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Thermal Comfort Challenges in Construction: Evaluating the Role of Clothing Insulation and Physiological Responses

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ABSTRACT

Construction workers are frequently exposed to extreme outdoor temperatures, which impact their thermal comfort and physiological well-being. High air temperatures and inappropriate clothing insulation can lead to heat stress, reducing worker productivity and increasing health risks. This study aims to evaluate the relationship between clothing insulation, environmental conditions, and physiological responses to improve thermal comfort for construction workers. It contributes to the field by providing empirical data on how clothing insulation influences thermal comfort and physiological responses in a hot and humid construction environment. The findings highlight critical insights for ergonomic work wear design to mitigate heat stress. Data collected over four weeks at an active construction site. Environmental parameters, including air temperature, humidity, air velocity, and solar radiation, were measured using a weather station. Physiological responses, such as heart rate, core body temperature, and skin temperature, were monitored using wearable sensors. Subjective thermal comfort was assessed through structured questionnaires. Association between air temperature, clothing insulation, and skin temperature ($p < 0.05$). The average air temperature exceeded ASHRAE's comfort range, and workers experienced increased physiological strain due to high clothing insulation values. Most workers reported discomfort, with 75% indicating that the thermal environment was unacceptable. The study also confirmed that ergonomic clothing adjustments, such as lightweight, breathable fabrics and cooling vests, could enhance thermal comfort and reduce heat stress. These findings emphasize the importance of optimizing work wear to improve construction workers' well-being. Future research should explore innovative materials and cooling technologies to enhance thermal regulation in extreme working environments.

1. Introduction

Climate change has led to rising global temperatures, significantly affecting outdoor workers, particularly in tropical and equatorial regions (Acharya et al., 2018; IPCC, 2023). In Indonesia, urban centers such as Semarang have experienced increasing air temperatures, with recorded averages between 27.10°C and 29.60°C (BPS-Statistics Indonesia, 2023). These temperatures surpass the comfort range of 22.2°C – 26°C recommended for human well-being (Cui et al., 2013). High-temperature exposure increases the risk of heat-related illnesses among construction workers, including heat stress, dehydration, and cardiovascular strain (Kjellstrom et al., 2009). The combination of high air temperature, humidity, and solar radiation exacerbates thermal discomfort, reducing productivity and increasing occupational health risks (Ibrahim, 2016; Parsons, 2007).

One critical factor affecting thermal comfort is clothing insulation, which influences heat dissipation and sweat evaporation (S. Gao et al., 2021; Ogulata, 2007). Inappropriate workwear can trap body heat, leading to elevated skin temperature and discomfort (Das & Alagirusamy, 2010; Islam et al., 2023). Beyond insulation, other clothing characteristics such as color and fabric type also play crucial roles in thermal regulation. Light-colored garments reflect more solar radiation compared to dark-colored ones, reducing heat absorption (Ji et al., 2024; Menter & Hatch, 2003). Additionally, fabric properties like breathability, moisture-wicking capability, and fabric weave density significantly influence evaporative cooling and air permeability (Conley et al., 2018; Kim, 2021; Patanaik & Anandjiwala, 2011). Studies have shown that lightweight, breathable fabrics enhance thermal regulation, improving worker performance (Chan et al., 2016). In response to these challenges, the development of ergonomic clothing solutions, such as anti-heat stress uniforms and cooling vests, has been proposed to optimize thermal comfort in extreme environments (Chan et al., 2016; Guo et al., 2019).

Previous research on thermal comfort has primarily focused on controlled indoor environments (Enescu, 2017), military personnel operating in extreme conditions Tang et al., (2022) or urban residents in recreational settings such as parks (Li et al., 2024; Liu et al., 2025). While these studies contribute valuable insights, their applicability to outdoor construction workers, especially in equatorial climates, remains limited. Construction workers in tropical environments are exposed to prolonged periods of high solar radiation, humidity, and physical exertion, which significantly differ from the settings of previous studies (Dibek & Agra, 2024). Moreover, research has extensively examined factors like ambient temperature and humidity (Mora et al., 2021), but less attention has been given to how specific workwear characteristics, such as clothing insulation and fabric type, impact physiological responses and thermal comfort perception in real construction scenarios (C. Gao et al., 2011; Havenith & Heus, 2004; Szer et al., 2022). There is a notable gap in empirical data that integrates environmental factors, clothing insulation, and physiological indicators specific to construction workers in tropical outdoor conditions. This study addresses this gap by systematically analyzing the correlation between clothing insulation, environmental variables, and physiological responses, providing field-based evidence that reflects actual working conditions in equatorial climates.

