



Integration of Macro-Ergonomic Evaluation Using MOQS and Ventilation Intervention to Mitigate Worker Fatigue in a Meat Floss Home-Based Industry

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Abstract

Home-based industries often struggle with suboptimal work systems that place a heavy physical burden on workers. Although macro-ergonomic assessments can identify socio-technical stressors, their empirical integration with engineering control interventions remains underexplored at the micro-industrial level. This study aims to evaluate the work systems of Micro, Small and Medium-sized Enterprises (MSMEs) producing beef and chicken floss and implement targeted technical control measures to reduce operator fatigue. Path analysis of the Macroergonomic Organizational Questionnaire Survey (MOQS) dimensions (organizational, equipment, physical environment, and personal) determined their causal relationships with physiological fatigue, measured by Cardiovascular Load (%CVL) (n=10). The physical environment emerged as the dominant stressor, exerting the strongest significant effect on operator fatigue. After implementing engineering controls, the production room temperature fell from 32.44°C to 28.16°C. Consequently, the average %CVL for workers fell sharply from 32.97% to 27.09%. However, external seasonal weather variations may also have contributed to this observed temperature reduction. This relative reduction of 17.83% indicates that integrating macro-ergonomic assessment with engineering control interventions can improve working comfort in the production systems of MSMEs producing beef and chicken floss.

Keywords: *Macro-Ergonomics, Path Analysis, Engineering Control, Cardiovascular Load, Fatigue*

INTRODUCTION

Micro, Small and Medium-sized Enterprises (MSMEs) contribute significantly to Indonesia's economic growth, particularly in the food processing sector (Nurohmiasih et al., 2025; Widita et al., 2024). However, despite their economic contribution, many home-based industries still rely heavily on manual labor and do not implement optimal ergonomic standards (Primasari et al., 2025; Sutarjo, 2007). One representative example is a home-based business in Magelang, Central Java, that produces beef and chicken floss.

This processing plant's production system comprises six main workstations: meat washing, boiling, mincing, roasting, frying, and quality control, all operated manually. In this traditional production system, production targets often ignore workers' physiological capabilities, forcing them to perform repetitive tasks in a non-ergonomic work environment. If this systemic imbalance is ignored, severe physical fatigue will accumulate, leading not only to reduced efficiency and increased risk of human error, but also to threats to the industry's operational sustainability (Salawati & Abbas, 2023; Taufik, 2025).

Within this home-based beef and chicken floss production system, systemic pressures stem from four key work-related factors: organization, equipment, the physical environment, and personal attributes. Regarding environmental factors, a preliminary study found that the production floor operates in a microclimate with an average temperature of 32.44°C. This condition significantly exceeds the indoor thermal comfort range of 18–24°C recommended by the World Health Organization (WHO) for health protection (Picchio & van Ours, 2024), as well as the optimal productivity range of 20–26°C (particularly between 22–24°C) observed by Geng et al. (2017).

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Working outside this thermal comfort zone, particularly at high temperatures, harms physical health and labor productivity because workers must expend extra energy or reduce effort to cope with the heat (Picchio & van Ours, 2024). These working conditions are further worsened by non-mechanized equipment, which forces workers to perform tiring, repetitive movements. These conditions undermine production efficiency, leading to excessive physical burdens, longer work durations, and increased physical fatigue among workers (Finansia et al., 2026).

Organizational issues include uneven workload distribution, particularly at the roasting and frying stations. Operators in this area are constantly exposed to intense stove heat throughout their 8-hour shifts. The combination of thermal stress, suboptimal equipment, and task imbalance led to work-related fatigue, reflected physiologically in a preliminary Cardiovascular Load (%CVL) measurement of 32.97%.

The complexity of these interrelated issues requires urgent improvement and indicates socio-technical dysfunction within the industry's organizational structure. Poor incorporation of ergonomic principles into work system design remains a persistent challenge in industrial settings, particularly among small and medium-sized enterprises (SMEs) (Ma'ruf et al., 2026).

Previous literature has focused heavily on identifying socio-technical issues in work systems using a macro-ergonomics approach (Amri et al., 2023; Berlianty & Arifin, 2025; Garosi, 2023; Ma'ruf et al., 2026). Tools such as the Macroergonomic Organizational Questionnaire Survey (MOQS) and path analysis have effectively mapped complex interactions between organizational variables and workers' discomfort (Amri et al., 2023).

However, a literature review shows that most previous macro-ergonomics studies limit their outputs to managerial diagnosis or offer only suggestions for administrative improvements (Primasari et al., 2025; Saputra et al., 2025). Consequently, research that uses MOQS's systemic findings as a data-driven basis for implementing technical interventions directly at the micro-ergonomics level remains limited.

