazards effectively. It is an essential step in ensuring workplace safety and compliance with standards like ISO 45001. [1] [19]

Risk Priority	Definitions of Priority
High	Situation is considered critical; stop work immediately or consider cessation of this operation/task.
Medium	Must be fixed as soon as possible; Zonal HSE team leader should take immediate action.
Low	Very important—must be fixed within two weeks. Zonal HSE team leader considers short-term and/or long-term actions. Can also be addressed via scheduled maintenance. If a quick/easy fix exists, resolve immediately. Otherwise, manage through routine procedures.

Table I. Risk Priority Table defining urgency levels (High/Medium/Low) for hazard mitigation, with corresponding response protocols for HSE teams.

2.1.3 Recommendation of Control Measures & their compliance with ISO Standards. - On the basis of previous evaluation, certain control measures are suggested in order to curtail the maximum hazard that is possible in the workplace. These controls are suggested based on the hierarchy of controls. [4]
After deducing the controls, their acquiescence is validated with previously stated ISO standards and the discrepancies are removed.

2.2 Calculations and comparison of measured and calculated Environmental parameters with standards. -
2.2.1 Noise. - The methodology involves calculating the combined noise levels of machines using logarithmic addition based on decibel differences. Identical machines are combined first, and incremental contributions from other machines are determined using values from a reference table (Table 2) for specific dB differences. [3]

Difference between two decibel levels to be added (dB)	Amount to be added to larger level to obtain decibel sum (dB)
0	3.0
1	2.6
2	2.1
3	1.8
4	1.4
5	1.2
6	1.0
7	0.8
8	0.6
9	0.5
10	0.4
11	0.3
12	0.2

Table II. Decibel summation reference chart showing correction values to add when combining two noise levels of differing intensities.

2.2.2 Lighting. - Lighting levels are assessed in accordance with ISO 8995-1:2002, which provides illumination standards for workplaces. Measurements are taken using a lux meter, and results are compared with ISO-recommended values.

Work Area	Recommended Illuminance (lux)
General Offices	300-500
Precision Assembly	1000-2000
Industrial Workspaces	300-750
Warehouse Areas	100-300
Laboratories	500-1000
Control Rooms	150-300

Table III. Recommend Lighting Levels (lux) for different areas according to ISO standards.

Proper lighting is essential for reducing eye strain, improving accuracy, and enhancing overall workplace safety. If measured values are below ISO standards, corrective actions such as additional lighting fixtures, LED upgrades, or task lighting adjustments are recommended.

2.2.3 Wet Bulb Globe Temperature (WBGT), Humidex and Thermal Work Limit (TWL). - Humidex is a measure used to describe how hot the weather feels to the average person, taking into account both temperature and humidity. It is primarily used to understand how heat and moisture together affect human comfort and health. Humidex here is calculated through the formula

$$HX = \mathrm{Ta} + \frac{5}{9}(\rho - 10) \qquad [18]$$

$$\rho = 6.11 * e^{\frac{5417.753}{\frac{1}{237.16} - \left(\frac{1}{Td}\right)}} \qquad [18]$$

$$T_{dew} = T - \frac{(100 - RH)}{5} \qquad [18]$$

Where;
air temperature Ta (C); T_d is dew point temperature (K); Wet-bulb temperature (T_x); Globe thermometer temperature (T_s); ρ is vapors pressure of water (in hPa); specific humidity q; surface air pressure Ps (Pa); HX is Humidex; WBGT is Wet Bulb Globe Temperature.

WBGT takes a more comprehensive approach, incorporating several factors like air temperature, humidity, wind speed, and radiant heat from the sun or other sources.

$$\mathrm{WBGT} = 0.7 \times T_x + 0.3 \times T_s \qquad [4]$$

Where;
Wet-bulb temperature (T_x); Globe thermometer temperature (T_s); Thermal Work limit (TWL).

The TWL (Thermal Work Limit) is another critical index used to evaluate the safety of working conditions in heat, particularly in hot and humid environments

$$TWL = 410.33 - 6.97T - 0.95RH \qquad [20]$$

Where;
Air temperature (T); Relative Humidity (RH).

a. Material Chemical property and Safety Analysis

2.2.4 Material data and safety data sheet. - Safety data sheets (SDSs) are hazard communication materials that accompany chemicals/Hazardous products in the workplace. Many SDSs contain dense, technical text, which places considerable comprehension demands on workers, especially those with lower literacy skills, such as technicians and line workers. Thus, there is a need for simplified and to-the-point data represented in an organized manner to help facilitate workers and make it easier to highlight chemical hazards and harmful actions emerges.

