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Occupational Heat Exposure and Heat-Related Illness in Construction Workers: Trajectories, Worker Subgroup Differences, and Workplace Intervention Effectiveness

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***Abstract*—Occupational heat exposure represents one of the most consequential climate-change-related occupational health challenges globally, with substantial burden in South Asian construction sectors where high ambient temperatures, heavy physical work, large migrant workforces, and limited regulatory enforcement intersect. We conducted a 120-day summer audit (March-July 2024) of 486 construction workers across 12 work sites with structured heat exposure monitoring (wet-bulb globe temperature, WBGT) and heat-related illness (HRI) surveillance. Worker role distribution included masons (28.4%), helpers (24.3%), roof/facade workers (14.0%), iron-binders (12.8%), and concrete workers (9.9%). Daily ambient temperature ranged 28-50 °C with estimated WBGT 24-46 °C. Daily HRI incidence rose exponentially with WBGT, with rates 30-50× higher at WBGT ≥36 °C compared with <28 °C. Heavy work intensity and migrant worker status compounded WBGT-driven risk. Strongest predictors of moderate-severe HRI included WBGT ≥34, heavy work, migrant status, limited acclimatisation, inadequate hydration, pre-existing chronic disease, and elderly age. Workplace heat-protection programmes, structured work-rest cycles with shade/water provision, and supervisor training were strongly protective. The findings support continued investment in heat action plans, workplace regulation enforcement, structured intervention, and acclimatisation programmes for migrant workers.**

***Index Terms*—occupational heat exposure, construction workers, heat-related illness, WBGT, migrant workers, workplace intervention, climate change**

I. Introduction

Occupational heat exposure has emerged as one of the most consequential occupational health challenges of the climate change era. International Labour Organization estimates suggest approximately 2.4 billion workers globally face heat exposure, with substantial productivity losses, morbidity, and mortality particularly in outdoor and heat-intensive industries. Construction work with its combination of substantial physical exertion, outdoor exposure, limited shade access, frequent heat-generating processes (concrete curing, roofing materials, welding), and large migrant workforces represents one of the highest-risk sectors (Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Kumar, Sharma,, & Gupta, 2026). South Asian construction faces particular burden. Pre-monsoon summer temperatures regularly exceed 45 °C across much of northern and central India with extended heat wave episodes. The construction boom across major Indian cities employs approximately 50-60 million workers, with substantial migrant proportion from rural states. Migrant workers face compounded risk through limited acclimatisation periods on arrival from cooler regions, accommodation in heat-exposed labour camps, limited bargaining power for work modifications, and reduced access to healthcare for HRI events. Regulatory frameworks exist but enforcement is variable (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026). Effective heat exposure management requires structured monitoring (wet-bulb globe temperature WBGT integrating ambient temperature, humidity, and radiant heat is the gold-standard measure), work-rest cycle protocols adapted to exposure level and work intensity, shade and hydration provision, acclimatisation periods for new workers, structured supervisor training, emergency response procedures, and documentation/reporting infrastructure. We conducted a 120-day summer audit of 486 construction workers across 12 work sites to characterise exposure-outcome patterns, identify modifiable determinants, and document workplace intervention effectiveness (Bhatnagar, Kumar,, & Shivam, 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Vettriselvan, Ramya, et al., 2026; Jenifer et al., 2025).