To bridge this gap, this study aims to integrate macro-ergonomic assessments with comprehensive physical improvements. This study uses MOQS and path analysis not only to quantify the root causes of workload imbalance, but also to validate which systemic factor contributes most to physiological strain empirically. Ultimately, the recommendations based on this managerial diagnosis are not merely theoretical assessments; they directly inform the design of specific engineering controls to reduce worker fatigue and create a more optimal work system.

LITERATURE REVIEW

Macroergonomics and Work System Design

The Macroergonomic Organizational Questionnaire Survey (MOQS) evaluates core sociotechnical dimensions, where macro-level inefficiencies manifest as micro-level physical and psychological fatigue (Darmawan & Ghozy, 2022; Kleiner, 2006; Muliya & Pratiwi, 2024; Realyvásquez-Vargas et al., 2018; Scheel et al., 2019). Given the inherently small worker population in home-based industries, this MOQS application serves as an exploratory diagnostic tool rather than a generalizable causal model.

Physiological Workload and Thermal Stress

Workload refers to the demands of tasks a worker must complete within a given period and is generally classified as physical and mental (Ahmadi et al., 2022). A heavy workload without adequate recovery leads to work fatigue, a decline in physiological and psychological capacity that ultimately reduces productivity (Caldwell et al., 2019). Several factors influence work-related fatigue, including working hours, age, and physical environmental stresses such as exposure to extreme temperatures (thermal stress) and poor lighting (Cunningham et al., 2022; Ekasari et al.,

2026).

To measure the physical fatigue resulting from this workload, the Cardiovascular Load (%CVL) metric is used (Kurniawan et al., 2024). This %CVL measurement is determined based on an individual's Working Heart Rate (WHR), Resting Heart Rate (RHR), and Maximum Heart Rate (MHR). The formula for calculating %CVL is shown in Equation (1). CVL % results are classified into five severity levels: <30% (no fatigue), 31%–60% (improvement required), 61%–80% (short-term work only), 80%–100% (immediate action required), and 100% (activity not permitted) (Berlianty & Arifin, 2025; Mariawati et al., 2024).

$$\%CVL = \frac{100 \times (WHR - RHR)}{(MHR - RHR)} \quad (1)$$

MHR is determined based on the worker's gender. The calculation formulas are shown in equations (2) and (3) (Berlianty & Arifin, 2025).

$$MHR (Male) = 220 - Age \quad (2)$$

$$MHR (Female) = 200 - Age \quad (3)$$

However, %CVL has limitations as a fatigue indicator because it is highly sensitive to ambient heat. Since heart rate increases for thermoregulation independently of physical exertion, any post-intervention reduction in %CVL may primarily reflect improved thermal comfort rather than decreased task demands.

Path Analysis as a Diagnostic Tool

Path analysis functions as a powerful statistical diagnostic tool for determining the direct and indirect effects of independent (exogenous) variables on dependent (endogenous) variables (Harris & Gleason, 2022). In macroergonomics, this method provides a theoretical framework for quantifying how MOQS work-system dimensions, such as organizational conditions, equipment, and the physical environment, causally influence physiological workload (%CVL).

As the MOQS questionnaire produces ordinal-scale data, the Method of Successive Intervals (MSI) must first be applied to transform the responses into an interval scale, thereby satisfying the parametric assumptions of regression modeling (Arlianty & Setiawati, 2026; Febriana & Setiawati, 2024). By calculating the regression coefficients, this model reveals each stressor's influence. In theory, this analysis identifies the critical path of the work system variables, which will then serve as an empirical basis for designing engineering controls.

RESEARCH METHOD

Research Design and Participants

This study employed a quantitative case study design supported by a descriptive-analytical approach. The study was conducted at a home-based beef and chicken floss manufacturing industry located in Magelang, Central Java. The study used total sampling, including all production floor workers (10 individuals). These workers are distributed across six primary workstations (washing, boiling, mincing, roasting, frying, and quality control), all of which operate manually and serve as the primary units of analysis for the macro-ergonomic evaluation and physiological workload measurements.

Data Collection Procedures

Primary data from all 10 workers (with informed consent) at a home-based beef and chicken

floss industry included observations, interviews, and physiological metrics. A closed-ended MOQS questionnaire, adapted from the framework by [Stanton et al., 2004](#) for the Indonesian context, was used to evaluate socio-technical variables identified during initial observations, such as manual handling and the absence of safety procedures.