The contribution of this research is to provide empirical evidence on the effects of clothing insulation on construction workers' thermal comfort, with a focus on physiological responses to extreme heat exposure. Unlike previous studies that primarily relied on controlled laboratory simulations or limited subjective surveys (Figueiredo et al., 2016; Havenith & Heus, 2004), this research employed a field-based, semi-experimental design that captured real-world conditions. Environmental parameters were measured in situ using a MISOL WS-2320 weather station and pyranometer, while physiological responses such as core body temperature, skin temperature, and heart rate were continuously monitored using wearable sensors (CORE Sensor and Fitbit Inspire 2). Additionally, subjective thermal perceptions were assessed using structured questionnaires, providing a comprehensive dataset. This approach allows for a more accurate understanding of how clothing insulation interacts with environmental conditions and physiological strain during actual construction activities in tropical climates. The findings enrich the existing body of knowledge by offering context-specific recommendations for workwear design and contribute to strategies aimed at improving occupational health and safety in high-temperature outdoor environments.

2. Method

This study was designed as an empirical field study to assess the impact of clothing insulation on the thermal comfort and physiological responses of construction workers in an equatorial climate. The primary objective was to analyze the correlation between environmental factors, clothing insulation, and physiological responses to provide practical recommendations for improving thermal comfort and reducing heat-related occupational risks.

2.1. Study Location and Participants

As shown in Fig. 1, The research was conducted at the construction site of the Integrated Laboratory Building, Faculty of Engineering, Diponegoro University, Semarang, Indonesia. Data collection spanned four weeks from November to December 2023.

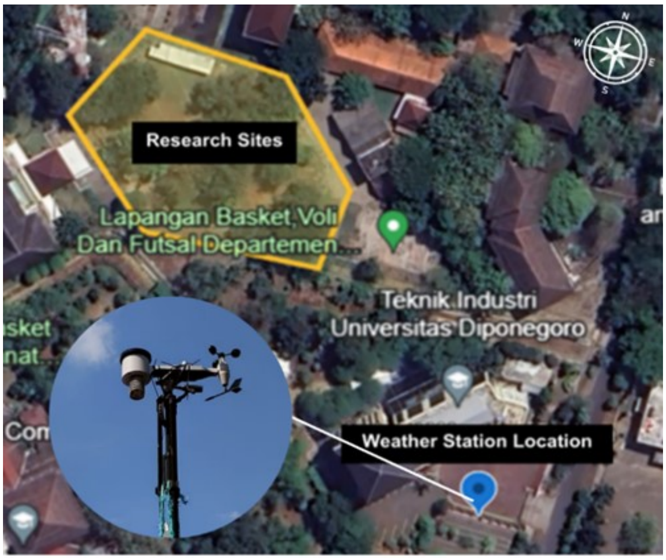

Fig. 1. Research Location and Weather Station Location

This site was selected due to its exposure to outdoor environmental conditions, which represent typical working environments for construction workers in Indonesia. A total of 20 male construction workers participated in this study. The inclusion criteria were: (1) at least 18 years old, (2) engaged in outdoor construction work, (3) residing in Semarang for at least 14 days to ensure physiological acclimatization to local climatic conditions, (4) no history of heat-related illnesses, and (5) not consuming caffeine or engaging in strenuous activities before data collection. Exclusion criteria included individuals with diagnosed cardiovascular diseases or congenital insensitivity to pain with anhidrosis (CIPA). Informed consent was obtained from all participants before data collection.

The research was conducted at the construction site of the Integrated Laboratory Building, Faculty of Engineering, Diponegoro University, Semarang, Indonesia. The construction site covers approximately 1,200 square meters and features a combination of open and semi-enclosed structures under active development. The terrain consists of bare soil and concrete foundations, with limited shading elements and high exposure to direct sunlight, making it an ideal setting for studying thermal conditions in outdoor environments. Scaffolding, steel frameworks, and stacks of construction materials such as cement and bricks were present across the site. The open design allowed for natural ventilation but also resulted in significant heat accumulation due to solar radiation.

Data collection spanned four weeks from November to December 2023, coinciding with the peak of the hot-humid season in Semarang. Approximately 35 construction workers were active on-site during this period. Of these, 20 male workers met the inclusion criteria and consented to participate in the study. The inclusion criteria were: (1) at least 18 years old, (2) engaged in outdoor construction work, (3) residing in Semarang for at least 14 days to ensure physiological acclimatization to local climatic conditions, (4) no history of heat-related illnesses, and (5) not consuming caffeine or engaging in strenuous activities before data collection. Workers who had diagnosed cardiovascular diseases or congenital insensitivity to pain with anhidrosis (CIPA) were excluded.