2.2.5 Analyzing chemical work protocol. - The following chemical compound check sheet is designed to act a s a structured to standardize and ensure safe handling, storage, and exposure control for various chemicals used in the workplace. It outlines essential information such as the specific storage requirements, permissible exposure duration, required personal protective equipment (PPE), and recommended handling protocols for each chemical. Additionally, it indicates the current level of training or awareness provided to personnel as well as recommended level.

Chemical	Storage	Exposure Time	Assigned PPE	Handling Protocol	Training / Awareness	Recommended level of Training

Table IV. Chemical compound check sheet example.

2.2.6 Safety analysis. - The chemical compound check Sheet shown above will serve as our fundamental tool for various safety analysis related to all chemicals encountered or worked with in any manufacturing industry. This acts as a support to our Hazard Identification and Risk Assessment (HIRA) by allowing us to quantize and categorize the risk and hazard associated with workplace chemicals, whilst considering factors like exposure duration, storage conditions, and required PPE. A PPE Gap Analysis can also be performed by comparing the listed PPE with what's in actual use, identifying mismatches or deficiencies in protection. The sheet's "Training/Awareness" column highlights areas lacking proper instruction, allowing for a Training Needs Analysis to plan targeted safety sessions. Furthermore, it can be utilized during compliance audits and safety inspections to verify that chemicals are stored correctly, labeled accurately, and handled according to safety protocols, ensuring compliance with standards such as ISO 45001.

2.4 Implementation of Control Measures. - Hierarchy of Risk Control should use when assessing the adequacy of existing controls and introducing new controls. The health and safety management system ISO 45001 states that the organization shall establish a process for achieving risk reduction based upon the following hierarchy. [17]

2.4.1 Elimination. - The first way to control an issue or hazard is to eliminate it. This can be achieved by changing design and physically solving the issue of hazard. Elimination is the most effective way to control hazards. For example, replacing sharp-edged tools with ergonomically designed alternatives to prevent cuts or hand injuries, replacing a solvent containing volatile organic compounds (VOCs) with water-based solutions to prevent inhalation risks and fire hazards, installing electric motors instead of diesel engines to reduce workplace noise exposure, and minimizing hearing damage risks. [17]

2.4.2 Substitution. - Substitution is the process of replacing hazardous materials or practices with safer alternatives. This is often applied in industries that handle toxic chemicals, dangerous equipment, or high-risk procedures. When implementing substitution, it is essential to evaluate the substitute thoroughly to ensure that it does not create new hazards, such as untested chemical reactions or other environmental concerns. For example, in a painting process, substituting solvent-based paints with water-based alternatives reduces workers' exposure to volatile organic compounds (VOCs), which can cause respiratory issues. Similarly, in manufacturing, replacing carcinogens like asbestos with synthetic, non-hazardous fibers significantly reduces long-term health risks. Substitution can also involve switching from manual handling to automated systems to minimize ergonomic risks. [17]

2.4.3 Engineering Controls. - Engineering controls aim to redesign or modify equipment or processes to remove hazards at the source or reduce the likelihood of exposure. This process is more commonly carried out in industries with the help of new technologies; especially the use of IOT bases systems for monitoring and controlling. [17]

2.4.4 Administrative Controls. - Administrative controls involve altering how work is performed to reduce risks. These measures include establishing safety policies, enforcing regular maintenance schedules, and training workers to recognize hazards. [15]

2.4.5 Personal Protective Equipment. - PPE is considered a last-resort control measure when other methods cannot fully mitigate risks. It includes items such as gloves, helmets, goggles, and respirators designed to protect individuals from specific hazards. [15] [16] [17]

3. Results. - Prior to identify hazard potential in gas meter manufacturing plant gluing and lapping production process, the manufacturing processes should be known first. The plant produces 2 major Models. Model A is made for lower altitude and higher temperature climates for cities such as Karachi. Model is made for the Sindh province of Pakistan. Model B is designed for Higher altitude climates and lower temperatures. They both serve the same purpose to measure gas flow rate and have some differences in the design, but our focus is the processes that are present for their manufacturing.