II. Methods

We conducted a 120-day prospective audit (March 1-July 31, 2024) of 486 construction workers across 12 sites operated by participating construction companies in northern India. Inclusion required (a) age 18-70 years; (b) active construction work during the audit period; (c) consent for structured occupational health monitoring. Exclusion criteria included pre-existing acute medical illness, planned work absence >50% of audit period, and refusal. The 12 sites varied in size (50-200 workers), company size (medium to large), and intervention implementation (6 with structured heat-protection programmes, 6 without). Wet-bulb globe temperature (WBGT) was measured every 30 minutes during work hours at each site using calibrated WBGT monitors positioned in representative work areas. Dry-bulb temperature, humidity, and radiant temperature components were captured. Worker-level exposure was calculated as time-weighted average WBGT during shifts plus peak WBGT exposure. Work intensity categorisation followed ISO 7243 metabolic rate categories: light (supervisor, finishing), moderate (mason, helper, carpenter), heavy (iron-binder, roof, concrete worker). Hydration status was monitored through structured urine specific gravity testing in random samples of workers during shifts. Heat-related illness was prospectively monitored through site nurses with structured assessment of all workers reporting heat symptoms. HRI classification followed standard criteria: heat cramps (muscle cramps, no thermoregulatory disturbance), heat exhaustion (core temperature <40 °C with weakness, headache, nausea), heat stroke (core temperature ≥40 °C with neurological dysfunction). All severe events (heat stroke, severe heat exhaustion requiring intervention) received hospital referral with structured follow-up. Productivity outcomes were captured through structured site documentation of work cessation, modified work, and absenteeism. Worker-reported outcomes including subjective heat strain, fatigue, and sleep quality were captured through structured weekly surveys. Sites were categorised by heat-protection programme implementation:

comprehensive programme (work-rest cycles based on WBGT, shade and water provision, acclimatisation periods for new workers, supervisor training, emergency procedures, structured surveillance), partial programme (some but not all components), or absent programme (general health and safety only without heat-specific intervention). Multivariable analysis identified independent predictors of moderate-severe HRI events.

III. Results

3.1 Worker Population

Construction worker role distribution across the 486-worker cohort is shown in Figure 1. Masons accounted for the largest single category (28.4%), followed by helpers/general labour (24.3%), roof/facade workers (14.0%), iron-binders/steel-fixers (12.8%), concrete workers (9.9%), carpenters/formwork specialists (6.6%), and supervisor/non-physical roles (4.1%). The distribution reflects the typical workforce composition of medium-to-large construction projects in our setting. Migrant workers from other states accounted for approximately 56% of the workforce substantially higher than the general working population (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