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The workforce was composed of laborers performing varied tasks, including manual material handling, structural assembly, concrete mixing, and site supervision. Although job roles varied, all participants selected for this study were involved in physically demanding outdoor activities to ensure consistency in exposure levels. Informed consent was obtained from all participants before data collection.

2.2. Research Design

A conceptual model Fig. 2, was developed to illustrate the research framework. The development of this model was based on a synthesis of previous studies that examined the relationship between environmental conditions, clothing insulation, physiological responses, and thermal comfort perception (Arsad et al., 2023; Budiawan & Tsuzuki, 2021; Chan et al., 2016; Damiati et al., 2016; Jin et al., 2017; Moohialdin et al., 2022; Ze et al., 2021). These references provided the theoretical foundation for identifying the variables and hypothesized interactions depicted in the model. Furthermore, this study extends the existing frameworks by integrating field measurements and subjective assessments specific to construction workers in tropical environments, thus enhancing the novelty and contextual relevance of the model.

In this study, environmental factors (air temperature, humidity, air velocity, and solar radiation), categorized as thermal comfort factors, were measured using a MISOL WS-2320 weather station as shown in Fig. 3. Clothing insulation, also part of thermal comfort factors, was evaluated through a structured questionnaire. Physiological responses were assessed using a CORE Sensor (for core body and skin temperature) and a Fitbit Inspire 2 (for heart rate monitoring). Meanwhile, subjective thermal comfort indicators including thermal sensation, comfort level, and acceptability were captured through a separate structured questionnaire to assess participant’s perceived thermal comfort.

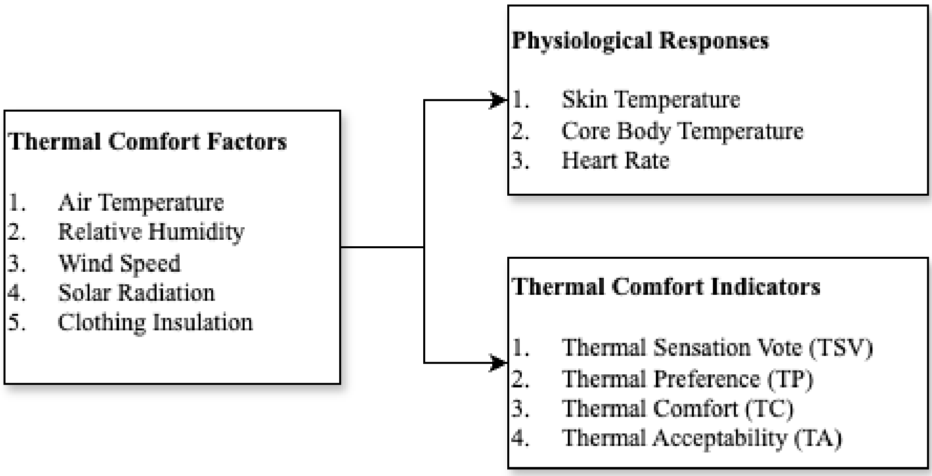

Fig. 2. Conceptual Model

(a) (b) (c)

Fig. 3. Research instrument: (a) MISOL WS-2320 Weather Station (b) CORE Sensor, (c) Fitbit Inspire 2

Environmental variables were measured using a MISOL WS-2320 weather station, selected for its affordability, portability, and capability to measure essential environmental factors such as temperature, humidity, wind speed, and solar radiation. This device has been widely used in field research for environmental monitoring in construction settings and other outdoor occupational studies due to its ease of setup and reliable performance (Parsons, 2014).

Physiological responses were assessed using two types of wearable sensors. Core body and skin temperature were measured using the CORE Sensor, which is a validated non-invasive device capable of continuously monitoring body temperature in dynamic field environments. Previous studies, including field applications for outdoor workers and athletes, have confirmed its accuracy and reliability (Khoshmanesh et al., 2021). Heart rate was monitored using the Fitbit Inspire 2, a wrist-worn consumer-grade fitness tracker that provides continuous heart rate monitoring with sufficient accuracy for field studies. Its use has been validated in occupational health research for real-time monitoring of cardiovascular strain during physical work (Mora et al., 2021).