Below is a birds eye view Schematic of the Shop in review

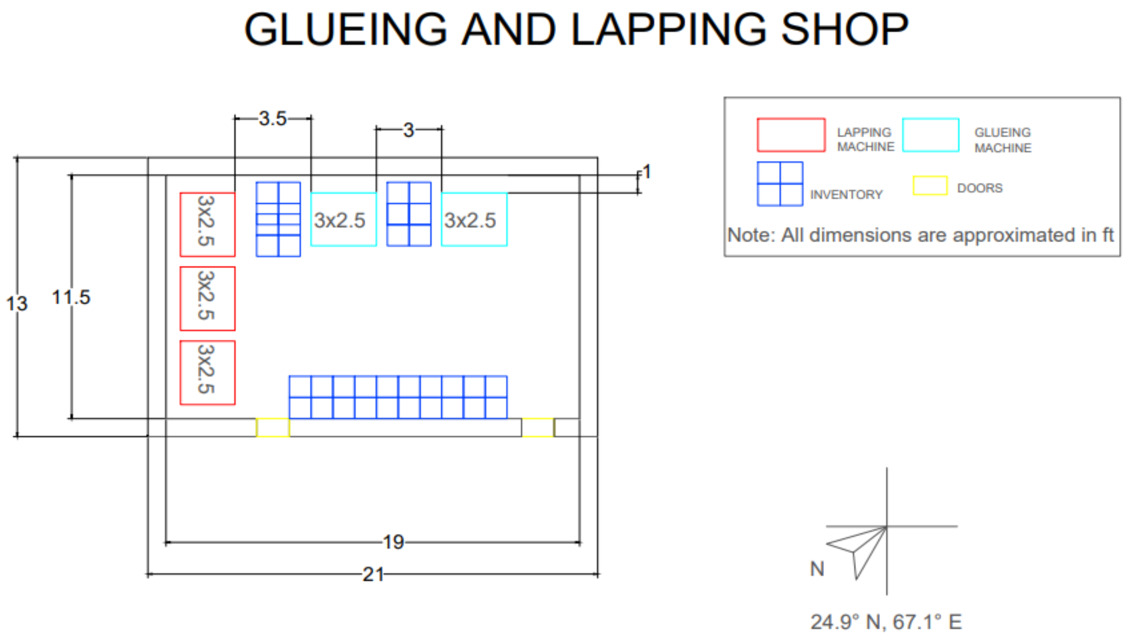

Figure I. Gluing Shop top-down view schematic drawing.

The processes and work operations occurring in the gas meter manufacturing plant's gluing and lapping are:
1. Adhesive Application – Application of adhesive at designated points on to the main body of the meter using pneumatic dispensers to ensure uniform bonding on the sealing areas between metal body and plastic jig panel.
2. Gluing and Curing – Components are placed in dedicated jigs within 10 high stacks on pallets, after adhesive application to maintain alignment and ensure proper bonding during curing. Curing time varies from 4 to 8 hours depending on temperature and weather.
3. Lapping Operation – Lapping of critical sealing surfaces using Lap Master machines with abrasive compounds (black sic) to achieve required flatness and surface finish to ensure plastic plates lay flat on the metal body.
4.Stacking and Handling – Finished parts are stacked in trolleys or crates with proper spacing and tagging to prevent damage and ensure batch traceability and shipped forward to next section.
After thoroughly analyzing the production process, a comprehensive Hazard Identification and Risk Assessment (HIRA) was conducted to systematically identify potential hazards, evaluate associated risks, and determine appropriate

control measures. Before proceeding with risk ranking, it is essential to establish clear criteria to accurately assess the seriousness of identified hazards and their associated risk levels, it is necessary to formulate criterion of seriousness or risk ranking degree. Likelihood (L) is the possibility of accidents occurrence (Table 4). Severity or Consequences (C) is the seriousness of the injury and working days loss (Table V).

Likelihood Criterion: Likelihood is the probability or possibility of an accident or hazardous event occurring. It is categorized into five levels as follows: [1] [19]

Level	Criteria	Qualitative Description	Semi-Qualitative Description
1	Rarely Occurred	Can be considered, but not only in extreme state	Less than once in ten years
2	Small Possibility	Not yet happened, but usually occurred at a time	Once-in-ten-year occurrence
3	Possible	Should have happened, and maybe have happened elsewhere	One in five years or once a year
4	Great Possibility	Can easily happen, may appear in the most common state	More than once in a year or month
5	Almost Definitely	Frequently happens and is expected in the most common state	More than once in a month

Table V. Likelihood Criterion – Classifying accident or event probabilities from 'Rarely Occurred' to 'Almost Definitely' with qualitative and semi-quantitative descriptors

Consequence Severity Criterion: Severity refers to the seriousness of potential injury, health effects, or property damage resulting from a hazardous event. It is categorized into five levels as follows (Table VI): [1] [19]

Level	Criteria	Qualitative Description	Semi-Qualitative Description
1	Not Significant	Does not cause any damage or injury to humans	No working days lost
2	Small	Causes minor injury, small losses, but does not affect work continuity	Can still work on the same day/shift
3	Moderate	Results in severe injury requiring hospitalization, no permanent disability but financial loss	Losing less than three working days
4	Great	Causes severe injuries and permanent disability, leads to significant financial losses affecting business continuity	Losing three or more working days
5	Disaster	Results in deaths and severe losses, leading to permanent business stoppage	Losing working days forever

Table VI. Consequence Severity Criteria Matrix – Classifying incident impacts from 'Not Significant' to 'Catastrophic' with qualitative and semi-quantitative descriptors