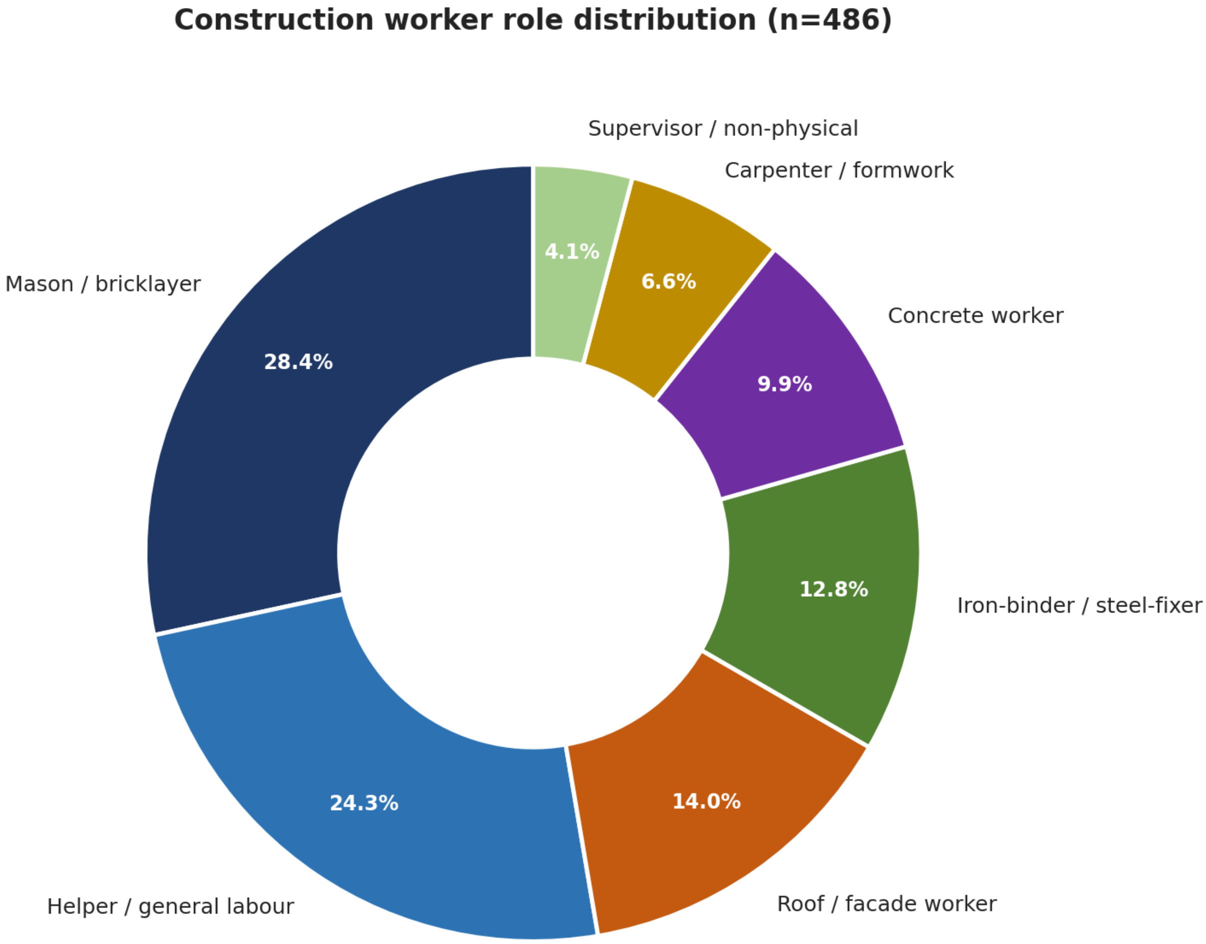

Figure 1. Construction worker role distribution.

3.2 Exposure-Incidence Trajectories

Daily ambient temperature, WBGT, and HRI incidence trajectories across the 120-day audit period are shown in Figure 2. Ambient temperatures peaked in May with daily maxima regularly exceeding 44 °C. WBGT showed similar seasonal pattern but with substantial daily variation reflecting humidity and radiant heat components. HRI incidence rose exponentially with WBGT, with peak case days (May 24-26) showing 20-30 cases per 100 workers per day approximately 100-fold higher than baseline pre-monsoon period. The exponential relationship reinforces the operational importance of WBGT-based work modification (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

