CLIMATE RISK ASSESSMENT:

HEAT-RELATED IMPACTS AND ADAPTATION STRATEGIES FOR DIGVIJAY TEXTILE FACTORY

2025

Risk Analytics Data Support

CLIMADA
Technologies

Disclaimer

Sustainable Living Lab was engaged by Digvijay Texfab Pvt Ltd to conduct a Climate Risk Assessment for the Sizing Unit of the Factory.

In preparing this document (the "Climate Risk Assessment"), SL2 has relied upon data gathered during the on-site visit, including environmental sensor readings, consultations with facility stakeholders (factory owner and workers) information provided by the Digvijay Texfab Pvt Ltd, and data from third-party sources such as CLIMADA Technologies (collectively, the "Supporting Information"). SL2 reserves the right to revise any analyses, observations, or recommendations referred to in this Report if additional Supporting Information becomes available after the date of this Report's release.

SL2 has assumed the supporting Information to be accurate and complete for the purposes of this Report. The data and information provided by Digvijay Texfab Pvt Ltd and third parties were not audited or independently verified for accuracy or completeness. Accordingly, SL2 expresses no opinion or other form of assurance regarding the Supporting Information. This report has been prepared for the exclusive use of the Digvijay Texfab Pvt Ltd, and SL2 does not assume responsibility for errors, omissions, or damages resulting from any person's reliance on this Report for any purpose other than the one for which it was prepared.

About the Author

Sustainable Living Lab

We are an ecosystem of organisations that design and implement solutions to navigate climate, societal, and digital transitions. Active across Asia, Europe and the US, with a footprint across 40 countries, we combine foresight, technology, and grassroots engagement to turn complex challenges into real-world outcomes where sustainability can be lived out.

SL2’s climate adaptation work will guide organisations through every stage of their climate adaptation journey, starting with helping them anticipate future climate scenarios through strategic foresight workshops and location-based risk analytics. We help assess specific climate vulnerabilities with tailored climate risk assessments. To align stakeholders, we develop collaborative adaptation strategies through target-setting, stakeholder-engagement sessions, and adaptation planning. We close the loop and adapt by implementing measurable climate solutions, offering on-ground implementation support, community programmes, and comprehensive training and capacity building.

At the core of SL2’s approach is the use of technology as a lever for sustainability, combined with a strong community-driven implementation model. SL2 builds resilient ecosystems by connecting data, innovation, and people, ensuring climate adaptation strategies are not only technically sound, but locally grounded, inclusive, and actionable.

Acknowledgment

We extend our sincere appreciation to all individuals and organisations who contributed to the successful completion of this assessment.

We are grateful to the management of the Digvijay Texfab Pvt Ltd for placing their trust in SL2 to undertake this important work, and for their continued support and transparency throughout the project. We also thank the workers and the owner of the factory for their generous cooperation, hospitality, and willingness to share their experiences, which provided invaluable insights for this study.

We wish to acknowledge CLIMADA Technologies for generously providing us with the required climate risk analytics data. The data played a crucial role in quantifying the potential climate impacts that went on to help us develop targeted recommendations and decisions to enhance the resilience of the factory.

Finally, we recognise the dedication and professionalism of the SL2 project team and thank our colleagues whose ongoing support and contributions made this report possible. This work represents a collective effort, and we are deeply appreciative of all who played a part.

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Executive Summary

Digvijay Texfab Pvt Ltd, a textile factory in Kishangarh, Rajasthan, faces significant operational and safety challenges from extreme heat, particularly within its sizing unit. This report, commissioned to analyse the factory's climate vulnerability, presents an evidence-based assessment of the occupational risks posed to its workforce and the compounding threats to its long-term viability. The analysis confirms that extreme heat, driven by both climate conditions and process machinery, creates hazardous working environments that undermine employee wellbeing and productivity, necessitating an urgent adaptation strategy.

Project Objective:

The central objective of this project is to provide Digvijay Texfab Pvt Ltd with a clear, actionable strategy to mitigate the severe risks of occupational heat stress. The strategy is designed to safeguard worker health, sustain productivity, and enhance the factory's overall resilience to current and future climate hazards. The foundation for this strategy is an on-site assessment grounded in detailed environmental data collection, thermal performance analysis, and direct stakeholder engagement.

Methodology:

Our methodology was designed to deliver an analysis of the climate risks by integrating three key approaches: on-site environmental measurements, direct stakeholder consultations, and future climate risk analysis. The on-site assessment involved deploying specialised sensors, including Wet Bulb Globe Temperature (WBGT) monitors to measure heat stress in accordance with ISO 7243 standards, and a thermal imaging camera to identify heat-generating hotspots from machinery. This quantitative data was contextualised through structured interviews with workers and management to understand the direct health impacts and operational challenges. Finally, to ensure our recommendations are forward-looking, we incorporated future climate analysis using data from CLIMADA Technologies, forecasting how heat, drought, and rainfall patterns are projected to intensify under various emissions scenarios (SSP1-2.6, SSP2-4.5, and SSP5-8.5).

Key Finding Highlights:

Our assessment identified vulnerabilities that place both the workforce and the facility's operations at significant risk. The findings indicate that operational and infrastructural deficiencies create a hazardous working environment.

- **Dangerous Occupational Heat Exposure:** The most immediate and severe risk is the prolonged exposure of workers to dangerous levels of heat. Our on-site measurements confirmed that WBGT values in the sizing unit reached as high as 33.1°C, a level exceeding international safety standards for strenuous work. This extreme heat is generated by process machinery, such as the boiler with surface temperatures over 200°C, and is trapped within the facility due to poor ventilation and heat-absorbent tin roofing.

- **Intensifying Future Heat Risk:** Climate projections indicate that these heat-related challenges will intensify significantly. By 2050, the region is forecast to experience a substantial increase in the number of days per year where the heat index exceeds the 41°C "Danger" threshold. The maximum temperature on the hottest day of the year is also projected to rise, compounding the thermal burden on workers and machinery.

- **Compounding Climate** Threats: Beyond extreme heat, the facility faces a high risk of persistent drought stress, which threatens the 60,000 litres of water required for daily operations. Furthermore, the analysis reveals an emerging threat from an increase in extreme rainfall events. The factory's current infrastructure is unprepared for localised surface flooding, posing a risk to machinery, raw materials, and operational continuity. The absence of a formal response plan for these events leaves the facility highly vulnerable.

- **Significant Health Impacts and Ineffective Relief:** Direct feedback from workers confirmed persistent discomfort and severe heat-related health issues, including excessive sweating, fatigue, headaches, and fainting. The assessment established a direct correlation between rising WBGT levels and a decline in work capacity throughout the day. Existing relief measures, such as exhaust fans and designated break areas, were found to be inadequate, as the rest areas are themselves subject to high ambient heat, preventing effective physiological recovery.

Introduction

1.1 Project Scope:

The primary scope of this project was to conduct a **comprehensive climate risk assessment** at a textile factory, “Digvijay Texfab Pvt Ltd” Kishangarh, Rajasthan. While this assessment broadly considered various climate-related threats, the project's **data-driven focus was specifically on extreme heat**, particularly within the sizing unit, which was identified as the area with the most significant worker exposure.

The core objectives were to conduct a **data-driven assessment of multifaceted climate impacts** and **develop a comprehensive climate risk framework**. This involved:

Data-Driven Assessment of Climate Impacts:

- **Worker Health & Safety:** Quantifying occupational heat stress by measuring the thermal environment using **Wet Bulb Globe Temperature (WBGT)** data, comparing it against international safety standards like **ISO 7243:2017**. This was complemented by qualitative surveys on workers' perception of heat and overall well-being, including self-reported health symptoms.

- **Productivity & Financial Impact:** Calculating empirical productivity loss by determining scientifically recommended work/rest schedules based on measured heat exposure and workload. The economic consequences of heat stress were also modeled by quantifying financial losses from reduced work capacity.

- **Operational & Asset Risk:** Evaluating the factory's physical infrastructure, including building materials (e.g., roofing), the adequacy of ventilation systems, and the vulnerability of critical machinery to high temperatures across relevant climate scenarios.

Developing a Comprehensive Climate Risk Framework:

- **Future Risk Projection:** Using collected data as a baseline to project future health and economic risks under various climate scenarios, enabling the factory to prepare for worsening conditions.

- **Short-Term Interventions:** Formulating immediate, actionable policy recommendations for management to reduce acute risks identified across climate hazards.

- **Long-Term Strategy:** Creating a detailed **Climate Adaptation Strategy** as a roadmap for infrastructure upgrades, policy changes, and fostering a culture of safety and resilience to climate impacts.

- **Risk Assessment Report:** Preparing a final report encompassing data analysis, inferences, overall climate risk assessment, and adaptation recommendations for the factory.

1.2 Site Overview

Located within the textile industrial area of Kishangarh, Rajasthan, the factory in assessment is a specialised pre-weave yarn preparation facility occupying a floor area of 8000 square meters. The factory's architecture is purpose-built, housing several interlinked operational units, including a boiler room, a warping section, and the sizing unit, all constructed within stone walls and tin roofs.

The physical arrangement of these units is detailed in the factory layout below (Image 1). The layout illustrates the positioning of the key operational areas, including the warping section, two sizing units, and the chemical mixers. The primary heat-generating zones, the steam-intensive sizing and chemical mixing units, are located centrally within the main building, while the wood-fired boiler is situated in an adjacent outdoor structure. The plan also indicates the location of the designated worker break area, which is positioned away from the main heat sources.

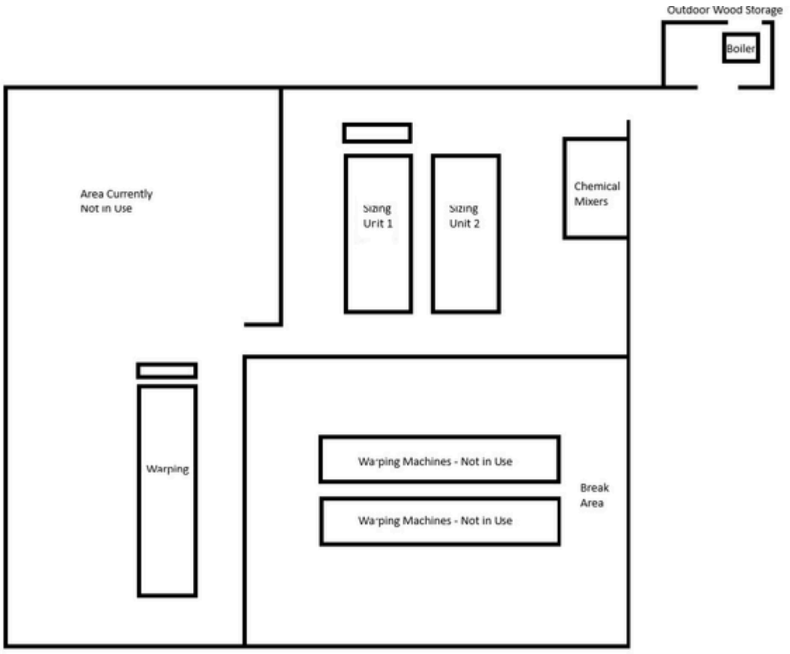

Image 1: Hand Drawn Layout of Digvijay Texfab

The facility's core business is the preparation of yarn for the weaving process. It does not produce finished cloth but instead processes raw yarn to create strengthened, weaver-ready beams for textile mills.

The production flow begins with raw cotton yarn, which arrives on cones from suppliers in Punjab. This yarn is first processed in the warping section. Here, hundreds of individual threads are drawn from a large rack called a creel and wound in a parallel sheet onto a large roller, creating what is known as a warp beam.

This beam of yarn is then transferred to the sizing unit. At this stage, the sheet of yarn is coated with a chemical mixture of maize starch, softeners, and wax. The preparation of this mixture and the sizing process itself are heavily reliant on steam. The boiler, fueled by burning wood, heats water to generate this essential steam, which is used to heat the chemical mix and the sizing machinery. This process, also known as sizing, enhances the yarn's strength and abrasion resistance, preparing it for the stresses of high-speed weaving.

Image 2: Warping Machine

Image 3: Boiler

The raw cotton yarn is highly sensitive to ambient conditions. Low summer humidity can make the thread stiff and prone to breaking. This is compounded by the process's extreme intolerance to water. The building features a unique "valley-like construction", specifically engineered to allow hot air to escape while making the unit rain-proof, as any water exposure at this stage is considered dangerous and will ruin the end product.

Image 4: Sizing Machine

This operational necessity for a dry, controlled environment has led to a workspace with minimal sunlight, thereby compounding the reliance on artificial systems. The machinery is sensitive to power fluctuations and risks getting damaged during power cuts. This risk is significant enough that the sizing unit is protected by its dedicated panel room with an unlimited power supply (UPS) device.

Image 5: Chemical Mixing Area

Image 6: Sizing Area with Minimal Sunlight and Ventilation

Water is a critical resource for the factory's operations. Historically, the factory has relied on groundwater for six months of the year and tanker water for the remaining six. The facility's daily requirement of 60,000 liters is now met entirely by groundwater. This is due to the recent changes in weather patterns, resulting in unusually heavy rainfall over the region. Water supply is indispensable, as it is essential for both the chemical mixing and steam generation vital to the sizing process. Without it, factory operations would cease.