Risk Rating Classification Criterion: This Risk Rating Classification Criterion (Table VII) provides a structured framework for prioritizing workplace hazards based on their calculated Risk Priority Number (RPN). By categorizing risks into four severity levels—Low (1–4), Medium (5–9), High (10–15), and Critical (16–25), it aligns quantitative risk assessments with actionable mitigation strategies. [1] [19]

Risk Rating (R)	Risk Level	Description
1 – 4	Low	Acceptable risk. No immediate action required.
5 – 9	Medium	Moderate risk. Requires planned action to mitigate.
10 – 15	High	Significant risk. Requires immediate action to mitigate.
16 – 25	Critical	Unacceptable risk. Requires urgent intervention to eliminate or control hazards.

Table VII. Risk Rating Classification Criterion – Categorizing risk levels (Low to Critical) based on calculated RPN scores with corresponding mitigation requirements.

3.1 Hazard Identification and Risk Assessment (HIRA) Table. -

Hazard Identification				Risk Evaluation
	Work activity	**Hazard**	**Possible Accident**	**Existing Risk Control**
1	Stacking of meters	Loose Inventory/Stack	Slipping or falling, leading to fractures, sprains, or head injuries	Fixed number of crates
2	Movement within Pathways	No pathway designated	Collisions, severe injuries	No physical markings on floor.
3	General Housekeeping	Trash Heap in Corner	Fire risk, pest infestation, slips/trips	Occasional cleanups
4	Working with Electrical Systems	Bare Wirings	Electrical shock, electrocution, sparks, fire hazards	Protective covers (Inadequate as wires are still bare),
5	Accessing Heights for Stacking	Use of unstable or inappropriate platforms (like crates) for elevation	Falls from height causing serious injury	No existing control

Table VIII. Hazard Identification and Risk Assessment (HIRA) table outlining workplace hazards, potential accidents, and existing control measures for various operational activities.

3.1.1 Risk Priority Number (RPN) Calculations. -

Hazard Identification			Risk Evaluation		
	Work activity	**Hazard**	**Severity**	**Likelihoo d**	RPN
1	Stacking of meters	Loose Inventory/Stack	3	4	12
2	Movement within Pathways	No pathway designated	3	3	9

3	General Housekeeping	Trash Heap in Corner	4	3	12
4	Working with Electrical Systems	Bare Wirings	4	3	12
5	Accessing Heights for Stacking	Use of unstable or inappropriate platforms (like crates) for elevation	4	4	16

Table IX. Risk Priority Number (RPN) calculations for identified workplace hazards, evaluating severity and likelihood to prioritize risk mitigation.

3.1.2 Risk Ranking Matrix. - The risk prioritization matrix offers a structured visualization of identified hazards by categorizing them based on their likelihood of occurrence and the severity of their impact, as determined through the preceding HIRA (Hazard Identification and Risk Assessment) analysis. This matrix supports a systematic approach to risk ranking, enabling focused and effective mitigation efforts aligned with the assessed risk levels according to calculated RPN in table 8 and classified according to Table 6 Risk Rating Classification Criterion.

Risk Ranking Matrix		**Very Likely**	**Likely**	**Possibly**	**Unlikely**	**Highly unlikely**
		5	**4**	**3**	**2**	**1**
Catastrophic	**5**					
Significant	**4**		Accessing Heights for Stacking	General Housekeeping, Working with Electrical Systems		
Harmful	**3**		Stacking of meters	Movement within Pathways		
Minor	**2**					
Negligible	**1**					

Figure II. Risk Ranking Matrix evaluating workplace hazards by likelihood and severity, highlighting critical risks like passage blockage and moving part contact.

3.1.3 Additional Control Suggestions and Improved Risk Priority Number (RPN) score. -

Hazard Identification			**Risk Control**				
Work activity		Hazard	Additional Controls	Hierarchy of controls	Severity	Likelihood	RPN*
1	Stacking of meters	Loose Inventory/ Stack	Restrict stack height Conduct daily checks. Set maximum load signs Conduct stacking training	Engineering controls, Administrative Controls	2	2	4

2	Movement within Pathways	No pathway designated Tripping Hazard	Clear Floor markings. Provide movement safety training.	Engineering controls, Administrative Controls.	2	1	2
3	General Housekeeping	Trash Heap in Corner Flammable	Regular and schedule cleanups Fireproof bins. Spot checks, assigned disposal duties.	Engineering controls, Administrative Controls.	2	2	4
4	Working with Electrical Systems	Bare Wirings – Electrical Fire	Protective enclosures/conduits for all bare wires. Lockout/Tagout procedures for electrical work. Audit wiring layout regularly Restrict access to electrical areas.	Engineering controls, Administrative Controls	1	2	2
5	Accessing Heights for Stacking	Use of unstable or inappropriate platforms (like crates) for elevation - Fall Hazard	Stop using crates as steps. Use step stools or ladders. Place items within reach or use adjustable platforms. Train on safe reaching and lifting.	Engineering controls, Administrative Controls.	2	2	4

Table X. Recalculated Risk Priority Number (RPN) calculations for identified workplace hazards, evaluating severity and likelihood to prioritize risk mitigation after the implementation of suggested controls.