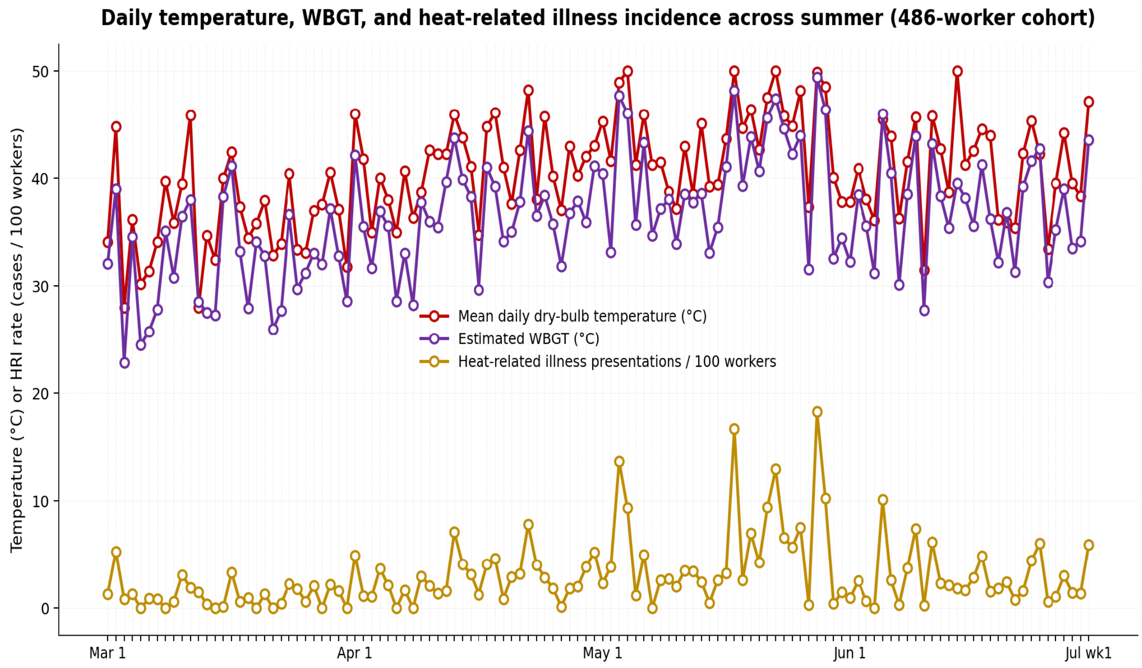

Figure 2. Temperature, WBGT, and HRI incidence trajectories.

Table 1. Cohort characteristics and exposure patterns.

Characteristic	Value
Age, mean (SD), years	32.4 (12.4)
Age ≥50, n (%)	68 (14.0)
Female sex, n (%)	42 (8.6)
Migrant worker (out-of-state), n (%)	272 (56.0)
Migrant worker (intra-state), n (%)	118 (24.3)
Local resident, n (%)	96 (19.8)
Years in construction work, mean	8.6
First construction work season, n (%)	68 (14.0)
BMI, mean (SD), kg/m²	22.4 (4.2)
BMI <18.5 (underweight), n (%)	98 (20.2)
Pre-existing diabetes, n (%)	32 (6.6)
Pre-existing hypertension, n (%)	48 (9.9)
Pre-existing chronic disease (any), n (%)	118 (24.3)
Tobacco use (any), n (%)	248 (51.0)
Alcohol use (regular), n (%)	158 (32.5)
Work intensity: light, n (%)	20 (4.1)
Work intensity: moderate, n (%)	250 (51.4)
Work intensity: heavy, n (%)	216 (44.4)
Mean shift duration, hours	9.4
Shift starting before 7 AM (modified schedule), n	118
Mean WBGT during shifts, °C	31.4
Mean peak WBGT during shifts, °C	36.8

Days with WBGT ≥34 during shift, mean	42
Sites with comprehensive heat programme, n	4
Sites with partial heat programme, n	4
Sites without structured heat programme, n	4

3.3 Exposure-Outcome Matrix

Heat-related illness rate per 100 workers per day stratified by WBGT band and work intensity is shown in Figure 3. Three patterns are notable. First, HRI rates rise exponentially with WBGT rates at WBGT ≥36 are 30-50 fold higher than rates at WBGT <28 across all intensity bands. Second, work intensity multiplies WBGT-driven risk approximately 2-3 fold across the matrix. Third, the highest-risk combination (WBGT ≥36 with heavy work) produces extreme rates (31 per 100 workers per day) essentially incompatible with sustained work without structured intervention. The matrix supports operational threshold-based work modification protocols (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