The interconnected sensitivities create a challenging thermal environment. The sizing process generates significant heat and steam. Throughout the sizing area, several open pipes were observed releasing steam directly into the room, which, combined with the poor ventilation, significantly heated the environment. This heat is only partially managed by a single steam hood installed above one of the machines. Workers unanimously describe the ventilation as "bad," "poor," and "not good," with some noting that the low roof height creates a suffocated feeling. While management plans to install 20 new ventilators, another proposal to install a transparent roof to save on lighting costs poses a serious risk of trapping heat and worsening conditions.

The entire operation is deeply entrenched in its current location. Relocating the facility would be difficult, both in terms of time and the large costs required to set up the specialised equipment elsewhere. This immobility underscores the importance of adapting the existing site, which is operated each shift by a team of approximately eight workers who are at the forefront of these operational and environmental challenges.

Image 7: Open Pipes Releasing Steam

1.3 The Heat Challenge

In Kishangarh, the temperature typically varies from 9°C to 39°C, depending on seasons. The hottest time of year is from mid-April to early July, with an average daily high temperature above 36°C. The cool season lasts from early December to mid-February, with an average daily max temperature below 25°C. The monsoon, or wet season, in Kishangarh is from July to August. During this time, the weather is hot and generally cloudy. The most rain falls in July and August, with an average of over 200 mm of rain each month.[1]

The challenge of heat at the Kishangarh textile factory is not a distant threat but a daily reality. It is characterised by intense, oppressive heat that workers endure in critical areas like the boiler room, chemical mixing station, and the sizing unit. On-site measurements tell a stark story, with Wet Bulb Globe Temperature (WBGT) readings climbing to hazardous levels of 32°C and 33.1°C, far exceeding the established safety threshold of 26°C for strenuous work.[2]

Workers experience significant discomfort and health issues due to the heat in the factory. Many report excessive sweating, thirst, fatigue, and headaches. Two of the surveyed workers reported having faced severe symptoms like fainting, nausea, or vomiting. A senior employee relayed that the factory (built in 2009) wasn't designed for today's climate. The ventilation system doesn’t suffice anymore due to rising temperatures and nearby development. The workers concur, describing a suffocating sensation. A worker stationed in the boiler room reported - “even the winds are hot during the day”.

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[1] https://weatherspark.com/y/108714/Average-Weather-in-Kishangarh-Rajasthan-India-Year-Round#google_vignette

[2] https://cdn.standards.iteh.ai/samples/67188/5a4c5553da5945aa872478c36755cded/ISO-7243-2017.pdf

This daily struggle is only a prelude to a more severe future. Climate projections as given by Climada for Kishangarh, using the year 2000 as a baseline, indicate that this reality is set to intensify significantly by 2050. The heat will only become more frequent and severe.

Figure 1 provides a summary of projected increases in extreme heat conditions, including the number of days classified under "danger" and "extreme caution" heat index levels, as well as the anticipated rise in peak annual temperatures.

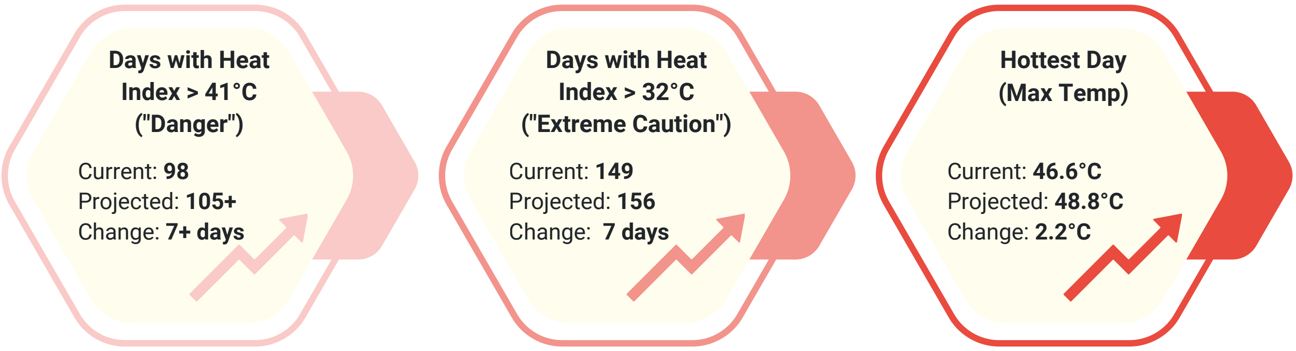

Figure 1: Projected Increases in Extreme Heat Indicators

The current heat in the factory, which is already testing the limits of both employees and the building's design, is set to worsen significantly. Today's struggles are just a preview of a much hotter and more hazardous future.

Methodology

2.1 Baseline Climate Data Collection

The project's initial phase began with a scoping exercise to **identify critical climate risks** for the Kishangarh textile factory. This involved a broad investigation of potential climate hazards, such as **extreme heat, water scarcity, and abundant precipitation**. This approach ensured that subsequent analysis would focus on the most relevant threats to the factory's operations and workforce.

This investigation was structured around a three-part assessment:

- **Historical Data Analysis:** Meteorological data for the Kishangarh region was reviewed to understand past patterns and the frequency of extreme weather events.
- **Stakeholder Engagement:** Structured interviews were conducted with the factory's management, operations staff, and floor supervisors. They documented their direct experiences with past climate-related challenges, including production disruptions, machinery performance issues, and impacts on worker health and safety.
- **Future Climate Modeling:** To identify and anticipate escalating threats to the facility, future climate trend data was analyzed using third-party risk analytics from CLIMADA Technologies across several emission scenarios.

Based on this integrated analysis, **extreme heat was concluded to be the primary hazard**. It was prioritised due to its significant potential to cause substantial harm to **worker well-being**, damage **inventory and machinery**, and disrupt **production schedules**.

2.2 Use of Third-Party Risk Analytics: CLIMADA Technologies

Data Provider and Role

This climate risk assessment incorporates third-party climate risk data and analytics provided by CLIMADA Technologies, a recognised provider of physical climate hazard modelling. CLIMADA Technologies supported this assessment by supplying asset-level and geographic-level projections of physical climate risk. Their data was instrumental in evaluating potential exposure and impact from climate-related hazards under various future climate scenarios.

Overview of Data and Methodology

The risk data applied in this assessment includes hazard maps, risk ratings, and climate indicators related to acute and chronic hazards such as heat waves, flooding, tropical cyclones, and windstorms. These outputs were generated using downscaled climate projections and asset exposure data, in combination with standardised vulnerability assumptions.

The methodology employed by CLIMADA Technologies reflects established best practices in scenario-based climate risk assessment. Key features of the approach include:

- Use of downscaled, bias-corrected climate data derived from CMIP6 models (e.g. NASA NEX-GDDP-CMIP6)
- Alignment with officially recognised IPCC scenarios (SSP1-2.6, SSP2-4.5, SSP5-8.5) for the years 2030, 2050, and 2080
- Application of over 170 climate indicators to assess hazard frequency, intensity, and change over time
- Generation of standardised risk ratings to support cross-hazard and cross-scenario comparison
- Estimation of financial impacts for selected hazards using vulnerability functions and metrics such as Average Annual Loss and Return Period Loss

Transparency, Limitations, and Replicability

The scope of CLIMADA Technologies' analytics is defined by the resolution and availability of climate projection data, coverage of hazard types, and model structure as of 2025. While the detailed computational framework remains proprietary, the approach is consistent with international standards such as those outlined by the Task Force on Climate-related Financial Disclosures (TCFD).

Due to the confidential nature of certain modelling components, full replication of the results is not possible. However, steps have been taken to promote transparency and support interpretation, including:

- Documentation of key data inputs, climate scenarios, and assumptions used in this report
- Clear statement of analytical boundaries and time horizons
- Cross-validation of selected results against available public datasets and sector benchmarks, where feasible

2.3 Baseline Heat Data Collection

The heat risk assessment at the Kishangarh textile factory was built upon a multi-layered methodology, designed to provide a detailed understanding of the heat challenge. This holistic approach combined a physical assessment, physiological monitoring, and worker surveys, all anchored in internationally recognized standards and risk assessment frameworks to create a robust evidence base for the findings.

The investigation commenced with a detailed reconnaissance of the factory. To structure this physical assessment, the team drew upon established risk management principles outlined in the "Climate Adaptation Playbook" by Sustainable Living Lab (SL2) Group. This guide integrates core aspects of the FEMA risk assessment framework with the international standards for climate adaptation, ISO 14090 and ISO 14091. This structured approach allowed for a systematic evaluation of the building's vulnerabilities, ranging from heat-absorbent tin roofs and stone walls to the specific design of ventilation systems and the operational layout of operational areas such as the sizing unit and boiler room.

Image 8: Building Recce with Factory Owner

A three-sensor toolkit, as detailed in the table below, was deployed to quantify the thermal environment and its impact on the workforce. This allowed for the simultaneous measurement of personal heat exposure, radiant heat from surfaces like machinery, and ambient outdoor baseline conditions. This integrated data approach ensured a holistic and accurate assessment of the factory's thermal load.

Table 1: Technical Specifications of the Sensors

Sensor Name / Model	Primary Use / Purpose	Key Specifications	Image
HTC HD-01 Heat Stroke Meter	Used for personal heat exposure monitoring. This wearable sensor measures Air Temperature, Humidity, and Wet Bulb Globe Temperature (WBGT) in accordance with the ISO 7243 standard.	- Air Temp Accuracy: ±0.6°C- Humidity Accuracy: ±5%RH- WBGT Accuracy: Based on a ±3.6°F variance- Sampling Rate: Every 20 seconds	

Sensor Name / Model	Primary Use / Purpose	Key Specifications	Image
UNI-T UTi260B Thermal Camera	Used to measure radiant heat from surfaces. This handheld camera identified and quantified thermal hotspots like machinery.	- Temperature Range: -20°C to 550°C- Accuracy: ±2°C- Thermal Sensitivity: <50mK- IR Resolution: 256×192 pixels	
UNI-T UT333 Digital Thermo-Hygrometer	Used to measure outdoor ambient conditions. This provided a baseline for outdoor temperature and humidity to compare against indoor measurements.	- Temperature Range: -10 to 60°C- Temperature Accuracy: ±1.0°C- Humidity Accuracy: ±5%RH	

To capture the full spectrum of heat exposure, WBGT Monitors were placed on a diverse cross-section of the workforce, ensuring a mix of roles, metabolic rates (work intensities), and factory locations. This included:

- A worker operating the sizing machine, to measure direct exposure to the process-generated steam and heat.
- A worker in the chemical mixing area, who was exposed to high radiant heat from large mixing containers and whose tasks involved periods of heavy lifting, representing a high and variable metabolic load.
- A worker in the boiler room, to capture the intense, radiant heat from the boiler itself, a location consistently identified by workers as one of the hottest and most physically demanding areas in the factory.
- A female cleaning staff member, whose duties shifted from active cleaning in the morning to more stationary work in the afternoon, allowing for an assessment of heat stress across different activity levels within a single shift.

Image 9: WBGT Sensor on Female Worker

Image 10: WBGT Sensor on a Worker in the Chemical Mixing Area

Image 11: WBGT Sensor on a Worker in the Boiler Area

Wearable Wet Bulb Globe Temperature (WBGT) monitors were deployed, affixed to workers' arms with adjustable straps. The sensors automatically captured environmental data at 20-second intervals, offering a continuous and granular dataset. For analytical purposes, these readings were subsequently aggregated and logged at hourly intervals.

To complement the quantitative environmental monitoring, structured one-on-one surveys were administered to all participating workers. The Qualitative Productivity Survey was rigorously developed with reference to established socioecological frameworks from existing occupational heat stress literature.[3] [4] [5] [6] This approach enabled an in-depth examination of heat exposure influences across individual, interpersonal, and organisational domains. The resulting qualitative data yielded critical insights regarding workers' experiences with heat-related symptoms, perceptions of workplace ventilation quality, and the broader effects of heat exposure on well-being and productivity.

All quantitative survey metrics and WBGT safety thresholds applied during analysis were directly benchmarked against the ISO 7243:2017 standard, ensuring scientific rigor and alignment with internationally recognized best practices throughout the assessment process.

2.4 Heat Analysis and Modelling

Following the data collection phase, the analysis was conducted using a step-by-step application of the ISO 7243:2017 standard titled "Ergonomics of the thermal environment: Assessment of heat stress using the WBGT (Wet Bulb Globe Temperature) index."[7] This approach enabled the transformation of raw environmental measurements into a consistent and quantifiable indicator of physiological heat stress risk.

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[3] https://www.undp.org/publications/climate-change-and-labor-impacts-heat-workplace

[4] https://iopscience.iop.org/article/10.1088/1755-1315/200/1/012053

[5] https://www.researchgate.net/publication/360275146_A_qualitative_study_of_the_working_conditions_in_the_readymade_garment_industry_and_the_impact_on_workers'_health_and_wellbeing

[6] https://pubmed.ncbi.nlm.nih.gov/26729144/

[7] https://cdn.standards.iteh.ai/samples/67188/5a4c5553da5945aa872478c36755cded/ISO-7243-2017.pdf

- **Classification of Worker Activity Levels:** Each worker's physical activity was classified into a metabolic rate category (for example, 'Moderate' or 'High') based on direct observation of routine job tasks. This classification followed the guidelines provided in ISO standards relevant to thermal ergonomics.