2.3. Data Collection

A structured data collection approach was implemented to ensure a comprehensive understanding of the relationship between clothing insulation, environmental conditions, and physiological responses. The study involved real-time monitoring of environmental variables, physiological indicators, and subjective thermal comfort assessments. Data were gathered systematically during workers' active hours to capture their exposure to thermal stress in construction settings. The methodology incorporated a combination of instrument-based measurements and self-reported evaluations to enhance the reliability of findings. The following subsections describe the specific procedures and tools used for data collection in this study. To assess the thermal environment, four environmental variables were measured:

1. Air Temperature (Ta): Measured using a MISOL WS-2320 weather station
2. Relative Humidity (RH): Collected using the same weather station.
3. Wind Speed/ Air Velocity (AV): Measured at worker height levels to capture actual working conditions.
4. Solar Radiation (SR): Evaluated using a pyranometer to quantify direct heat exposure.

Measurements were conducted from 08:00 to 11:00 each day, representing peak working hours with significant heat exposure. As shown in Fig. 4, Fig. 5, Fig. 6, physiological responses were assessed using non-invasive wearable devices:

1. Core Body Temperature (T_c): Monitored using a CORE Sensor, a validated device for continuous temperature tracking. Prior to each measurement session, the device was checked following manufacturer guidelines to ensure sensor accuracy. Calibration was verified against reference temperature data during initial field setup.
2. Skin Temperature (T_{sk}): Measured at exposed body areas using the same sensor. Regular verification of sensor readings was performed to minimize drift or inaccuracies.
3. Heart Rate (HR): Recorded using a Fitbit Inspire 2 wrist-worn sensor, which captures real-time cardiovascular responses. Sensor performance was checked daily to ensure accurate data capture, and any anomalies were cross-verified with manual pulse checks at random intervals.

Data were continuously recorded while workers performed their regular tasks to capture realistic physiological responses under working conditions. Each worker's outfit's clothing insulation value (clo) was calculated based on ISO 9920 standards. Workers' attire was documented, and the insulation values were estimated based on existing standards for different fabric materials and layering combinations. Questionnaire data were used to validate self-reported clothing characteristics.

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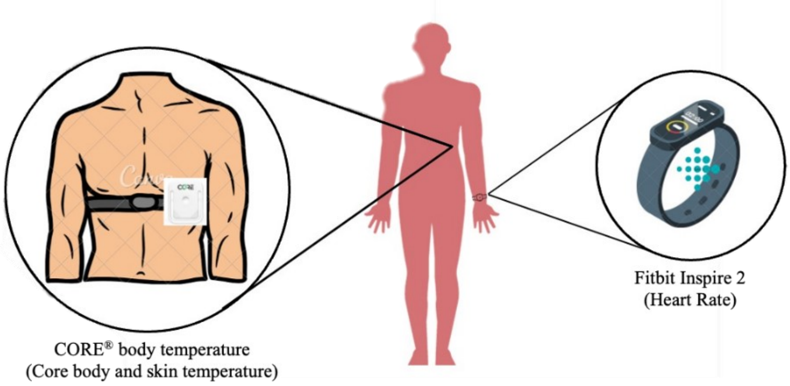

Fig. 4. Wearable device placement

Fig. 5. Installation CORE Sensor (Core Body and Skin Temperature)

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Fig. 6. Examples of Clothing Worn by Participants

A structured questionnaire was administered to evaluate workers’ perceptions of thermal comfort. The survey included the following scales:

1. Thermal Sensation Vote (TSV): 7-point ASHRAE scale (-3 = cold, 0 = neutral, +3 = hot).
2. Thermal Preference (TP): Preference for warmer, cooler, or no change.
3. Thermal Comfort (TC): 7-point scale ranging from very comfortable to very uncomfortable.
4. Thermal Acceptability (TA): Binary scale (acceptable/unacceptable).

2.4. Data Processing and Statistical Analysis

The collected data were systematically processed and analyzed using SPSS Statistics 22 to ensure accurate interpretation of findings. Descriptive statistical methods were employed to summarize key variables, including environmental conditions, physiological responses, and subjective thermal comfort perceptions, by calculating the mean, standard deviation, and overall data distribution. To examine potential relationships among these factors, Pearson correlation analysis was conducted, identifying significant associations between air temperature, clothing insulation, physiological responses, and perceived thermal comfort. Additionally, multiple linear regression modeling was applied to assess the predictive influence of clothing insulation on skin temperature and subjective thermal sensation, providing deeper insights into the extent to which insulation impacts workers' thermal experiences.