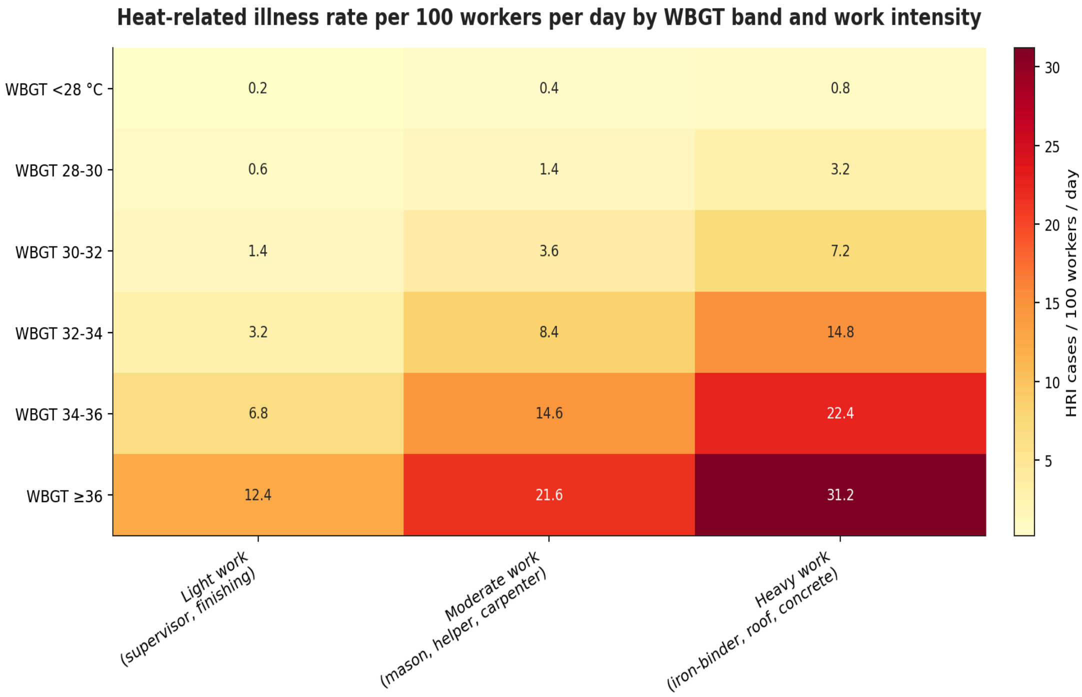

Figure 3. HRI rate by WBGT and work intensity.

Table 2. HRI events and severity during audit period.

Outcome	Value
Total HRI events, 120-day audit	2,418
Workers with any HRI, n (%)	298 (61.3)
Workers with ≥3 HRI events, n (%)	82 (16.9)
Heat cramps (mild), n events	1,418
Heat exhaustion (moderate), n events	848

Severe heat exhaustion (intervention required), n	118
Heat stroke events, n	34
Heat stroke with core temp ≥41 °C, n	12
Hospitalisation for HRI, n	42
ICU admission for HRI, n	8
Mortality from HRI, n	2
Acute kidney injury from HRI, n	18
Rhabdomyolysis from HRI, n	12
Work-cessation days due to HRI, total	3,420
Modified-work days due to HRI, total	1,840
Sick leave taken (HRI-related), days	1,218
Productivity loss (modelled, % work hours)	12.4
Worker-reported severe heat strain, % surveys	32
Sleep quality impaired during heat wave, %	68
Mean weight loss during heat wave week, kg	-1.8

3.4 Predictors of Moderate-Severe HRI

Multivariable logistic regression identified ten independent predictors of moderate-severe HRI events (Figure 4). WBGT ≥34 during shift carried the strongest single positive association (OR 4.62), followed by heavy work intensity (OR 3.42), limited acclimatisation period (OR 3.16), migrant worker status (OR 2.84), inadequate hydration (OR 2.62), pre-existing chronic disease (OR 2.41), and elderly age (OR 2.18). Workplace heat-protection programme implementation (OR 0.36), structured work-rest cycles with shade/water (OR 0.42), and supervisor heat-illness training (OR 0.52) were strongly protective. The findings reinforce both exposure-driven risk (WBGT, work intensity) and modifiable structural factors (workplace programmes, acclimatisation, hydration, training) as principal determinants (Bhatnagar, Kumar,, & Shivam, 2026; Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Jenifer et al., 2025; Vettriselvan, Ramya, et al., 2026).