3.1.4 Risk Action Priority Matrix. - The Risk Action Priority matrix is a structured analytical tool used to determine and visualize the urgency and sequence of risk control measures implementation. The systematic ranking of identified hazards based on criterions such as severity, likelihood, and exposure time allows this matrix to categorizes risks into action tiers, from immediate action to scheduling controls in the near future or setting up routine monitoring. It is designed with recognized safety standards in mind, including ISO 12100 (Safety of Machinery), ensuring adherence to the hierarchy of risk controls.

Color Key for Risk Action Priority Matrix (Figure 3)

Risk Action Priority Matrix	Very Likely	Likely	Unlikely	Very Unlikely
Catastrophic	Bare Wirings Electrical Fire	Trash Heap in Corner - Flammable		
Significant	Loose Inventory/Stack	Heat Stress Summer	Heat Stress Winter	
Harmful	Accessing Heights for Stacking – Fall Hazard	No Pathway Designated – Tripping Hazard		INSUFFICIENT LIGHTING

Figure III. Risk Action Priority Matrix – Mapping workplace hazards by severity and probability to guide mitigation efforts, with drilling operations and passage blockage flagged as highest priority.

Hazard Level	Action
	No need to act immediately, but keep inspecting
	Perform reparation/control maintenance in the next one year.
	Take action in the next three months.
	Take reparation/ control maintenance action within one month ahead.
	Take action immediately/Emergency protocol - possible use restriction.

Figure IV. Hazard Response Timeline Guide – Color-coded action priorities from emergency protocols (immediate) to routine monitoring (no urgent action).

3.2 Environmental Conditions Analysis. - Noise, light intensity, temperature, and humidity were measured using dedicated mobile applications that leverage the smartphone's built-in sensors. The details are as follows:

- Noise Measurement: Conducted using a Noise Meter app - Sound meter developed by Smart Tools Co, utilizing a MEMS (Micro-Electro-Mechanical Systems) microphone to capture sound pressure levels in decibels (dB).
- Light Intensity Measurement: Conducted using a Lux Meter app – Illuminance - light luxmeter. Developed by Phuongpn, relying on a photodiode-based ambient light sensor to measure illumination levels in lux (lx).
- Temperature and Humidity Measurement: Conducted using a climate monitoring app - Room temperature Thermometer Dev by Master Texhnologis, using a combination of capacitive humidity sensors and silicon bandgap temperature sensors for ambient readings.

To ensure accuracy, reliability and repeatability, all sensors were calibrated against known reference values, and multiple readings were taken at different times over an extended period. This approach enabled a more consistent and representative dataset for calculating environmental indices

3.2.1 Noise Level Comparison. - A comparison between the measured noise level within the work area and the permissible limit established by ISO 45001 can be seen in the following bar graph
standards. The recorded noise level in the facility is approximately 79 dB, which is in the range of the ISO 45001 prescribed limit of 85 dB.

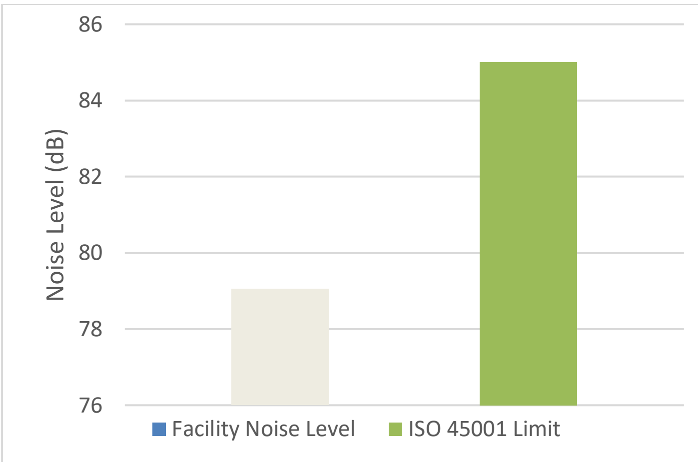

Figure V. Facility noise level (dB) assessment compared to ISO 45001 occupational exposure limits, highlighting compliance gaps.

This deviation is non-compliant with occupational health and safety guidelines, suggesting that workers are exposed to potentially harmful noise levels. Prolonged exposure to these conditions will lead to hearing damage, putting an emphasizing on the need for immediate intervention.