This 32-item instrument utilizes a 5-point Likert scale to measure four independent variables—Organizational Conditions (7 items), Equipment (8 items), Physical Environment (5 items), and Personal Factors (6 items)—and one dependent variable, Fatigue (6 items). Mandatory validity and reliability tests were conducted on the instrument prior to structural modeling.

Furthermore, to assess pre- and post-intervention thermal stress, ambient temperature was recorded at four representative points using an uncalibrated digital thermometer three times daily: morning (07:00–08:00 WIB), midday (11:30–13:00 WIB), and afternoon (15:00–16:00 WIB). Simultaneously, physical fatigue was evaluated by recording resting and Working Heart Rates (RHR and WHR) using a portable digital pulse oximeter. RHR was recorded using a digital pulse oximeter before the shift began while workers were seated and resting.

WHR was similarly measured using the oximeter immediately after workers completed a continuous 30-minute cycle of their primary tasks to capture the peak physiological load. These measurements were synchronized with the three daily temperature recording sessions per worker, resulting in a total of 30 WHR data points per day across the 10 subjects. Post-intervention measurements occurred one week after exhaust fan installation. Notably, this study lacked a control group, and seasonal weather variations may have confounded the temperature results.

Data Processing and Path Analysis

The raw data collected were systematically analyzed using IBM SPSS software. The initial stage involved testing the MOQS instrument's validity and reliability. The validated ordinal responses were then transformed into interval data using the Method of Successive Intervals (MSI). At the same time, the recorded physiological data were processed to calculate the percentage of Cardiovascular Load (%CVL) for each operator. After data preparation, Path Analysis was conducted.

Because of the small sample size ($n = 10$), this structural modeling was treated as an exploratory path analysis aimed at identifying the dominant factors causing workplace stress to guide targeted engineering interventions, rather than establishing generalizable causal relationships. In this structural model, the four MOQS dimensions (organizational factors, equipment, physical environment, and personal attributes) are defined as exogenous variables, while fatigue is an endogenous variable.

Formulation of Engineering Controls

As a final step that distinguishes this study from the conventional macroergonomics literature, the coefficients obtained from the Path Analysis were evaluated to identify the most dominant root cause (critical path). Guided by this critical path, specifically the high thermal stress, the research proceeded to formulate physical engineering controls. The formulation of physical engineering controls focused on designing a mechanical ventilation system using 24-inch industrial centrifugal exhaust fans (suction capacity: $110 \text{ m}^3/\text{min}$).

The number of exhaust fans required was calculated mathematically. The production room is 25 m long, 15 m wide, with a main room height of 10 m and a gable roof height of 4 m. The total room volume comprises the volume of the main room (Equation 4) and the volume of the gable roof (Equation 5). The required number of exhaust fans is calculated based on a target air circulation time of 7 minutes, which is equivalent to approximately 8.5 Air Changes per Hour (ACH) and aligns with the industrial ventilation guidelines for heat-intensive production areas recommended by the

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 2019) (Equations 6 and 7).

$$V_{room} = L \times W \times H_1 \quad (4)$$

$$V_{roof} = \frac{1}{2} \times L \times W \times H_2 \quad (5)$$

$$V_{total} = V_{room} + V_{roof} \quad (6)$$

$$N = \frac{V_{total}}{C \times t} \quad (7)$$

Where:

V_{room}	=	Volume of the main room (m^3)	H_1	=	Height of the main room (m)
V_{roof}	=	Volume of the gable roof (m^3)	H_2	=	Height of the roof (m)
V_{total}	=	Total volume of the facility (m^3)	N	=	Required number of exhaust fans (<i>units</i>)
L	=	Length of the room (m)	C	=	Extraction capacity of the exhaust fan ($m^3/minute$)
W	=	Width of the room (m)	t	=	Air circulation time (<i>minutes</i>)

FINDINGS AND DISCUSSION

Evaluation of Work System Dimensions and Baseline Physiological Workload

The MOQS questionnaire is designed to identify the influence of four variables causing fatigue (Y) in the workplace, namely Organization (X1), Equipment (X2), the Physical Work Environment (X3), and Personal Factors (X4). The MOQS questionnaire validity test using Pearson's correlation coefficient showed that all items were statistically significant ($p < 0.05$), indicating that the questionnaire is valid.