- **Adjustment of Measured WBGT Values:** The WBGT readings collected from on-site environmental sensors were adjusted to reflect the insulating properties of the clothing worn by workers. This was done by adding a Clothing Adjustment Value (CAV), as specified in ISO 9920 tables,[8] to calculate the effective WBGT for each individual.

- **Comparison with Reference Limits:** For every hourly reading, the effective WBGT was compared against the specific reference limit defined in ISO 7243:2017. These limits are based on the estimated metabolic rate and acclimatisation status of the worker. An exceedance was recorded if the effective WBGT surpassed the corresponding reference limit.

- **Identification of Threshold Exceedances:** Any instance of an effective WBGT exceeding the ISO threshold was classified as a heat stress exceedance. These events indicate hazardous working conditions that require mitigation according to ISO 7243 guidance.

- **Calculation of Work-Rest Requirements:** Using the ISO standard's recommended work-rest cycles, the number of rest minutes required per hour was calculated for each job role experiencing threshold exceedances. These values were then used to estimate productivity losses attributable to heat stress.

- **Integration of Climate Projection Data:** To evaluate how current heat risks may change under future climate conditions, the assessment incorporated projection data from the CLIMADA Technologies platform. Downscaled data specific to the factory's location were analysed, comparing a historical baseline (year 2000) with a future projection (year 2050) under a moderate emissions scenario (SSP2-4.5).

- **Selection of Key Heat Risk Indicators:** The following climate indicators were used to quantify the projected changes in heat exposure:
    - Annual number of days with a heat index above 41°C ("Danger" level)
    - Annual number of days with a heat index above 32°C ("Extreme Caution" level)
    - Maximum daily heat index projected for the year

- **Contextualisation of Future Risk:** The projected increase in both the frequency of high-risk heat days and the severity of extreme heat events was used to contextualise current findings. This supports the conclusion that heat-related operational and financial risks are likely to intensify in the absence of targeted adaptation measures.

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[8] https://cdn.standards.iteh.ai/samples/39257/0cb19bbb84214a03b53c77d076dc77f8/ISO-9920-2007.pdf

2.5 Productivity Loss Modelling

A forward-looking model was developed to estimate the financial implications of rising heat stress under future climate scenarios. This model leverages on-site environmental and production data to quantify how changes in temperature will affect operational performance and financial outcomes at the factory.[9] [10] [11] [12]

The first step was to establish the **current financial impact of heat**. Using the hourly effective WBGT data and the corresponding work/rest schedules mandated by ISO 7243:2017, the current average required rest time for the Sizing and Chemical roles was calculated to be 15.7 minutes per hour. This translates to a baseline hourly productivity loss of 26.1% on hot days. This percentage was then applied to the factory's hourly production value to quantify the financial loss incurred during a single high-heat day under current conditions.

The second step involved creating a **site-specific climate projection model**. By correlating the on-site sensor data for outdoor air temperature with the indoor effective WBGT, a precise relationship was established for this specific factory environment. This analysis yielded a slope of 0.4195, meaning, for every 1°C rise in outdoor temperature, the indoor effective WBGT increases by approximately 0.42°C.

This site-specific model was then used to **project future indoor heat stress**. The projected 1.6°C rise in outdoor temperature for the region by 2050 (from the CLIMADA SSP245 scenario) was applied to the calculated slope. This resulted in a projected future increase of **0.67°C in the indoor effective WBGT** that workers will experience.

Finally, this future heat scenario was translated into a **projected financial loss**. According to the ISO 7243:2017 work/rest tables, the projected 0.67°C increase in effective WBGT is significant enough to push workers across the next safety threshold, mandating an additional **10 minutes of rest per hour**. This increases the total required rest to 25.7 minutes per hour, elevating the future hourly productivity loss to 42.83%. This value was used to calculate an increased financial loss per hour of the hot day shift. This updated daily loss figure was then multiplied over the projected number of "danger" days for the year 2050 to arrive at the final projected annual financial loss.

2.6 Adaptation Strategy

To ensure a robust, transparent, and strategically aligned approach to selecting the most suitable heat adaptation solutions, the **Multiple Criteria Decision Analysis (MCDA)**[13] was chosen. The objective was to move beyond subjective assessments and create a data-driven framework for decision-making.

The MCDA process was conducted through a series of structured steps, designed to integrate technical data, financial considerations, and stakeholder priorities into a single, coherent analysis.

[9] https://www.researchgate.net/publication/360275146_A_qualitative_study_of_the_working_conditions_in_the_readymade_garment_industry_and_the_impact_on_workers'_health_and_wellbeing_

[10] https://www.emerald.com/ijppm/article/70/3/507/166122/Heat-related-productivity-loss-benefits-derived-by_

[11] https://www.researchgate.net/publication/320563157_Performance_loss_among_workers_due_to_heat_stress_in_high-temperature_workplaces_

[12] https://pmc.ncbi.nlm.nih.gov/articles/PMC4221496/_

[13] https://www.sustainablelivinglab.org/climate-adaptation-playbook/#/

Step 1: Identification of Potential Solutions: The first step was compiling a list of potential heat adaptation solutions. This list was developed based on a review of industry best practices, academic research, and solutions specifically relevant to the operational context of a textile factory.[14] [15] [16] [17] The identified solutions ranged from low-cost administrative controls to more significant capital-intensive engineering projects.

Step 2: Stakeholder Engagement and Vetting: A critical component of this methodology was direct stakeholder engagement. A detailed consultation was conducted with the business owner to review the practicality and operational relevance of each proposed solution. This discussion ensured that the options being evaluated were not only theoretically sound but also feasible within the specific constraints and working environment of the factory. This collaborative vetting process was essential for grounding the analysis in reality.

Step 3: Establishing Evaluation Criteria: Four key criteria were established to form the basis of the evaluation. These criteria were chosen to provide a holistic assessment of each solution:

- **Economic Efficiency:** The cost-effectiveness of the solution, balancing implementation costs against long-term financial benefits.
- **Technical Feasibility:** The practicality of implementing the solution, considering complexity, required expertise, and potential disruption to operations.
- **Environmental Impact:** The wider environmental consequences of the solution, including co-benefits like reduced emissions.
- **Social Acceptability:** The likelihood that the solution would be well-received by employees, contributing to a safer and more comfortable working environment.

Step 4: Scoring the Solutions: Each vetted adaptation solution was scored on a scale of 1 to 10 against the four criteria, where a higher score indicated a more favourable performance. This scoring was based on the qualitative and quantitative research undertaken for each solution, including case studies and product specifications.

Step 5: Weighting the Criteria via Stakeholder Alignment: Recognising that not all criteria are of equal importance, weights were assigned to each to reflect the factory's strategic priorities. This crucial step was also conducted in close consultation with the factory owner to ensure the final ranking would align with their primary objectives. The agreed-upon weights were as follows:

- **Economic Efficiency:** 40%
- **Technical Feasibility:** 30%
- **Social Acceptability:** 20%
- **Environmental Impact:** 10%

These weights signify a strong emphasis on financial viability and practical implementation, followed by a significant consideration for worker well-being and a secondary focus on environmental benefits.

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[14] https://pmc.ncbi.nlm.nih.gov/articles/PMC4462038/

[15] https://www.researchgate.net/publication/323402530_PERFORMANCE_ASSESSMENT_AND_COST_ANALYSIS_OF_PIPING_INSULATION_FOR_STEAM_DISTRIBUTION_SYSTEM_IN_DYEING_AND_PRINTING_MILL

[16] https://www.researchgate.net/publication/328201452_Workplace_Heat_Exposure_Management_in_Indian_Construction_Workers_Using_Cooling_Garment

[12] https://www.scribd.com/document/419370088/10WasteHeatRecoveryinBoiler-pdf

Step 6: Calculating the Prioritised Ranking: The final step involved calculating a total weighted score for each adaptation solution. This was achieved by multiplying the score for each criterion by its assigned weight and then summing these figures.

The resulting total weighted score allowed for each solution to be ranked from highest to lowest. This final, prioritised list provides a clear and defensible roadmap for investment and implementation, ensuring that resources are directed towards the most effective and strategically aligned adaptation measures.

Findings: current heat risk profile

The collected data provided a complete heat risk profile, combining subjective worker feedback with objective environmental measurements. This analysis synthesises these data streams to identify where and when the heat risk is greatest, and who are most vulnerable. The analysis identifies the primary heat sources and then assesses the impact on the factory environment and workers.

3.1 Identifying Key Sources of Heat

The factory's heat-related challenges originate primarily from its machinery. While worker feedback was valuable in identifying general hotspot areas, sensor data enabled a more precise analysis by pinpointing specific sources of thermal load within the facility.

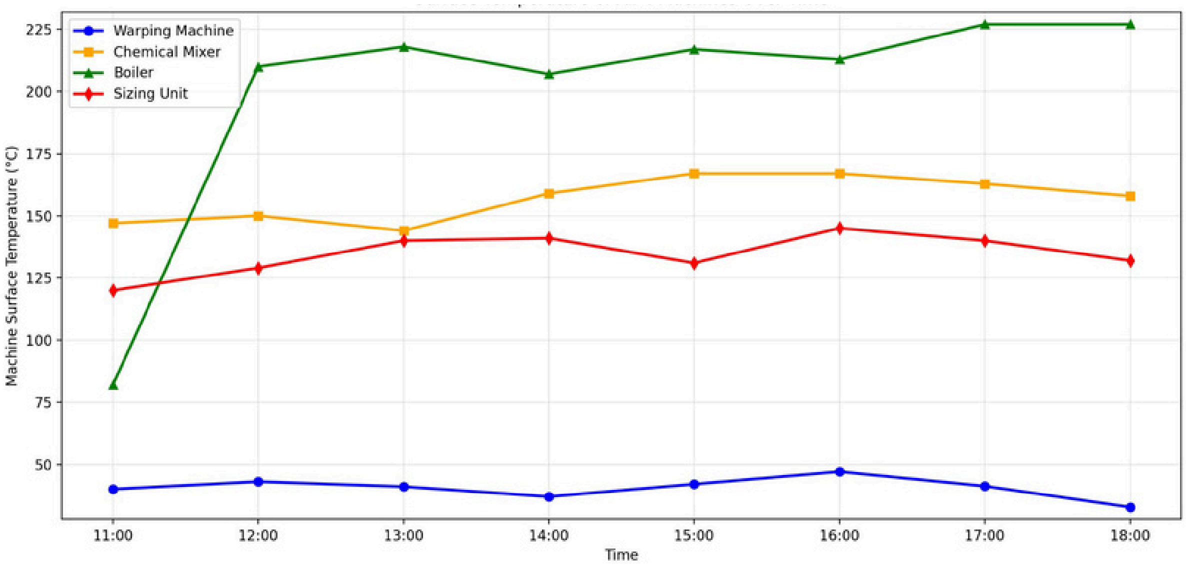

Figure 2: Surface Temperature of All 4 Machines Over Time

The '**Surface Temperature of All 4 Machines Over Time**' chart plots the radiant heat emitted directly from the factory's core equipment. The graph reveals a critical finding: the machinery acts as a set of powerful, relentless heaters. The Boiler is the most significant source, with its surface temperature soaring to over 200°C within an hour of starting and remaining above that level for the entire day, peaking at a staggering **227°C**. The Chemical Mixer and Sizing Unit are also major contributors, consistently operating at surface temperatures of **167°C** and **145°C**, respectively.

This intense radiant heat directly impacts the immediate environment, which is illustrated in the '**Temperature Around All 4 Machines Over Time**' chart.

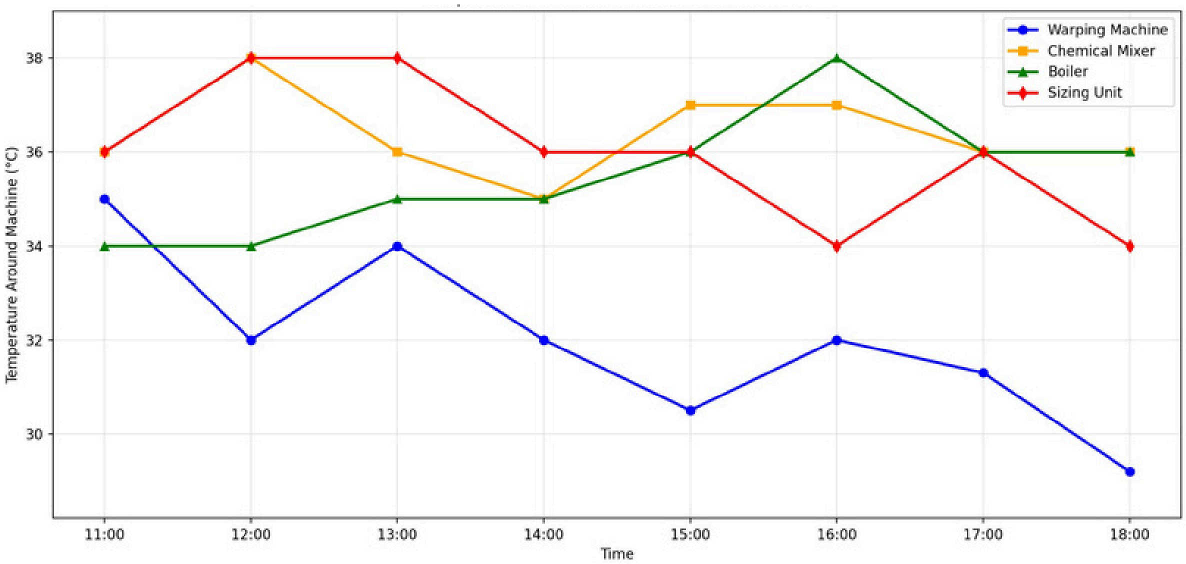

Figure 3: Ambient Air Temperature Aorund All 4 Machines Over Time

This chart shows the ambient air temperature in the direct vicinity of each machine. The findings are clear: the air temperature around the Sizing Unit, Boiler, and Chemical Mixer consistently remains between 34°C and 38°C during peak hours. This demonstrates that workers in these areas are not just in a hot room; they are working in close proximity to what are essentially large industrial ovens, creating dangerously hot microclimates.