3.2.2 Light Level Comparison. - The bar graph is based on the comparison between the measured light level in the facility and the recommended standard according to ISO guidelines. The measured illumination within the area is approximately 150 lux, which is significantly below the ISO workshop standard of 300 lux. This indicates inadequate lighting conditions in the current workspace, which can negatively impact workers' visibility, productivity, and safety. Insufficient lighting can lead to eye strain, increased error rates, and a higher risk of accidents.

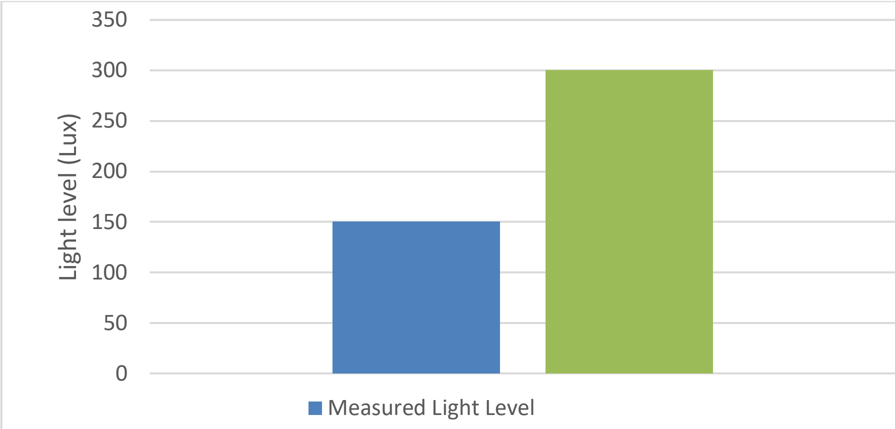

Figure VI. Workspace illumination analysis comparing measured light levels against OSHA/NIOSH recommended standards for workshop safety.

3.2.3 Heat Stress Level Comparison. - The following bar graph depicts the Calculated Thermal Work Limit (TWL), which is a real-time or site-specific measurement of the risk of heat stress, against the ISO Standard TWL. Showing close alignment between the two, though the calculated value is slightly higher. This indicates that the working environment is safe.

The next set of bar graphs compare WBGT and humidex with their ISO standard values. These supportive metrics underline the need for bolt various barometric stresses along in conjunction with the above evaluation.

These indicators hot stress measured standards at these values may be alluded to records, that the surrounding conditions verged on or approach the internationally accepted thresholds within minimum safety standards when it comes to thermal exposure. The compliance support lifts exact guidelines prove the dependability of the measurements

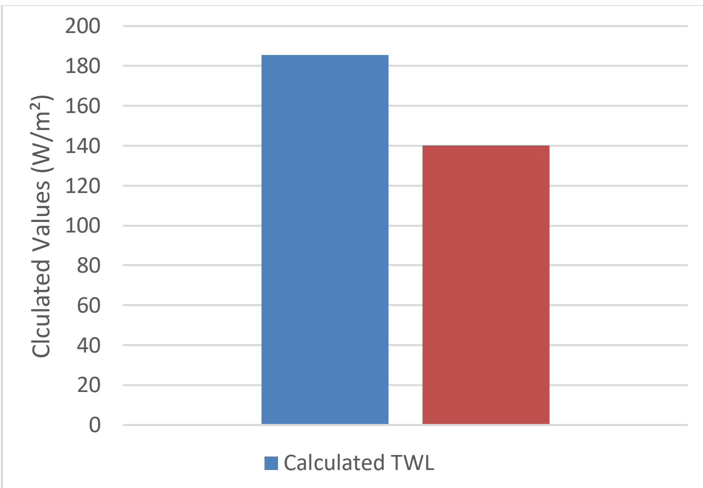

Figure VII. Thermal Work Limit (TWL) assessment showing measured heat stress risk (0.07 kW) against ISO safety thresholds for industrial environments.

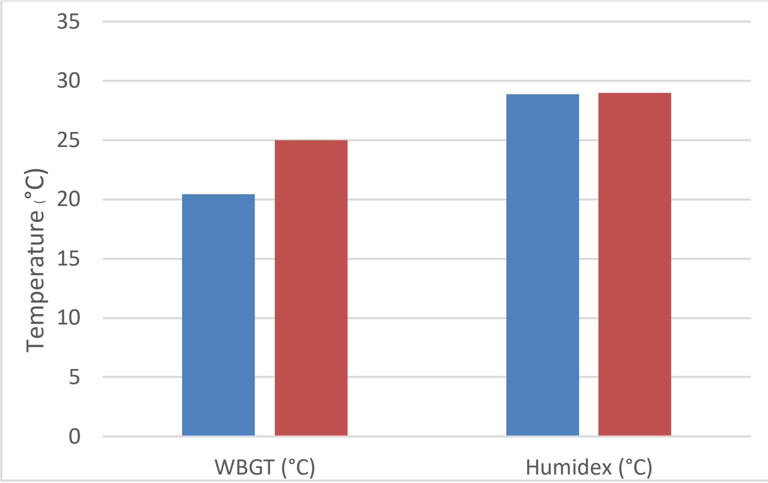

Figure VIII. Heat stress exposure analysis comparing measured Wet Bulb Globe Temperature (WBGT) and Humidex values against ISO safety thresholds.