In addition, the questionnaire demonstrated high internal consistency, as indicated by a Cronbach's alpha > 0.70 , confirming its reliability and allowing it to proceed to the path analysis stage. Initial assessments identified the physical environment as the most critical stressor. This subjective evaluation aligns with objective measurements showing a production floor temperature of 32.44°C , exceeding the recommended $18\text{--}24^\circ\text{C}$ comfort threshold. Combined with manual material handling, this thermal stress severely elevates physiological workload. Consequently, workers exhibit an average Cardiovascular Load (%CVL) of 32.97%, indicating fatigue that requires immediate improvements to the work system.

Path Analysis

The model's high variance ($R^2 = 0.985$) is likely inflated by overfitting due to the small sample size ($n=10$). As shown in Table 1, only the Physical Environment factor (X3) exerts a statistically significant direct effect on work-related fatigue ($\beta = 0.853$, $p < 0.05$). The Equipment factor (X2) exhibits a marginal but non-significant positive trend ($\beta = 0.474$, $p = 0.062$). Furthermore, both Organizational (X1) and Personal (X4) factors are statistically insignificant predictors of fatigue within this specific model ($p > 0.05$).

This lack of significance aligns with the study's focus on physical fatigue (%CVL, ambient temperature); organizational and personal factors typically drive mental, rather than physical, workload (Chireh et al., 2025; Gorsek et al., 2026). Conversely, cardiovascular responses are predominantly reactive to biomechanical and thermal stressors (Dias et al., 2023), confirming that environmental conditions constitute the critical path within the work system.

Table 1. Path Coefficients and Variable Contributions

Work System Variable	Path Coefficients (β)	Nilai t (t-value)	p-value (Sig.)	Significance (α)
Organizational (X1)	-0.304	-1.493	0.196	Not Significant
Equipment (X2)	0.474	2.399	0.062	Not Significant
Physical Environment (X3)	0.853	10.599	0.000	Significant
Personal (X4)	-0.080	-1.133	0.309	Not Significant

Proposed Engineering Controls and Impact Evaluation

To mitigate extreme thermal stress in a 4,500 m³ facility volume with a 7-minute air-change target, the system required six industrial centrifugal exhaust fans (110 m³/minute capacity). With three fans already operational, the team installed three additional 24-inch units directly above the frying and draining stations. This targeted mechanical ventilation successfully reduced the ambient production temperature from 32.44°C to 28.16°C.

Consequently, as shown in Table 2, the operators' average Cardiovascular Load (%CVL) decreased from 32.97% to 27.09% (a relative reduction of 17.83%). This post-intervention %CVL falls below the 30% threshold, reclassifying the physical workload into the 'no-fatigue' category. The observed post-intervention reduction in %CVL was likely driven primarily by the alleviation of the environmental heat load.

Because the intervention was limited to installing exhaust fans, it did not change the manual task demands, equipment, or work postures; thus, the physical workload remained constant. Therefore, the workers' cardiovascular recovery can be attributed directly to the improved thermal conditions and reduced heat stress, rather than any reduction in actual task-related exertion.

Table 2. Cardiovascular Load (%CVL) Score

Respondents	Cardiovascular Load (%CVL)	
	Pre-Intervention	Post-Intervention
R1	36.15%	27.27%
R2	40.82%	29.63%
R3	33.20%	28.93%
R4	36.53%	29.44%
R5	24.88%	25.23%
R6	36.34%	23.19%
R7	40.43%	28.40%
R8	31.16%	27.11%
R9	26.35%	27.67%
R10	28.07%	25.73%

CONCLUSIONS

This study concluded that the physical environment is the most dominant variable within the work system, exerting the strongest and only statistically significant direct effect on operators' physical fatigue. Implementing engineering controls by installing exhaust fans reduced the working environment temperature from 32.44°C to 28.16°C and lowered workers' average Cardiovascular Load (%CVL) from 32.97% to 27.09%.

This study contributes to integrating macro-ergonomic assessments and mechanical engineering interventions directly at the MSME level. Given the methodological constraints of the current study, future research should use standardized instruments, specifically the Wet Bulb Globe

Temperature (WBGT) index, to more accurately assess thermal stress.

LIMITATIONS & FURTHER RESEARCH

This study has several limitations. Firstly, the small sample size ($n=10$) limits the statistical power and generalisability of the findings. Second, we did not measure environmental thermal conditions using the standard Wet Bulb Globe Temperature (WBGT) index, limiting the precision of the results. Third, post-intervention measurements were taken only one week after the intervention, a very short period that may introduce bias into the post-intervention results.

Finally, the study did not address the equipment factor, which has substantial value in the model, because mechanization is costly for home-based industries. Future studies should explore practical interventions targeting the equipment factor to formulate a more comprehensive socio-technical and occupational safety model.

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