2.5. Ethical Considerations

This study adhered to ethical research guidelines, ensuring voluntary participation, data confidentiality, and informed consent. Ethical approval was obtained from the Health Research Ethics Committee, Faculty of Public Health, Diponegoro University under the ethical approval number 433/EA/KEPK-FKM/2024. The study protocol was reviewed and declared ethically appropriate based on the seven WHO 2011 ethical standards, which include social value, scientific validity, equitable distribution of risks and benefits, risk minimization, protection from coercion or exploitation, confidentiality and privacy, and informed consent, as referenced in the CIOMS 2016 guidelines. Participants were informed of their rights, including the right to withdraw at any stage without consequences. By maintaining strict adherence to these ethical principles, this study ensures compliance with international research standards and protects the well-being of all participants involved. By employing this comprehensive methodological approach, the study provides robust insights into the effects of clothing insulation on thermal comfort and physiological well-being in construction workers. The results aim to inform future workwear design improvements to enhance occupational safety in hot environments.

3. Results and Discussion

3.1. Respondent Characteristics

The study involved 20 male construction workers with an average age of 28.3 years (SD = 9.01), ranging from 19 to 46 years. All participants were actively involved in outdoor construction work and met the selection criteria to ensure acclimatization to local environmental conditions. The majority of workers (85%) had over two years of experience in construction, with job roles including manual labor, concrete mixing, steel framework assembly, and site supervision. Participants had resided in Semarang for an average of 24 months, supporting acclimatization to the local tropical climate. Educational backgrounds varied, with most having completed secondary education. The controlled sample selection process, which considered factors such as prior heat illness history and recent caffeine or strenuous activity avoidance, minimized confounding variables and enhanced the reliability of the findings.

3.2. Thermal Comfort Factors and Environmental Conditions

Measurements were conducted from 08:00 to 11:00 each day, capturing peak working hours under high-temperature conditions. During this time, workers typically performed continuous tasks with intermittent short breaks, including hydration pauses and occasional task-related pauses depending on work intensity and site conditions. While formal scheduled water breaks were not enforced, workers generally took short pauses averaging every 45 to 60 minutes, primarily for hydration and equipment adjustments. The average air temperature recorded during the study period was 30.92°C (SD = 0.88°C), exceeding ASHRAE's recommended comfort range of 25°C–28°C. Humidity levels averaged 64.49% (SD = 5.67%), with only four recorded values falling within the ASHRAE comfort limits. Wind speed averaged 0.74 m/s (SD = 0.14), which surpasses the recommended threshold of 0.5 m/s, potentially enhancing evaporative cooling. Solar radiation averaged 6,501.85 fc (SD = 967.36), contributing significantly to heat stress exposure.

Environmental data were collected continuously over the four-week research period, from 08:00 to 11:00 each working day, aligning with the peak activity and heat exposure hours at the construction site. Measurements for air temperature, relative humidity, air velocity, and solar radiation were recorded at 10-minute intervals using the MISOL WS-2320 weather station and pyranometer. The data presented in Fig. 7 represent the daily average values computed from these interval readings, aggregated across the monitoring period. This approach allows for capturing day-to-day variations while reflecting the typical environmental conditions experienced by the workers during their active hours on-site. These environmental patterns are characteristic of tropical regions, where climatic factors often fall outside globally accepted thermal comfort thresholds (Mora et al., 2021). Studies have reported that high ambient temperatures, coupled with elevated humidity and intense solar radiation in tropical climates, frequently exceed the recommended ranges for indoor and outdoor thermal comfort, leading to increased heat stress risks for workers (De Dear & Brager, 2002).