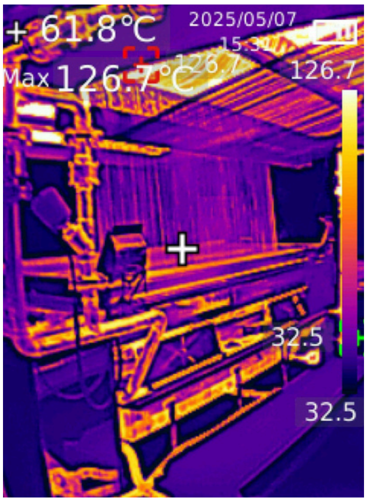

Image 12: Thermal Image of Sizing Unit

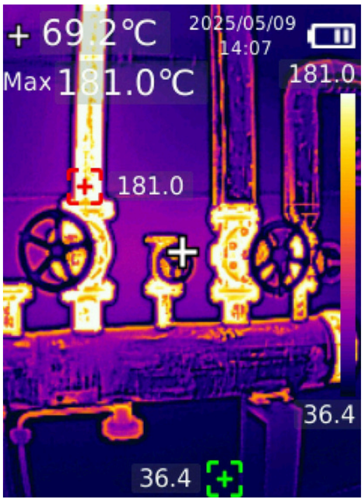

Image 13: Thermal Image of Chemical Area

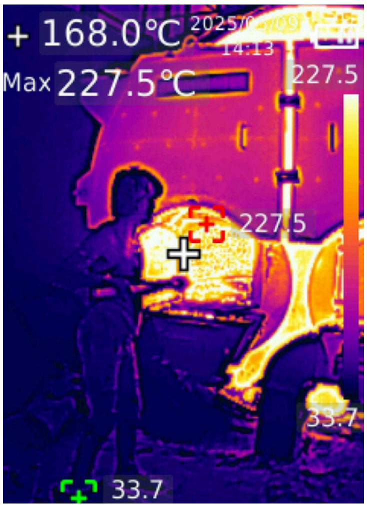

Image 14: Thermal Image of Boiler Unit

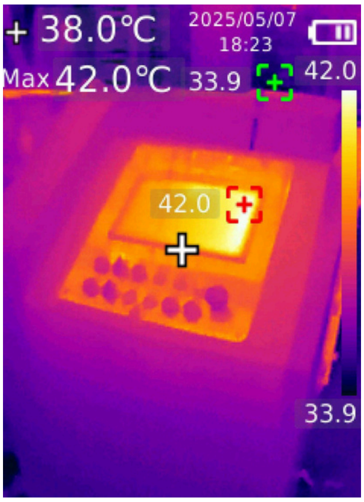

Image 15: Thermal Image of Warping Machine

3.2 The Environment: Mapping the Factory's Thermal Landscape

The heat generated by the machinery does not remain contained. It radiates outwards, influencing the air temperature experienced by operators.

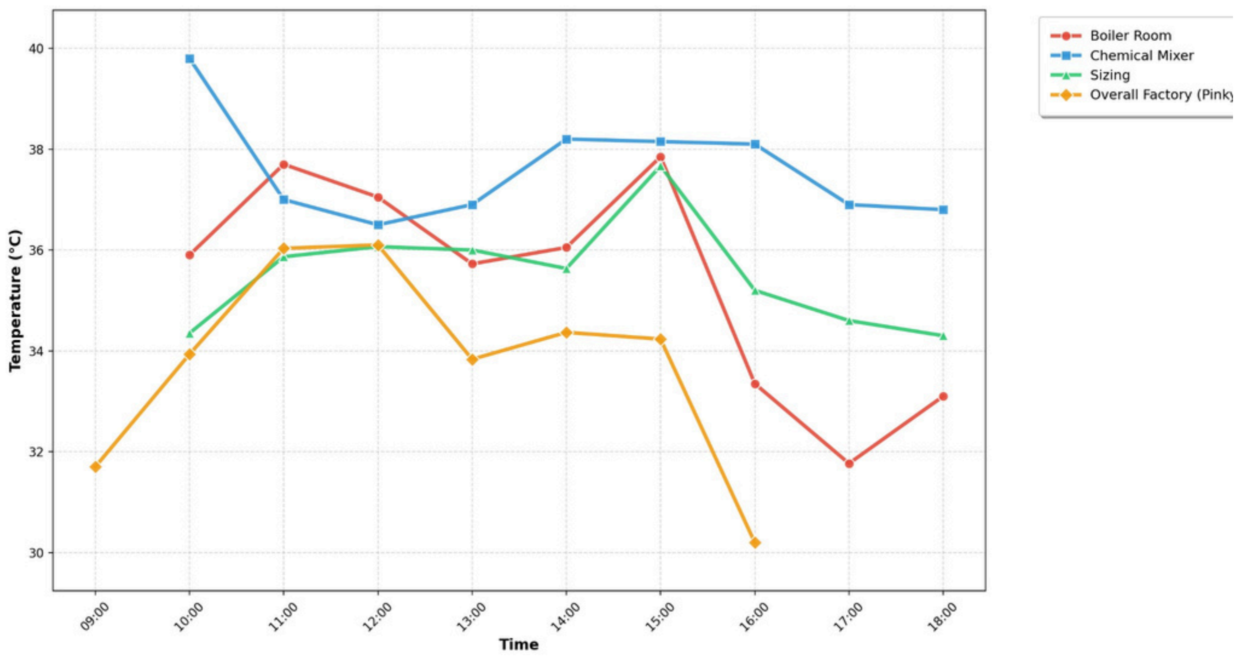

Figure 4: Average Indoor Temperature by Work Area Over Time

The **'Average Indoor Temperature by Work Area Over Time'** chart tracks how the ambient temperature fluctuates in the key operational zones. This data validates worker perceptions, confirming that the Sizing and Boiler rooms frequently experience the highest pure temperatures, often approaching 40°C. However, this metric alone is misleading. Assessing physiological heat risk requires accounting for both temperature and humidity. This combined effect is measured using the Wet Bulb Globe Temperature (WBGT), a recognised standard for evaluating heat stress on the human body.

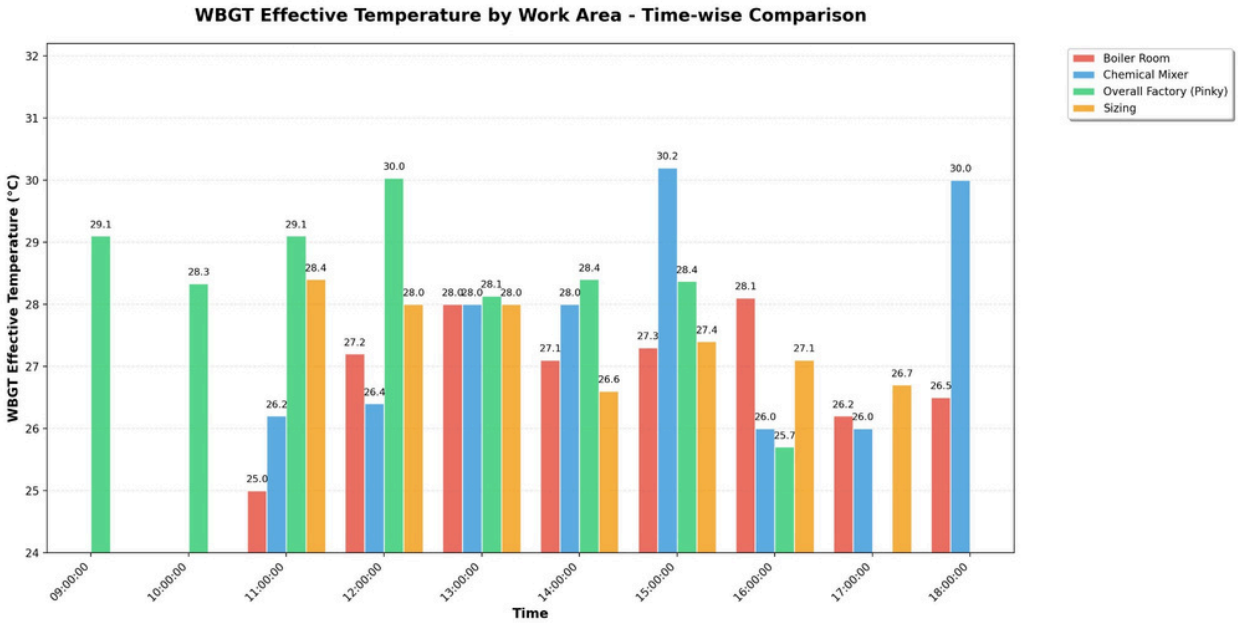

Figure 5: WBGT Effective by Work Area - Time Wise Comparison

The **'WBGT Effective Temperature by Work Area - Time-wise Comparison'** chart is critical for understanding the hierarchy of risk across different work areas. This chart displays the actual heat stress experienced by the workers' bodies. The findings show the most hazardous areas have the highest combination of heat and humidity, not necessarily the highest ambient temperature. The Chemical Mixer area and the 'Overall Factory' environment (represented by the cleaning staff, Pinky) consistently show the highest WBGT values, frequently crossing the **30°C** threshold. This reveals that the baseline condition for any worker is one of high, systemic heat stress, which is then amplified by specific processes.

To make this danger more tangible, the **'Heat Index Heat Map'** translates the complex environmental data into a "feels like" temperature.