3.3 Material and chemical safety analysis. - The following table highlights all current data and protocols in

Chemical Compound Check Sheet					
Chemical	Storage	Expose time	Assigned PPE	Handling Protocol	Training/Awareness
Silica flex 221	Store in a dry place at room temperature; avoid moisture. Keep containers sealed.	8 hours (avoid prolonged dust inhalation)	Gloves	Minimize skin contact	None
Black Sic	dry, cool place; keep away from oxidizing agents	8 hours (limit dust exposure)	Gloves	Minimize skin contact	None

Table XI. Basic information extracted from MSDS for the mentioned chemicals used in the workplace.

3.4 Safety protocols updates and recommendations. - In-depth analysis of SDS allow for following new improved protocols to be suggested. We have updated the Chemical Component Check Sheet to align with SDS hazard data by adding required PPE (respirators, eye protection), enhancing handling protocols (ventilation, wet methods), and mandating hazard-specific training, ensuring compliance with safety standards like ISO 45001

Chemical Compound Check Sheet					
Chemical	Storage	Expose time	Assigned PPE	Handling Protocol	Training/Awareness
Silica flex 221	Store in a dry place at room temperature; avoid moisture. Keep containers sealed.	8 hours (avoid prolonged dust inhalation). Risk: Respiratory irritation	- Nitrile gloves - NIOSH-certified N95 respirator - Safety goggles	- Use local exhaust ventilation - Avoid dust generation - Wash hands after handling	Mandatory training: - Dust control measures - Proper PPE use - Emergency procedures
Black Sic	dry, cool place; keep away from oxidizing agents	8 hours (limit dust exposure). Risk: Carcinogen (H350)	- Nitrile gloves - NIOSH-certified respirator (P100 for dust/fibers)	- Handle in fume hood/ventilated area - No dry sweeping (use wet methods) - Static charge precautions	Mandatory training: - Carcinogen hazards - Spill response

			- Lab coat + eye protection		- Medical surveillance requirements

Table XII. updated information for previously extracted data taken from MSDS for the mentioned chemicals used in the workplace.

4. Improvement Proposals and Result Discussions. - Based on the expected goals which fit the data and its processing results presented, conclusions are made as follows;

1. The skin contact of the worker with the coolant needs to be monitored, and the risk level should be mitigated by use of either substitution with lesser toxic and work-efficient coolant or by use of adequate PPEs.
2. Automated sensors must be introduced or the use of and, or gates-based technological devices that help optimize the present machinery and reduce chances of contact with moving parts during operation. This applies to all drilling machines and rotating machines within the shop.
3. Reinforcement of worker training programs. Along with periodic safety audits and continuous monitoring of key environmental parameters, such as noise and ventilation, for maintaining a safe and compliant work environment.
4. The Light intensity levels in the workplace needs to be improved in order to match the ISO standard of 300 Lx by use of energy energy-efficient LED-based lighting system in order to counter visibility issues.
5. Continuous monitoring of temperature and humidity levels along with proper inspection of ventilation equipment during various times and seasons throughout the year, to eradicate the effects of humidity and high temperatures that are measured through the previously calculated parameters.
6. The integration of ISO 45001, ISO 14001, and ISO 9001 standards contributed to a structured approach to occupational safety, environmental management, and quality control. Compliance with these standards ensured a systematic risk management process, improving worker safety, reducing environmental impact, and enhancing overall operational efficiency.
7. An efficient workplace management system needs to be developed and reinstated in order to facilitate the flux of raw material and finished products, which would otherwise lead to the blocking of passages serving as an obstacle to movement and would in turn increase safety risks for the workers.
8. Providing Personal Protective Equipment to the workers, which aligns with D. P. Restuputri and M. Fakhri (2015), namely:
   - Ear Plugs/Muffs to reduce the effect of harmful noise.
   - Respirators or Dust Masks that protect the lungs from harmful dust, fumes, and vapors generated by processes like grinding, cutting, and welding.
   - Safety Goggles for avoiding contact with chips and other small flying metal pieces from shop operations.
   - Safety Gloves that reduce damage in case of contact with rotating parts and reduce skin contact time with coolant.
   - Safety Shoes (Steel-Toed Boots) that reduce damage from falling objects such as gas meters stacked in piles and other tools being used.
   - Specialized Work clothing's (Coveralls, Aprons) such as fire-resistant coveralls or aprons, protects the body from hot surfaces, sparks, and chemicals while preventing loose clothing from getting caught in machinery.
   - Hair Protection (Hairnets or Caps) that prevent hair from getting caught in machines.