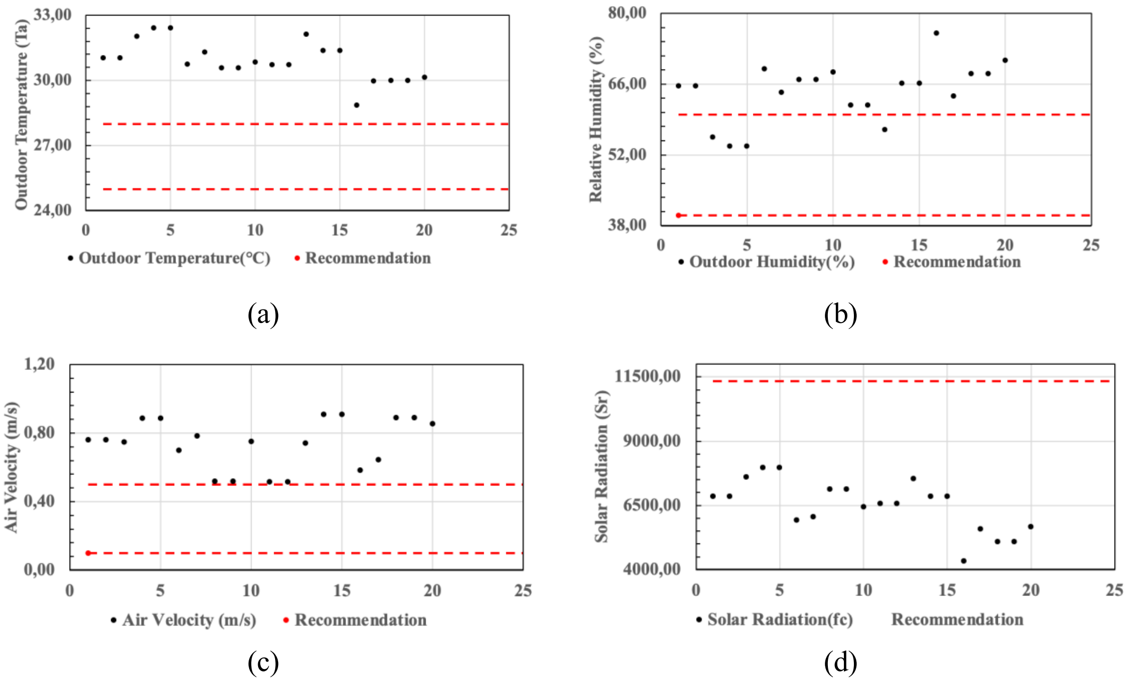

Fig. 7. Measured environmental parameters: (a) outdoor temperature, (b) relative humidity, (c) air velocity, and (d) solar radiation

In similar studies conducted in Southeast Asia, extreme humidity combined with elevated air temperatures has been shown to significantly increase thermal discomfort and risk of heat-related illness among outdoor workers (Acharya et al., 2018; Kjellstrom et al., 2009). In tropical cities such as Jakarta, Kuala Lumpur, and Manila, researchers have found that urban workers are frequently exposed to environmental conditions exceeding thermal tolerance limits, particularly during dry seasons (Ibrahim, 2016)

In Indonesia, construction sites often lack passive cooling interventions such as shading structures or optimized ventilation, resulting in workers being directly exposed to high ambient temperatures and solar radiation (Iqbal et al., 2022; Kjellstrom et al., 2009). Studies have reported that many construction sites in tropical developing countries, including Indonesia, prioritize structural progress over environmental modifications, leading to limited implementation of passive cooling strategies (Cramer et al., 2022). This exacerbates heat accumulation and reduces workers' ability to thermoregulate, especially when combined with impermeable clothing or personal protective equipment. The persistence of these extreme microclimatic exposures underscores the need for more context-specific thermal guidelines and work-rest schedules that consider local climate realities.

3.3. Physiological Responses and Clothing Insulation Effects

The physiological data showed that workers experienced notable increases in core body temperature and heart rate as a response to high environmental temperatures and clothing insulation. The average heart rate recorded was 96.30 bpm (SD = 11.28), exceeding the normal resting range of 60–80 bpm (Farias et al., 2023), suggesting an elevated cardiovascular load due to thermal stress. Core body temperature averaged 37.51°C (SD = 0.36°C), which falls within the acceptable physiological range of 36°C–38°C (Das & Alagirusamy, 2010). However, prolonged exposure to the upper limits of this range may still indicate significant thermal strain. Skin temperature averaged 35.11°C (SD =

0.51°C), with two participants showing values above the normal range (33°C–36°C), emphasizing the influence of high clothing insulation on heat retention (Makan et al., 2005). During data collection, clothing type and color were not controlled by the researchers; instead, observations recorded that most workers naturally wore standard construction attire consisting of long-sleeved shirts and long pants, predominantly in dark colors such as dark blue and black, aligned with common practices at the construction site. These clothing choices, combined with the environmental heat load, likely contributed to increased heat absorption and physiological strain. These physiological indicators reflect the body's effort to maintain homeostasis in a thermally stressful environment and closely align with patterns reported in other studies on outdoor workers in tropical regions (Chan et al., 2016). In such climates, elevated core and skin temperatures have been linked to reduced work capacity, dehydration risk, and impaired focus.

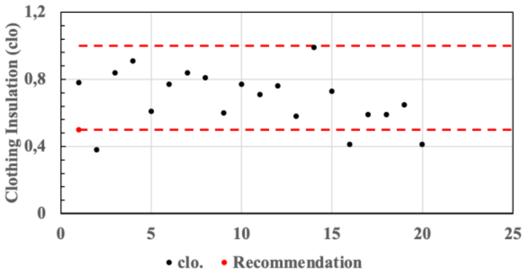

Fig. 8. Measured clothing insulation (clo) values

Clothing insulation plays a critical role in regulating skin temperature. As shown in Fig. 8, the average insulation value of the workers' attire was 0.69 clo, which is relatively high for tropical working environments. This insulation level contributed to increased skin temperatures, reducing the efficiency of natural heat dissipation mechanisms such as evaporative cooling and convective heat loss. Previous research suggests that insulation values above 0.5 clo in tropical settings can significantly delay heat loss and intensify thermal discomfort (Das & Alagirusamy, 2010).