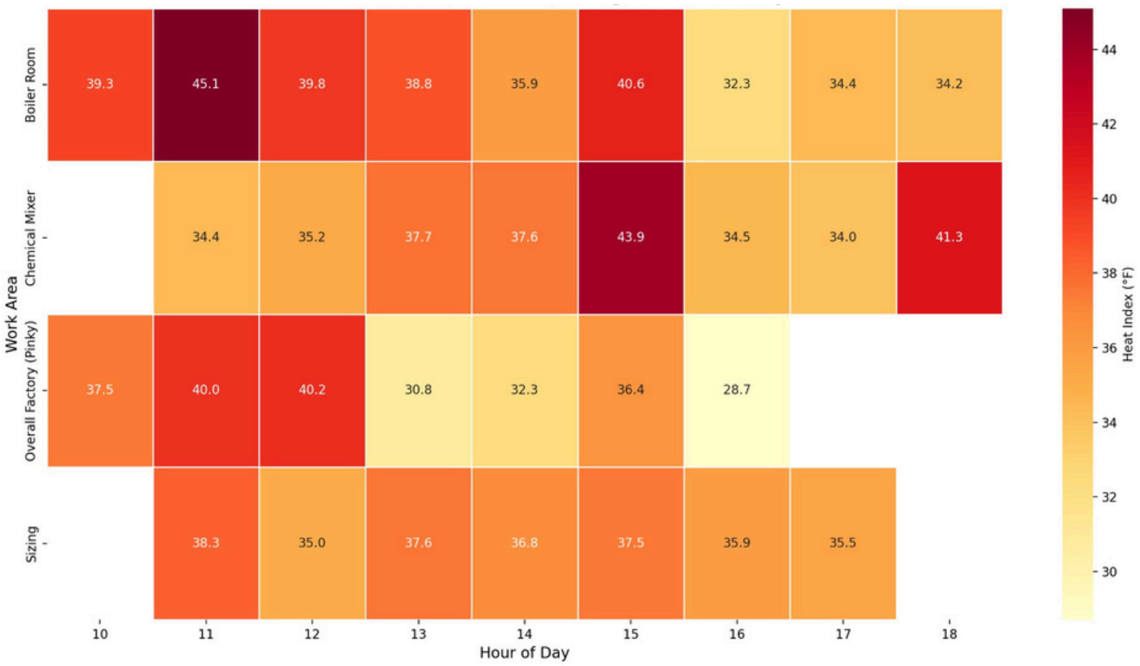

Figure 6: Heat Index Map - Day 1

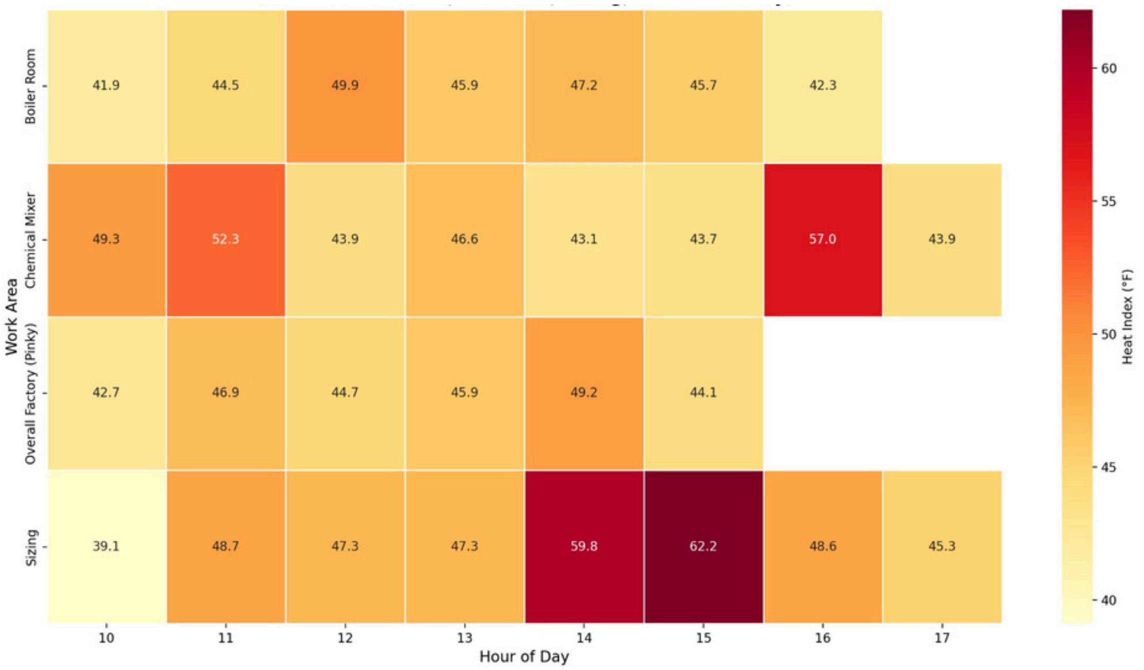

Figure 7: Heat Index Map: Day 4

The heatmap for Days 4 is particularly alarming. It shows that between 2:00 PM and 3:00 PM, workers in the Sizing unit were exposed to a "feels like" temperature of **59.8°C** to **62.2°C**. In the Chemical Mixer area, the Heat Index peaked at **57.0°C**. These are extreme conditions, far exceeding the 41°C "Danger" threshold and highlighting the severe physiological burden placed upon the workforce.

3.3 The Human Impact: Tracing Worker Fatigue

The hazardous environmental conditions translate directly into physiological strain. The connection between heat stress and worker fatigue is illustrated by comparing environmental data with self-reported fatigue levels.

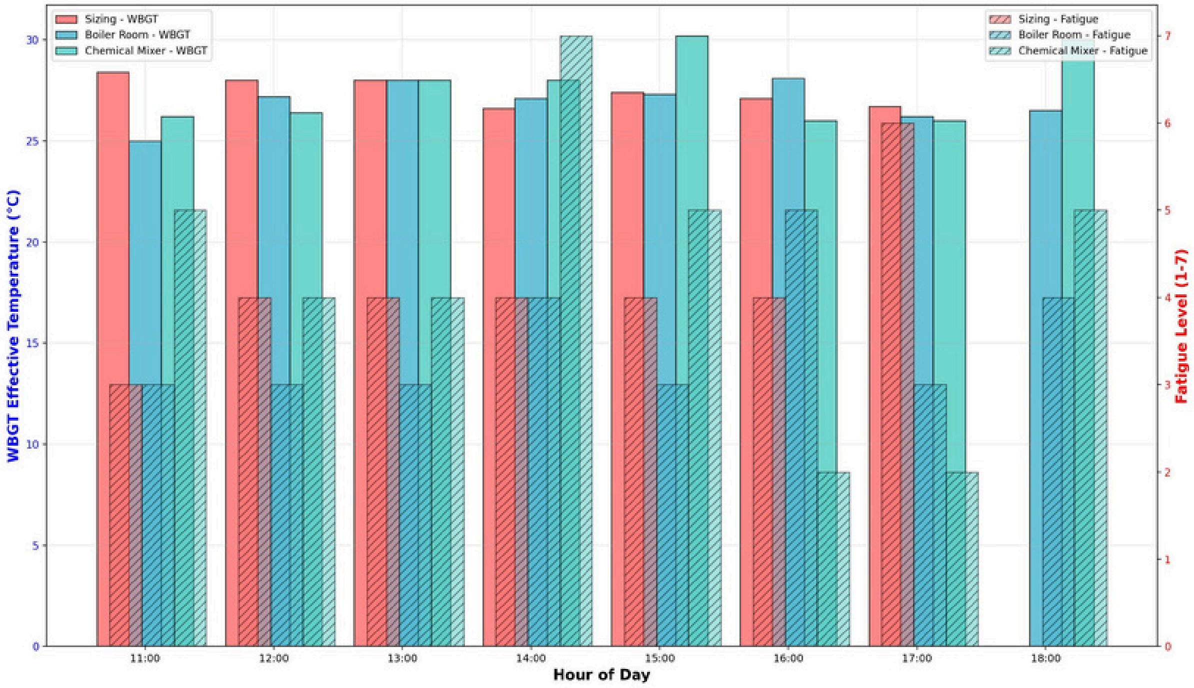

Figure 8: WBGT Effective and Fatigue Levels Throughout the Day

The chart **'WBGT Effective Temperature and Fatigue Levels Throughout the Day'** provides a compelling overview. It plots the heat stress (WBGT) against fatigue levels for workers in different areas. A clear pattern emerges: as the effective WBGT rises during the day, so does worker fatigue. The highest fatigue levels are consistently reported in the Boiler Room and Chemical Mixer areas, the same zones identified as having dangerously high WBGT.

This cumulative strain is best understood through a case study of a worker working in the chemical mixing area. The chart **'Suresh: Heat Stress vs. Fatigue Throughout Workday'** provides a detailed narrative of a single worker's experience.

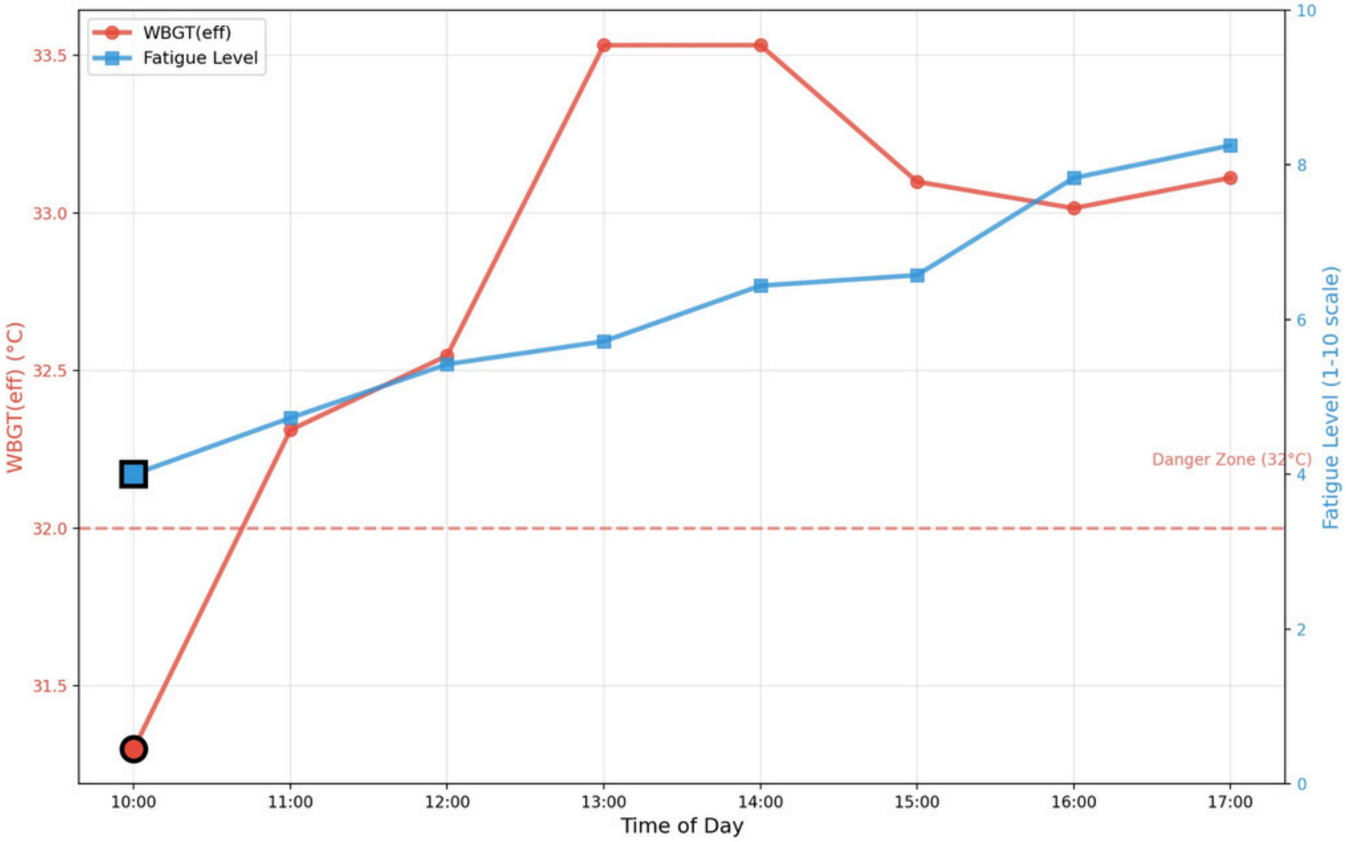

Figure 9: Suresh: Heat Stress vs. Fatigue Throughout Workday

At 10:00 AM, Suresh's heat exposure was already approaching the danger zone, and his fatigue was at a moderate level of 4 out of 10. As his work continued, his heat exposure crossed the 32°C danger line and remained there for the next four hours. In direct correlation, his fatigue climbed relentlessly, reaching a critical level of 8 out of 10 by the end of his shift. This demonstrates a clear cause-and-effect relationship: the sustained period of high heat stress directly contributed to the doubling of his fatigue.

3.4 Ineffectiveness of Breaks in High WBGT Conditions

It was found that rest periods do not provide adequate physiological recovery due to the hazardous heat conditions in the designated break areas. The data from the worker WBGT monitoring reveals that while a worker's metabolic rate decreases during a break, their WBGT readings remain dangerously high.

During observed lunch and rest periods, the Wet Bulb Globe Temperature (WBGT) consistently hovered between **26°C** and **30°C**. In one alarming instance on Day 5, a worker (Pinky) recorded a WBGT of **31.9°C** during her break period.

Thermal imaging of the breakroom was conducted to identify the sources of heat within the space.

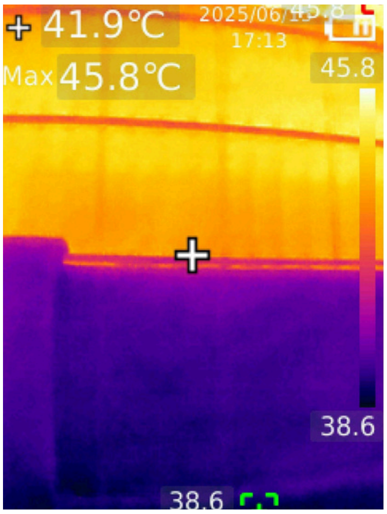

Image 16: Thermal Image of Breakroom (Day 5)

Image 16 (Day 5): This image was taken when the average outside temperature was 40.7∘C. It shows significantly elevated temperatures in the upper portion of the breakroom. The maximum surface temperature recorded near the ceiling was 45.8∘C, while the upper wall measured 41.9∘C. This heated ceiling structure radiates heat downward into the occupied space, contributing to the elevated WBGT levels measured.

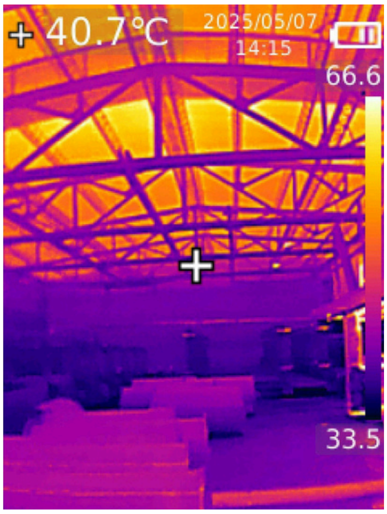

Image 17: Thermal Image of Breakroom (Day 2)

Image 17 (Day 2): A similar condition was observed on Day 2, when the average outside temperature was 32.7∘C. The thermal image shows the overhead metal trusses and roof structure registering high temperatures, with the crosshair measuring a surface temperature of 40.7∘C. This finding suggests that the building's roof absorbs and retains solar heat, which it then radiates into the break area.

The reading represents a **high-risk** work environment - certainly not a restorative one. Workers were seen taking breaks in unconventional areas of the workplace, laying on sacks spread on the floor. The hot floor and lack of ventilation is felt acutely in these conditions.

This lack of ‘cool-down’ environments explains the cumulative fatigue observed in workers. Their bodies are not given the chance to dissipate the heat accumulated during work, resulting in fatigue that builds throughout the shift. Consequently, the designated rest periods are ineffective for physiological recovery. While the metabolic rate decreases, the environmental heat stress continues, preventing recovery and ensuring workers end their shifts in a state of significant physiological strain and heightened heat risk.