5. Conclusions. - The results suggest the importance of HIRA, HSE, and environmental conditions analysis, these are integral to a safe working environment.

Despite all of these findings and suggestions to maintain HSE standards it is implicative that HIRA is conducted on a regular basis and older findings are updated with more newer data especially for the section environmental conditions analysis as environmental conditions are changing at a considerable pace across the world due to global warming and extreme temperature shifts have been seen in the last decade.

Future work should focus on integrating advanced technologies like Internet of Things (IoT) and Artificial Intelligence (AI) based monitoring systems for real-time hazard detection, developing industry specific risk models, and creating adaptive HIRA frameworks. Emphasis should also be placed on incorporating human factors, supporting lifecycle based environmental assessments, and aligning practices with international safety and environmental standards.

Conflict of interest. - There are no significant competing financial, professional, or personal interests that might have affected the performance.

Acknowledgment. - The researchers acknowledge all people who participated in this study for their efforts. We gratefully acknowledge the developers of the mobile applications used in this study for their role in ensuring reliable environmental data collection. The Noise Meter app by Smart Tools Co., the Lux Meter app by Phuongpn, and the Room Temperature Thermometer app by Master Technologies provided accurate and consistent measurements of noise, light, temperature, and humidity. These tools were essential to our calibrated data gathering and greatly enhanced the validity of our analysis. The research team acknowledge the support provided by ChatGPT by OpenAI for the formulations and enhancement for literature review and research abstracts and its significant role in enhancing the linguistic quality of our work.

Glossary:

- ISO: International Organization for Standardization for risk and safety standards.
- HIRA: Hazard Identification and Risk Assessment – a process for potential hazards and evaluate risks.
- IRA: Individual Risk Assessment – focused on risks to individual personnel.
- Humidity: Refers to the environmental moisture level, a factor in thermal stress.
- Noise: Environmental hazard affecting hearing and concentration.
- Severity: Refers to the extent of potential harm from a hazard.
- Likelihood: Probability of occurrence of a hazard.
- Identification: The Process of recognizing potential hazards.
- Risk: The combination of the probability of an event and its consequences.
- Hazard: A source or situation with the potential to cause harm.
- Artificial Intelligence (AI): a pattern based on human intelligence process followed by machines, especially computer systems for tasks such as decision-making, pattern recognition, and automation.
- Information Technology (IT): study or use of computers, networks, and other electronic systems for storing and processing information.
- TWL: The sustainable metabolic rate under specific environmental conditions for a human body.
- WBGT: estimates the effect of temperature, humidity, wind speed, and solar radiation.
- PPE: Personal Protective Equipment Gear designed to be worn to minimize exposure to hazards or the damage caused by them.
- M3 Tapping Machine: Tapping machine that creates 3mm diameter internal threads via tapping tool into predrilled holes.
- M13 Tapping Machine: Tapping machine that creates 13mm diameter internal threads via tapping tool into predrilled holes.
- M5 Tapping Machine: Tapping machine that creates 5mm diameter internal threads via tapping tool into predrilled holes.

List of Symbols:

- TWL: Thermal Work Limit (W/m^2)
- WBGT: Wet Bulb Globe Temperature (°C)
- GT: Globe Temperature – Part of WBGT calculation.
- Ta: air temperature(C)
- Td Is dew point temperature (K)
- T_x:Wet-bulb temperature
- T_s: Globe thermometer temperature
- ρ: Vapour pressure of water (in hPa)
- q:specific humidity
- Ps:surface air pressure (Pa)
- HX : Humidex
- WBGT: Is Wet Bulb Globe Temperature
- Q: Heat dissipation rate
- SA : Skin area
- ΔT : temperature gradient
- T: Air temperature
- RH: Relative Humidity

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Author contribution:

1. Conception and design of the study

2. Data acquisition

3. Data analysis

4. Discussion of the results

5. Writing of the manuscript

6. Approval of the last version of the manuscript

AZ has contributed to: 1, 2, 3 4 and 5.

MA has contributed to: 4, 5 and 6.

IS has contributed to: 5 and 6.

MHN has contributed to: 5 and 6.

MH has contributed to: 4, 5 and 6.

HA has contributed to: 4, 5 and 6.

Acceptance Note: This article was approved by the journal editors Dr. Rafael Sotelo and Mag. Ing. Fernando A. Hernández Gobertti.