3.4. Subjective Thermal Comfort Perception

According to Table 1, subjective thermal comfort assessments revealed that most workers perceived their working environment as uncomfortably warm. The Thermal Sensation Vote (TSV) results indicated that 45% of respondents felt "hot," while 25% rated their experience as "slightly warm." Only 10% of participants reported feeling neutral, and none reported a cool or comfortable sensation. Similarly, the Thermal Comfort (TC) scale showed that 30% of workers felt "uncomfortable," and only 20% described their thermal experience as "very comfortable." Thermal Acceptability (TA) results further confirmed discomfort, with 75% of respondents stating that their thermal conditions were unacceptable. This percentage aligns with trends identified in studies conducted in other tropical regions, such as Malaysia and Thailand, where outdoor workers consistently reported poor thermal comfort during hot seasons.

Table 1. Percentage of Thermal Comfort Perception

TA		TC		TP		TSV	
Scale	**%**	**Scale**	**%**	**Scale**	**%**	**Scale**	**%**
		Very Comfortable	20			Hot	45
		Comfortable	50			Warm	10
Acceptable	75	Slightly Comfortable	0	Prefer Warm	5	Slightly Warm	25
Unacceptable	25	Neutral	-	Neutral	0	Neutral	10
		Slightly Uncomfortable	0	Prefer Cool	95	Slightly Cool	10
		Uncomfortable	30			Cool	0
		Very Uncomfortable	0			Cold	0

These subjective results demonstrate a disconnect between current environmental conditions and workers' thermal needs. Importantly, they highlight the psychological strain imposed by continuous exposure to heat, which may affect cognitive performance, concentration, and, ultimately, productivity. Such insights are essential when designing worker-centered thermal comfort strategies in tropical construction environments.

3.5. Correlation Between Environmental, Physiological, and Thermal Comfort Variables

Statistical analysis using Pearson correlation was conducted to examine the relationships among environmental variables (air temperature, relative humidity, wind speed, and solar radiation), physiological responses (core body temperature, skin temperature, and heart rate), and subjective thermal comfort indicators (TSV, TC, and TA). The results in Table 2 revealed a significant positive correlation between air temperature and skin temperature ($r = 0.497$, $p < 0.05$), indicating that higher ambient temperatures tend to increase peripheral heat accumulation. Clothing insulation in Table 3 also showed a strong positive correlation with skin temperature ($r = 0.621$, $p < 0.01$), confirming that excessive insulation impairs the body's ability to dissipate heat, especially in high humidity. These findings align with prior research in hot-humid settings, where clothing insulation above 0.5 clo has been found to restrict evaporative cooling and elevate skin temperature (Das & Alagirusamy, 2010).

Table 2. Correlation between Environmental Conditions and Physiological Conditions

Environmental Condition	Physiological Conditions	Correlation Coefficient	Significancy
Ta	HR	0.151	0.524
	Tc	* 0.550	0.012
	Tsk	* 0.497	0.026
RH	HR	0.073	0.758
	Tc	-0.326	0.161
	Tsk	-0.370	0.108
Av	HR	0.048	0.841
	Tc	0.037	0.876
	Tsk	0,334	0.150
Sr	HR	0.145	0.541
	Tc	* 0.474	0.035
	Tsk	0.393	0.086

Table 3. Correlation between Clothing Insulation and Ohysiological Conditions

Clothing Insulation	Physiological Conditions	Correlation Coefficient	Significancy
clo	HR	-0.263	0.262
	Tc	0.282	0.228
	Tsk	** 0.621	0.003

Relative humidity showed a negative correlation with thermal acceptability ($r = -0.544$, $p < 0.05$) can be seen in Table 4, suggesting that higher humidity levels reduce workers' perception of a tolerable thermal environment. High moisture content in the air inhibits sweat evaporation, intensifying discomfort even under moderate air temperatures. Meanwhile, air velocity demonstrated a weak positive correlation with thermal comfort perception, likely due to its support of convective and evaporative cooling, although the observed wind speed remained insufficient to fully alleviate thermal discomfort.