Future Climate Risk Profile

Heat stress at the factory is projected to escalate significantly in the future. While the preceding analysis details the daily operational reality of today, this section uses forward-looking climate projection data from the CLIMADA Technologies platform to quantify how this reality will intensify.

By comparing the baseline climate of the year 2000 with projections for 2030, 2050, and 2080, a clear trend emerges. Regardless of whether the world follows a low (SSP126), moderate (SSP245), or high (SSP585) emissions pathway, the factory is locked into a future with a significantly more severe thermal environment. However, global emissions choices made today will determine the severity of future conditions. This forecast highlights the business imperative for proactive adaptation.

4.1 The Intensification of Extreme Heat: A Quantitative Outlook

One of the most significant challenges the factory may face in the future is the increasing intensity of extreme heat. The climate models show a future where days currently considered dangerously hot become the norm, and the absolute peak temperatures push the boundaries of human tolerance. This is not a gradual warming, but a fundamental shift in the character of the seasons, transforming the operational calendar and posing an ever-present threat to the workforce.

The table below quantifies this escalating heat profile, showing how both the frequency and intensity of extreme heat events are projected to rise dramatically.

Table 2: Future Projections of Heat-Related Climate Indicators by Emission Scenario

Climate Indicator	Baseline (2000)	Scenario	2030	2050	2080
Temperature on the single hottest day of the year	55.6°C	Low (SSP126)	59.6°C	61.2°C	62.3°C
		Moderate (SSP245)	59.4°C	62.1°C	65.0°C
		High (SSP585)	59.7°C	62.5°C	71.0°C
Average of 3-day 1-in-2 year heatwave	35.6°C	Low (SSP126)	36.6°C	36.9°C	37.1°C
		Moderate (SSP245)	36.6°C	37.1°C	38.0°C
		High (SSP585)	36.6°C	37.8°C	39.7°C

Climate Indicator	Baseline (2000)	Scenario	2030	2050	2080
Days with heat index >32°C	213.8	Low (SSP126)	224.4	229.4	232.7
		Moderate (SSP245)	224.7	230.2	233.1
		High (SSP585)	225.8	234.6	237.4
Days with heat index >41°C	98.5	Low (SSP126)	125.0	139.4	142.9
		Moderate (SSP245)	124.7	143.3	156.7
		High (SSP585)	127.7	151.1	166.9

By 2050, even under a moderate emissions scenario, the factory will have to endure over **143 "Danger"** days per year, an increase of 45% from the baseline. This means that for nearly five months of the year, the outdoor conditions will be so severe that they pose a significant risk to health and safety, forcing major adjustments to work schedules and threatening productivity.

Furthermore, the peak temperature on the single hottest day of the year is projected to climb above **62°C**. A temperature of this magnitude is a direct threat to life and can push the factory's machinery, like the air compressors that are critical for the warping machines, past their operational limits. In a high-emissions future, this narrative becomes even more dire, with the number of "Danger" days reaching 167, nearly half the year, and peak temperatures soaring to a life-threatening 71°C by 2080.

4.2 A Shifting Climate Landscape

The factory's future climate risk is not limited to heat. The data reveals compounding risks from both persistent water scarcity and intense rainfall.

Table 3: Climate Hazard Projections by Scenario and Year

Climate Hazard	Baseline (2000)	Scenario	2030	2050	2080
Drought Stress	Very High	Low (SSP126)	High	High	High
		Moderate (SSP245)	High	High	High
		High (SSP585)	High	High	High
Heavy Precipitation	Very Low	Low (SSP126)	Low	Medium	Low
		Moderate (SSP245)	Low	Medium	High
		High (SSP585)	Low	Low	High

The first pressure point is the unrelenting threat of drought. The factory's baseline drought risk is already rated as "Very High". While this is projected to moderate slightly, it will remain at a "High" risk level for the foreseeable future, regardless of the emissions scenario.

This is a critical vulnerability. The factory is a thirsty operation, consuming **60,000 litres of water every day** for its chemical mixing and steam-intensive processes. For six months of the year, it relies entirely on groundwater to meet this demand. A future defined by persistent high drought stress tells a story of increasing uncertainty and risk for this essential resource. It raises the probability of falling water tables, increased pumping costs, and potential water shortages that could halt production entirely. In this future, water is no longer a given; it is a strategic asset that will be under constant threat.

The other side is the emergence of a new and unfamiliar danger: heavy precipitation. The factory's infrastructure, with its heat-absorbent tin roofs, was built for a dry climate. The baseline risk from heavy rainfall is "Very Low". However, the projections show this risk escalating dramatically, reaching "Medium" by 2050 and "High" by 2080 under a moderate emissions scenario.

This shift in weather patterns indicates the factory is unprepared for this new risk. The production process is acutely sensitive to moisture; any water leaking onto the thread can ruin entire batches of product. The sudden arrival of intense downpours, a phenomenon the building was not designed to handle, introduces a significant operational risk. The evolving climate in the region includes the potential for flash flooding, which may affect transport and supply chains, as well as cause water ingress through the roof, potentially resulting in product damage and financial loss.

In essence, the factory's future will require managing contradictory climate challenges. This complex, compound hazard environment requires a fundamental shift in planning, from preparing for the known challenge of heat to building resilience against a more volatile and unpredictable climate.

Cost of Inaction

This section details the significant consequences of failing to implement proactive climate adaptation measures at the Kishangarh textile factory. It quantifies the direct financial losses stemming from reduced productivity due to escalating heat stress and outlines broader long-term risks impacting workforce retention and global market access, thereby threatening the factory's overall profitability.

5.1 Productivity Loss

Productivity loss was modelled using available environmental and operational data, applying ISO 7243:2017 guidelines to estimate required rest periods based on projected heat stress. The analysis assumes that workers are engaged in continuous activity at a moderate metabolic rate throughout each hour, with rest only taken during formal break times, and that prescribed ISO-recommended work-rest ratios are followed. These assumptions were necessary to produce a consistent, quantifiable estimate.

In reality, conditions on the factory floor are more variable. At times, adequate staffing and workflow patterns allow for natural pauses between high-exertion tasks, resulting in longer rest periods than modelled. In other cases, operational demands, lack of regulatory enforcement, or production pressures may compel workers to continue despite hazardous heat conditions, foregoing necessary rest altogether.

As such, the modelled productivity loss should be considered indicative rather than definitive. It represents a standardised estimate of potential operational downtime under projected climate conditions but does not fully capture the complexities of real-world working environments. The figures presented reflect the visible, measurable portion of the risk. The broader, long-term consequences including impacts on worker health, safety, morale, and the factory's ability to retain a productive workforce, are less easily quantified but may carry equally significant financial and operational implications.

Using our site-specific projection model, which links rising outdoor temperatures to the effective heat stress inside the factory, we can forecast the direct financial consequences. As established, a projected 1.6°C rise in regional temperature by 2050 will translate to a **0.67°C increase in the indoor effective WBGT.**

According to the safety thresholds mandated by ISO 7243:2017, this increase is enough to push working conditions into a higher risk category. To remain compliant and protect worker health, this will require an additional **10 minutes of mandatory rest per hour** for employees in high-risk roles. This increase in downtime has a direct and significant impact on the factory's output. The hourly productivity loss on "danger" days is projected to climb from the current 26.1% to **42.83%**.

While the model offers a useful estimate of potential productivity loss due to increased heat stress, it is important to acknowledge that real-world conditions may introduce additional risks and operational challenges.

5.2 Workforce Retention

In addition to direct financial loss, inaction towards climate related risks, creates significant second order ripples. This refers to the long-term consequences of failing to adapt, which threaten not just a portion of the factory's annual profit, but its future workforce, its market access, and its overall viability.

This risk became apparent during the one-on-one worker surveys. While discussing the factory's conditions, several experienced workers drew comparisons to other facilities they had worked in. They spoke of simple, yet effective, measures they had seen elsewhere: fans installed in the boiler room, factories with higher roofs and better ventilation systems to allow steam to escape, and even the use of honeycomb-webbed cardboard as a false ceiling to absorb the radiant heat from the tin roof.

These insights are invaluable. The feedback indicates that the workforce is aware that safer working conditions exist in other facilities. As the climate projections make clear, the conditions are only going to worsen. This creates a significant long-term threat to labour retention and recruitment. If the factory is perceived as a place with subpar and dangerous working conditions, it risks losing skilled workers who may prefer safer environments. Further, attracting new talent will become progressively more difficult and expensive.

5.3 Access to Global Markets

As global supply chains come under greater scrutiny, social and environmental responsibility is rapidly moving from a voluntary ideal to a mandatory requirement for doing business.

The European Union, a key market for textiles, is leading this charge with new legislation that has direct implications for its global suppliers. The recently adopted **Corporate Sustainability Due Diligence Directive (CSDDD)** will require large companies operating in the EU to identify and mitigate adverse impacts on human rights and the environment throughout their value chains. Crucially, the definition of human rights explicitly includes the right for workers to have "access to safe and healthy working conditions". Furthermore, trade unions and regulatory bodies are pushing for a specific EU directive on occupational heat risk, citing the severe health effects of heat stress.

This means that in the near future, European buyers will be legally obligated to ensure their suppliers, including textile factories in Kishangarh, are protecting their workers from extreme heat. Failure to provide adequate cooling, ventilation, and scientifically-backed work-rest schedules could result in a factory being deemed non-compliant. The consequences could range from contractual penalties to being dropped entirely from lucrative European supply chains, a financial loss that would far exceed the modelled productivity costs. Inaction on worker safety is no longer just a local issue; it is a direct threat to the factory's passport to the global market.

Potential Adaptation Solutions for Heat Stress

Following the analysis of productivity impacts, the next logical step is to identify and evaluate a portfolio of potential adaptation solutions. The aim is to move beyond merely coping with heat stress towards building systemic, long-term resilience. A range of solutions has been identified, spanning from low-cost administrative controls to significant capital investments in engineering solutions.

6.1 Proposed Adaptation Solutions

Five distinct adaptation solutions have been identified for evaluation:

- **Worker Training and Awareness:** A procedural measure focused on education. This involves developing and delivering mandatory training on recognising heat stress symptoms, the importance of hydration, and effective self-management techniques. It also includes establishing clear work/rest schedules and a 'buddy system' for mutual monitoring.

- **Insulation of Pipes and Machinery:** An engineering control aimed at reducing ambient heat at its source. This involves conducting a technical audit to identify hot surfaces (e.g., steam pipes, furnaces) and insulating them with appropriate materials to minimise radiant heat in the work environment.

- **Personal Cooling Vests:** A form of personal protective equipment (PPE) that provides direct cooling to an individual. This involves providing workers in the hottest areas with personal cooling garments and setting up the necessary infrastructure for re-soaking or recharging them.

- **Designated Rest Areas:** An administrative and engineering control that provides spaces for recovery. This involves creating cool, shaded areas near work zones, ensuring easy access to cold drinking water, and encouraging scheduled cool-down breaks. On-site measurements found that the heat stress level (WBGT) in existing rest stations was 5.8°C lower than at active workstations.

- **Waste Heat Recovery from Exhaust:** A significant engineering project that captures and reuses waste heat. This involves installing a heat exchanger on high-temperature exhaust stacks (e.g., from the boiler) to preheat combustion air or water, thereby reducing energy consumption and the overall heat load on the factory.

6.2 Weighted Scoring of Solutions

Each of the five solutions was scored on a scale of 1 to 10 against four key criteria: Economic Efficiency, Technical Feasibility, Environmental Impact, and Social Acceptability. The results are summarised in the table below.

Table 4: Weighted Solution Score

Adaptation Solution	Economic Efficiency	Technical Feasibility	Environmental Impact	Social Acceptability
Worker Training & Awareness	10	10	5	10
Insulation of Pipes & Machinery	8	7	9	9
Cooling Vests	7	10	4	8
Designated Rest Areas	9	9	6	10
Waste Heat Recovery from Exhaust	7	5	10	7

The following provides a detailed justification for the scores assigned to each adaptation solution.

1. Worker Training & Awareness

- **Economic Efficiency (10/10):** This solution has a very low implementation cost, consisting mainly of staff time for training development and delivery. Given the significant financial losses from heat-related productivity decline (estimated at ₹28,188 per hot day), any improvement in worker self-management offers an exceptionally high return on investment.

- **Technical Feasibility (10/10):** Implementation is purely procedural and educational, requiring no specialised equipment or disruptive engineering work, making it highly feasible.

- **Environmental Impact (5/10):** The impact is neutral. The training does not physically reduce ambient heat or consume significant resources, so it neither harms nor directly benefits the physical environment.

- **Social Acceptability (10/10):** This measure directly addresses worker well-being by empowering them with knowledge to manage symptoms like dizziness and fatigue, which were reported in surveys. It fosters a stronger safety culture and is therefore viewed very favourably by employees.

2. Insulation of Pipes & Machinery

- **Economic Efficiency (8/10):** While the initial capital cost is medium to high, the solution yields significant long-term energy savings and a potentially short payback period. A case study in a similar facility demonstrated substantial fuel cost reductions.

- **Technical Feasibility (7/10):** The process requires a technical audit and can be disruptive to install during ongoing operations, presenting a moderate technical challenge.

- **Environmental Impact (9/10):** By reducing energy consumption, this solution directly lowers the factory's carbon footprint. It also reduces radiant heat from sources like the boiler and sizing units, lowering the ambient temperature and creating a positive environmental co-benefit.

- **Social Acceptability (9/10):** This solution directly improves worker safety by preventing burns and makes the work environment more comfortable, addressing a key complaint from workers about specific hot zones.

3. Cooling Vests

- **Economic Efficiency (7/10):** The cost is medium and, crucially, ongoing due to maintenance and replacement needs. While effective at improving individual productivity, the recurring cost makes it less efficient than one-time capital investments.

- **Technical Feasibility (10/10):** The technical requirements are straightforward (purchasing vests and setting up charging/soaking stations).

- **Environmental Impact (4/10):** This solution has a minor negative impact. The vests are manufactured products, and the required charging stations (e.g., refrigerators) consume energy, contributing to operational emissions.

- **Social Acceptability (8/10):** The benefit of direct, personal cooling is a significant advantage for workers in high-heat roles. However, potential comfort issues related to the bulkiness of some designs could reduce compliance and overall acceptance.

4. Designated Rest Areas

- **Economic Efficiency (9/10):** The cost is low to medium, particularly for basic shaded structures. The benefit is significant, as providing a cool space for recovery directly combats fatigue and supports sustained productivity throughout the shift.

- **Technical Feasibility (9/10):** Creating a shaded area with water access is relatively easy to implement. While finding available space near all work zones can be a challenge, improving existing informal rest areas is highly feasible.

    - **Environmental Impact (6/10):** A simple shaded structure has a negligible environmental impact. An air-conditioned room, however, would increase energy costs and emissions. This score assumes a well-ventilated but not necessarily actively cooled space.

    - **Social Acceptability (10/10):** This solution benefits all workers and validates the need for proper work/rest cycles, addressing a clear need identified by workers who currently rest in informal, often hot, areas. It would be a universally appreciated improvement.

5. Waste Heat Recovery from Exhaust

- **Economic Efficiency (7/10):** This option has the highest initial capital investment. However, it also promises to drastically reduce long-term energy costs, with an estimated payback period of 2–3 years, making it a sound long-term investment.

- **Technical Feasibility (5/10):** This is the most technically complex solution, requiring significant engineering design, specialised installation work, and potential changes to existing processes.

- **Environmental Impact (10/10):** This solution offers the greatest environmental benefit. It significantly reduces energy consumption, thereby lowering the factory's carbon footprint, and also reduces the overall heat load vented into the local environment.

- **Social Acceptability (7/10):** While it does not offer a direct, visible benefit to workers in the same way as rest areas or PPE, the reduction in ambient heat and the company's investment in sustainable technology would likely be viewed positively.

6.3 Prioritisation through Weighted Criteria

While the scoring provides a comparative baseline, not all criteria hold equal importance for every organisation. To reflect specific strategic priorities, a weighting is applied to each criterion. This step transforms the analysis from a simple comparison into a strategic decision-making tool that aligns with the factory's core objectives.

After discussion with the factory owner to ensure alignment with their operational and financial priorities, the following weights have been assigned to the four evaluation criteria:

    - **Economic Efficiency: 40%** - Reflecting the critical importance of cost-effectiveness and return on investment for any new capital expenditure.

    - **Technical Feasibility: 30%** - Acknowledging the need for solutions that can be implemented with minimal disruption to ongoing production.

    - **Social Acceptability: 20%** - Highlighting the commitment to worker safety, well-being, and morale.

    - **Environmental Impact: 10%** - Recognising the value of environmental co-benefits, while placing a lower priority on it compared to immediate economic and operational factors.

By applying these weights to the initial scores, a total weighted score is calculated for each adaptation solution. This final score provides a clear, data-driven ranking that reflects the factory's specific priorities.

Table 5: Final score for the identified adaptation solutions

Adaptation Solution	Economic Efficiency (40%)	Technical Feasibility (30%)	Social Acceptability (20%)	Environmental Impact (10%)	Total Weighted Score
Worker Training & Awareness	4	3	2	0.5	9.5
Designated Rest Areas	3.6	2.7	2	0.6	8.9
Insulation of Pipes & Machinery	3.2	2.1	1.8	0.9	8
Cooling Vests	2.8	3	1.6	0.4	7.8
Waste Heat Recovery from Exhaust	2.8	1.5	1.4	1	6.7

6.4 The Prioritised Adaptation Roadmap

The weighted ranking reveals a clear path forward for implementing heat adaptation measures. The analysis indicates that the most effective and strategically aligned solutions are those that combine high feasibility and social acceptance with strong economic sense.

The top-ranked solution, **Worker Training & Awareness** (Score: 9.5), emerges as the highest priority due to its extremely low cost, ease of implementation, and direct positive impact on employee well-being. This is closely followed by **Designated Rest Areas** (Score: 8.9), another highly feasible and socially beneficial measure with a relatively low cost.

The third-ranked solution, Insulation of **Pipes & Machinery** (Score: 8.0), represents the most viable capital investment. While it requires a higher initial outlay, its strong economic case (through energy savings) and significant improvement to the working environment make it a compelling option.

This prioritised list serves as a strategic roadmap, allowing the factory to focus initial efforts on low-cost, high-impact measures while planning for more significant capital investments in the medium term.

6.5 Strategic Recommendations for Long-Term Resilience

To complement the prioritised adaptation measures, the following strategic initiatives are recommended to enhance the long-term climate resilience of the facility. These actions focus on structural improvements and the integration of climate risk into core business processes.

1. Commission a Structural Engineering Assessment for Passive Cooling Enhancements

Given the factory's construction, characterised by stone walls and an extensive tin roof, it is advisable to commission a formal assessment. The objective of this assessment should be to identify and specify viable passive cooling interventions tailored to the facility's operational and structural profile. Key areas for investigation should include:

- **Ventilation System Optimisation:** A technical review of current ventilation systems to identify opportunities for redesigning airflow pathways. This is particularly critical in the sizing unit and break areas, where heat accumulation and inadequate air circulation have been noted.

- **Application of High-Albedo Roof Coatings:** An analysis of suitable reflective or high-albedo coatings for the tin roofing. The goal is to reduce solar heat gain whilst ensuring no negative impact on the humidity and temperature controls essential for textile processing.

- **Evaluation of Alternate Building Materials:** An investigation into the feasibility of incorporating alternative materials, such as cooling tiles or other specialised surface applications, to passively lower the surface temperatures of the roof and external walls.

These passive measures are designed to address structural vulnerabilities in the factory's thermal regulation, offering a low-maintenance and effective means of lowering indoor ambient temperatures without disrupting production integrity.

2. Integrate Climate Risk Analysis into the Enterprise Risk Management (ERM) Framework

For sustained operational resilience, it is strongly recommended that Digvijay Texfab incorporates climate risk analytics into its existing Enterprise Risk Management (ERM) framework. The facility's exposure to heatwaves, water stress, and the increasing likelihood of both drought and intense precipitation events constitutes a material risk to operations. A systematic integration of climate data would facilitate:

- **Informed Reviews of Operational Planning:** The periodic review of workplace health and safety protocols, productivity targets, and maintenance schedules, informed by up-to-date climate models and hazard projections specific to the Kishangarh industrial zone.

- **Enhanced Business Continuity Planning:** The proactive adaptation of business continuity strategies to mitigate financial and operational disruption from extreme weather events, utilising scenario analysis and predictive analytics.

    - **Alignment with Supply Chain and Investor Standards:** Ensuring compliance with the growing expectation from international buyers and stakeholders for demonstrable climate adaptation and robust occupational health measures within supplier facilities.

By embedding climate risk assessment into core management functions, the facility can transition from a reactive to a proactive posture, ensuring that climate adaptation becomes an integral component of routine governance and strategic planning.

Annexure 1: Day Wise Average Indoor Temperature

This annexure provides a quantitative, visual summary of the thermal conditions across different operational zones within the Kishangarh textile facility. It was designed to feature a series of bar charts, each corresponding to a specific measurement day, displaying the average indoor ambient temperatures recorded in four key work areas: the Boiler Room, the Sizing Unit, the Chemical Mixing Area, and the Warping Machine Area.

The primary purpose of this annexure is to serve as a foundational component of the facility's overall heat risk assessment. By systematically documenting and comparing the thermal load in each area, the data is intended to objectively identify the primary "hotspots" within the factory. This visual evidence is critical for validating worker-reported experiences and providing the empirical basis needed to prioritize and justify targeted heat mitigation strategies, as detailed in the main body of the report.