These findings confirm that both environmental and personal factors interact to shape workers' thermal experiences. The strong correlations between skin temperature, clothing insulation, and subjective discomfort reinforce the importance of comprehensive heat mitigation strategies. These strategies should consider not only climate conditions but also the design of workwear, task duration, hydration management, and scheduled rest breaks in shaded or cooled areas.

The correlation analysis in Table 5, provides quantitative evidence that informs practical interventions to reduce heat stress and improve occupational comfort and health outcomes in outdoor construction settings.

Table 4. Correlation between Environmental Conditions and Thermal Perception

Environmental Condition	Thermal Perception	Correlation Coefficient	Significancy
Ta	TA	-0.341	0.141
	TC	**-0.602	0.005
	TP	-0.279	0.233
	TSV	0.358	0.121
RH	TA	0.341	0.141
	TC	** 0.668	0.001
	TP	0.199	0.399
	TSV	*-0.544	0.013
Av	TA	-0.010	0.966
	TC	-0.031	0.895
	TP	0.241	0.306
	TSV	-0.028	0.908
Sr	TA	-0.421	0.064
	TC	**-0.674	0.001
	TP	-0.319	0.170
	TSV	0.381	0.097

Table 5. Correlation between Clothing Insulation and Thermal Perception

Clothing Insulation	Thermal Perception	Correlation Coefficient	Significancy
clo	TA	-0.150	0.527
	TC	-0.240	0.309
	TP	-0.060	0.802
	TSV	0.143	0.547

3.6. Implications for Ergonomic Workwear and Thermal Comfort Optimization

The findings underscore the need for improved workwear designs tailored to hot and humid environments. The average clothing insulation level of 0.69 clo, while potentially suitable in cooler climates, is excessive for tropical settings, where insulation values above 0.5 clo have been shown to reduce the efficiency of natural heat dissipation (Das & Alagirusamy, 2010). Most standard construction uniforms are made from thick cotton or polyester fabrics, which are durable but often lack adequate breathability and moisture-wicking properties.

The results support the recommendation for adopting lightweight, moisture-wicking fabrics with optimized breathability to enhance heat dissipation. Previous studies have demonstrated that anti-heat stress uniforms with phase-change materials (PCM) and cooling vests can significantly lower skin temperature and improve comfort (Chan et al., 2016). Integrating such ergonomic solutions into construction workwear could effectively mitigate heat stress and enhance worker safety. The broader implications of these findings support the adoption of industry-specific guidelines for thermal workwear tailored to tropical environments. When combined with appropriate scheduling, hydration strategies, and shaded rest areas, clothing optimization can significantly reduce heat-related risks and improve worker safety, performance, and well-being on construction sites.

4. Conclusion

This study highlights the significant influence of environmental conditions and clothing insulation on the thermal comfort and physiological responses of construction workers in hot climates.

The findings confirm that excessive insulation impairs heat dissipation, leading to elevated skin temperature and increased cardiovascular strain. The correlation analysis further establishes strong relationships between air temperature, clothing insulation, and thermal comfort indicators, emphasizing the need for targeted interventions to improve working conditions. The results underscore the necessity of optimizing workwear to mitigate heat stress risks. Implementing breathable, moisture-wicking fabrics and cooling technologies, such as phase-change materials (PCM) and ventilated clothing, can enhance thermal comfort and reduce physiological strain. Adopting work schedules that minimize exposure to peak temperatures and integrating shaded rest areas can further support worker well-being. Future research should explore the long-term impacts of ergonomic clothing interventions on worker performance and health. Investigating a broader range of climatic conditions and expanding sample sizes would improve the generalizability of findings. Furthermore, technological advancements in smart fabrics with adaptive cooling properties present promising opportunities for enhancing occupational safety in high-temperature environments. By addressing clothing insulation and environmental factors, this study provides a foundation for improving thermal comfort standards and promoting sustainable working conditions in the construction industry. Integrating ergonomic workwear solutions is crucial in ensuring worker productivity and occupational health in challenging outdoor environments.

Supplementary Materials: No supplementary materials are available. All relevant data supporting the findings of this study are included within the manuscript.

Author Contribution: Wiwik Budiawan was responsible for project administration, supervision, and manuscript review. Vanri Apri Yanto Limbong contributed to conceptualization, data curation, and the initial draft preparation. Heru Prastawa assisted with formal analysis, visualization, and software. Dhimas Wachid Nur Saputra contributed to methodology, validation, and manuscript editing. All authors contributed to the interpretation of findings and approved the final version of the manuscript for submission.

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Conflicts of Interest: The authors declare no conflict of interest.

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