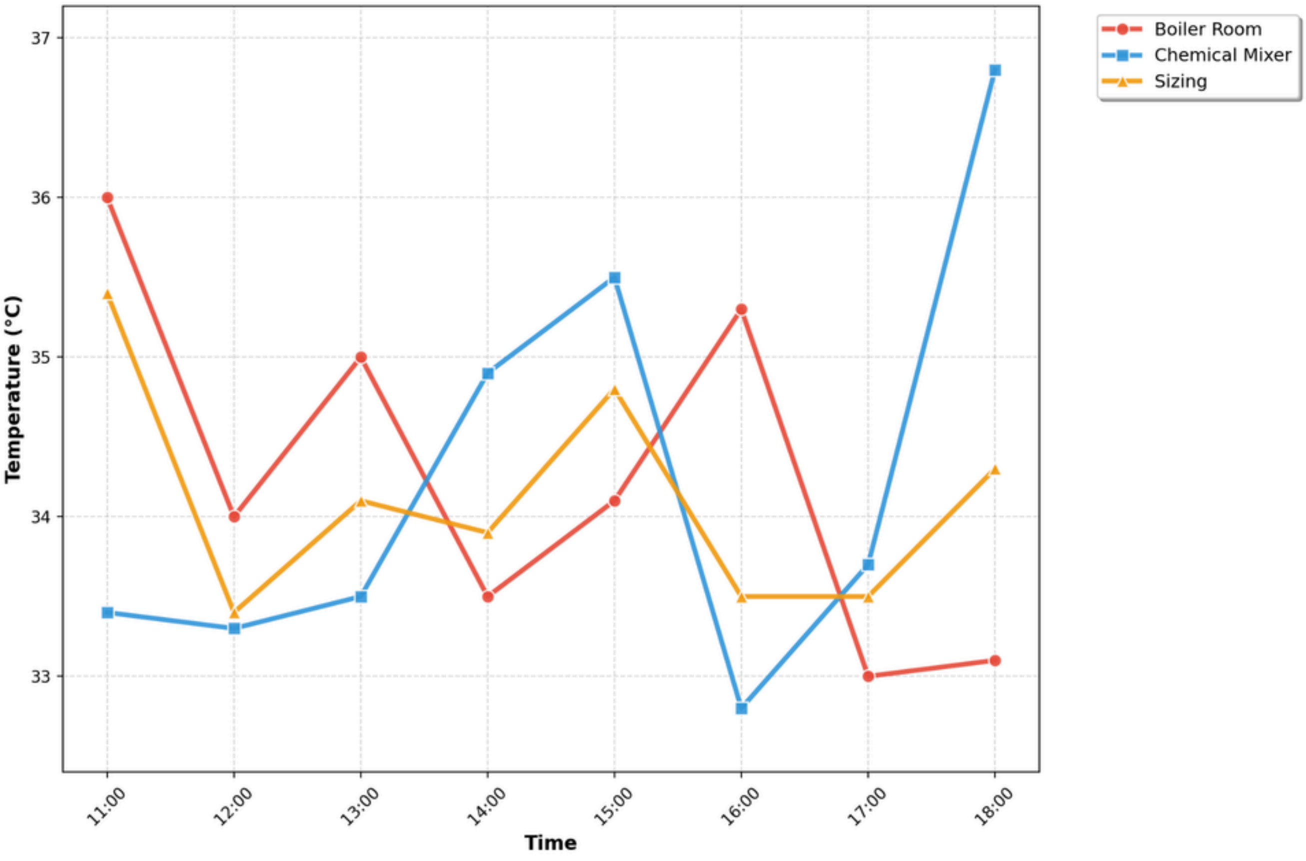

Figure 10: Day 1 - Average Indoor Temperature by Work Area

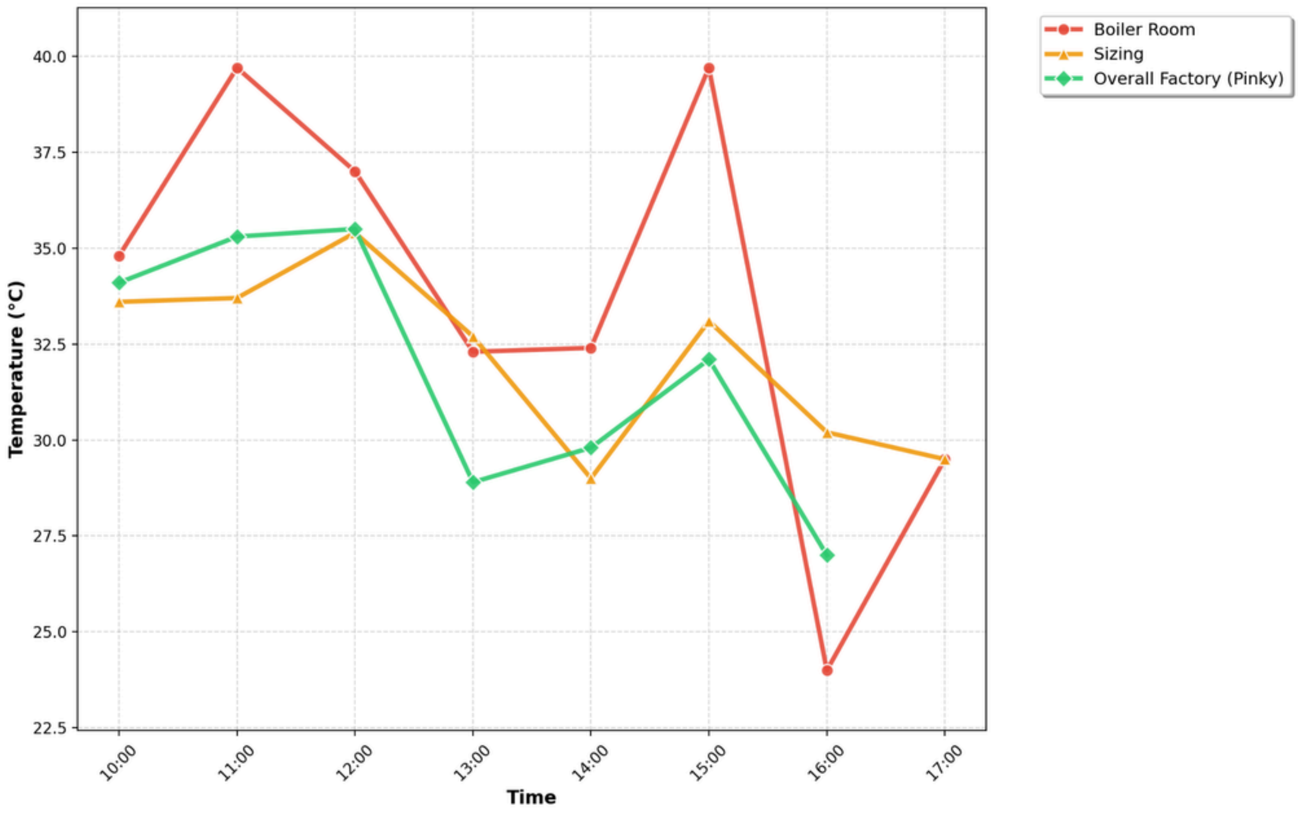

Figure 11: Day 2 - Average Indoor Temperature by Work Area

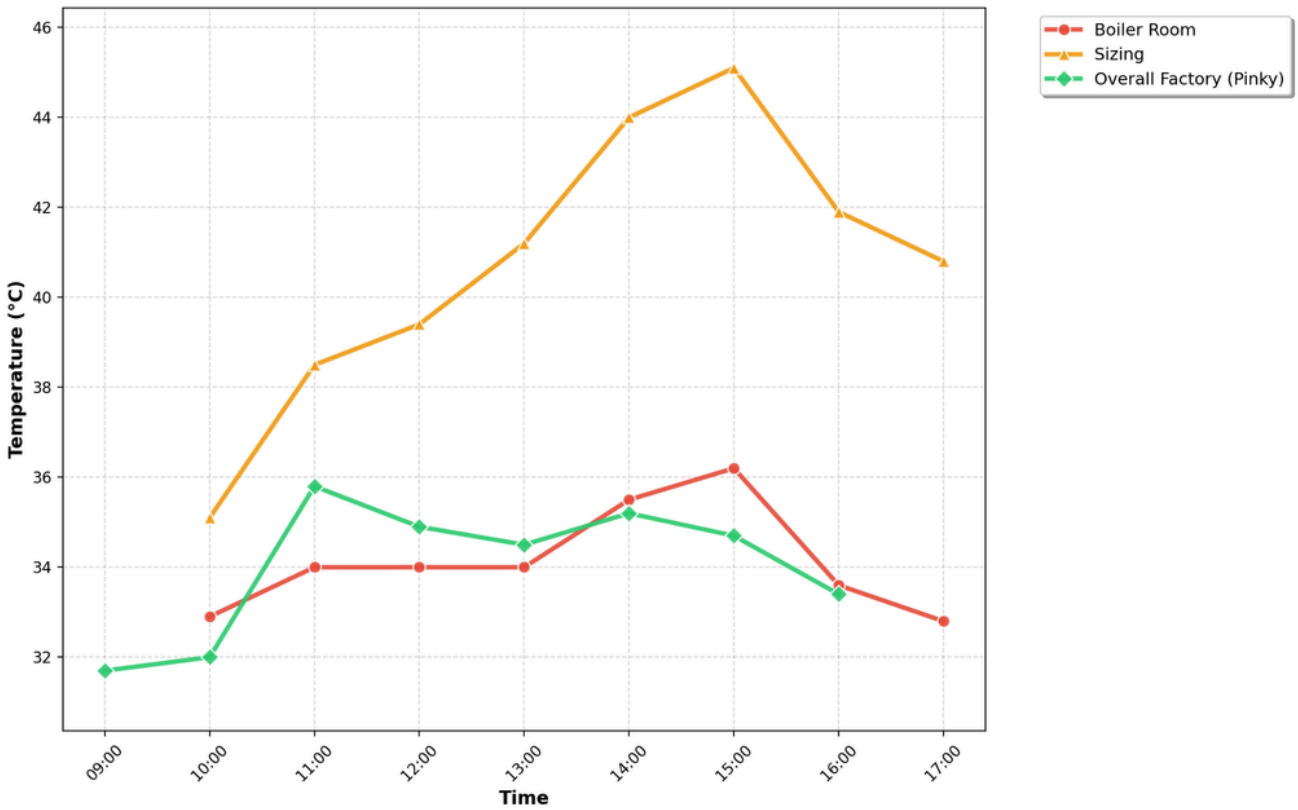

Figure 12: Day 3 - Average Indoor Temperature by Work Area

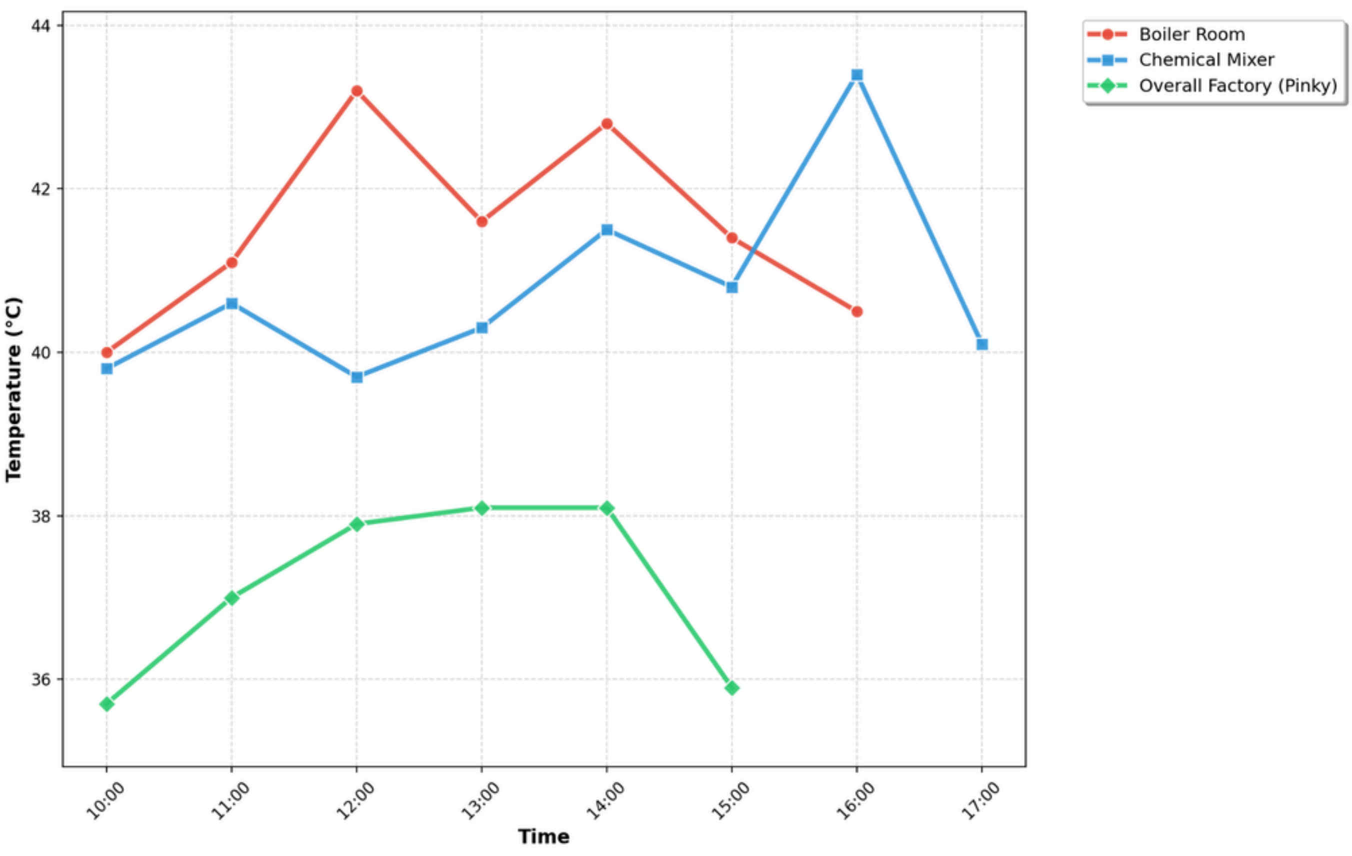

Figure 13: Day 4 - Average Indoor Temperature by Work Area

References

1. **Ashtekar, S., Mishra, S., Kapadia, V., Nag, P., & Singh, G.** (2018). Workplace heat exposure management in Indian construction workers using cooling garment. Workplace Health & Safety, 67(1), 18–26. https://doi.org/10.1177/2165079918785388

2. **Sustainable Living Lab. (n.d.). Climate Adaptation Playbook.** Climate Adaptation Playbook. (n.d.). https://www.sustainablelivinglab.org/climate-adaptation-playbook/#/

3. **Climate Change and Labor: Impacts of heat in the workplace.** (n.d.). UNDP. https://www.undp.org/publications/climate-change-and-labor-impacts-heat-workplace

4. **Haque, I.** (n.d.). 10WasteHeatRecoveryinBoiler.pdf. Scribd. https://www.scribd.com/document/419370088/10WasteHeatRecoveryinBoiler-pdf

5. **ISO.** (2017). Ergonomics of the thermal environment — Assessment of heat stress using the WBGT (wet bulb globe temperature) index. In ISO 7243. https://cdn.standards.iteh.ai/samples/67188/5a4c5553da5945aa872478c36755cded/ISO-7243-2017.pdf

6. **ISO, & ISO.** (2007). Ergonomics of the thermal environment — Estimation of thermal insulation and water vapour resistance of a clothing ensemble. In ISO 9920:2007. https://cdn.standards.iteh.ai/samples/39257/0cb19bbb84214a03b53c77d076dc77f8/ISO-9920-2007.pdf

7. **Kabir, H., Maple, M., Islam, M. S., & Usher, K.** (2022). A qualitative study of the working conditions in the readymade garment industry and the impact on workers' health and wellbeing. Environmental and Occupational Health Practice, 4(1). https://doi.org/10.1539/eohp.2021-0020-ohw

8. **Kishangarh climate, weather by month, Average temperature (Rajasthan, India) - Weather Spark.** (n.d.). Weather Spark. https://weatherspark.com/y/108714/Average-Weather-in-Kishangarh-Rajasthan-India-Year-Round#google_vignette

9. **Lundgren, K., Kuklane, K., & Venugopal, V.** (2014). Occupational heat stress and associated productivity loss estimation using the PHS model (ISO 7933): a case study from workplaces in Chennai, India. Global Health Action, 7(1). https://doi.org/10.3402/gha.v7.25283

10. **Morabito, M., Messeri, A., Crisci, A., Bao, J., Ma, R., Orlandini, S., Huang, C., & Kjellstrom, T.** (2020). Heat-related productivity loss: benefits derived by working in the shade or work-time shifting. International Journal of Productivity and Performance Management, 70(3), 507–525. https://doi.org/10.1108/ijppm-10-2019-0500

11. **Setyawan, H., Qodrijati, I., Widjanarti, M. P., Rinawati, S., Atmojo, T. B., Fajariani, R., Wardhani, T. L., & Utomo, E. W.** (2018). The impact of hot work climate on textile industry productivity. IOP Conference Series: Earth and Environmental Science, 200, 012053. https://doi.org/10.1088/1755-1315/200/1/012053

12. **Tailor, H., Desai, F., Dave, P., Wichita State University, & Sardar Vallabhbhai National Institute of Technology Surat.** (2014). Performance assessment and cost analysis of piping insulation for steam distribution system in dyeing and printing mill. IJARESM. https://www.researchgate.net/publication/323402530

13. **Venugopal, V., Chinnadurai, J., Lucas, R., & Kjellstrom, T.** (2015). Occupational heat stress profiles in selected workplaces in India. International Journal of Environmental Research and Public Health, 13(1), 89. https://doi.org/10.3390/ijerph13010089

14. **Weather Spark.** (n.d.). Kishangarh climate, weather by month, Average temperature (Rajasthan, India). https://weatherspark.com/y/108714/Average-Weather-in-Kishangarh-Rajasthan-India-Year-Round#google_vignette

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