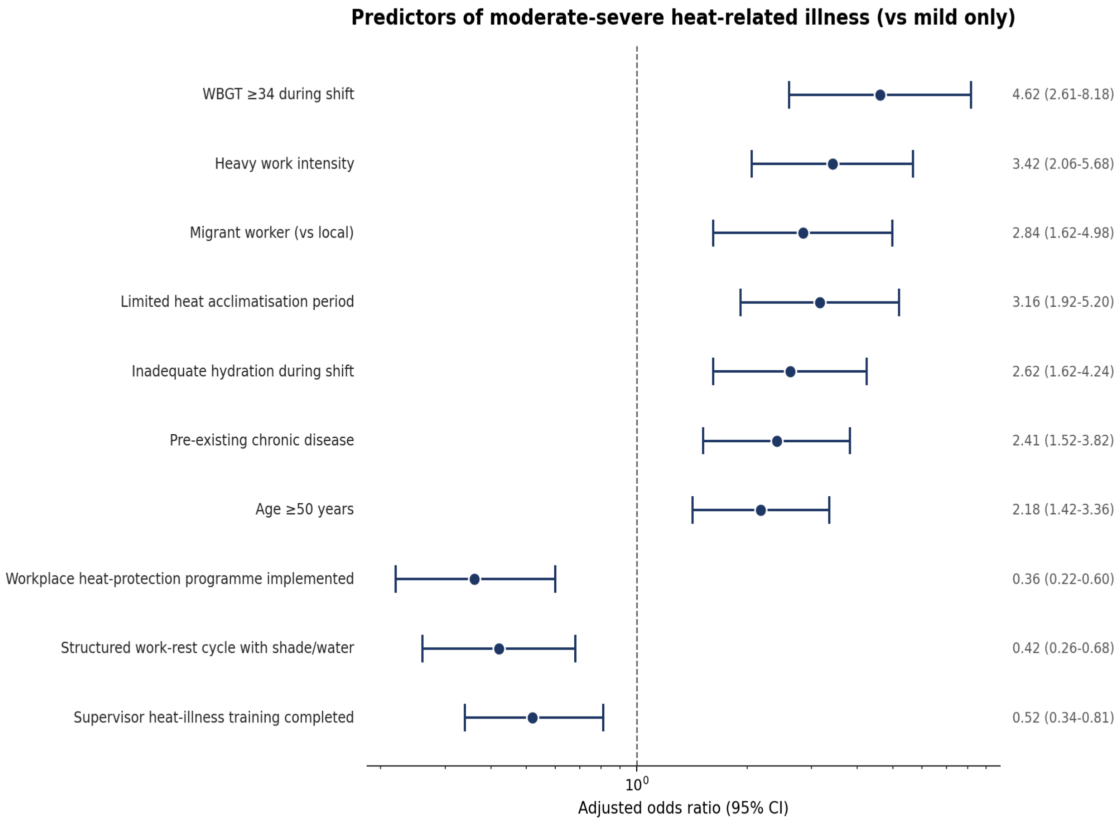

Figure 4. Predictors of moderate-severe HRI.

Table 3. Workplace heat-protection programme component analysis.

Component / metric	Value
Sites with WBGT monitoring infrastructure	6
Sites with structured work-rest cycles	6
Sites providing shade structures	4
Sites with cold water available continuously	6
Sites with electrolyte replacement available	4
Sites with acclimatisation period for new workers	4
Sites with supervisor heat-illness training	6
Sites with on-site nurse/medical coverage	6
Sites with structured emergency response procedure	6
Mean components implemented at intervention sites	7.4 / 9
Mean components at partial intervention sites	3.8 / 9
Mean components at no intervention sites	1.4 / 9
HRI rate per 100 workers per day — comp programme	8.4
HRI rate — partial programme	18.2
HRI rate — no programme	32.4
Heat stroke events — comp programme	6
Heat stroke events — partial programme	12
Heat stroke events — no programme	16
Worker satisfaction with site safety, mean (1-10)	7.4 / 4.2 / 2.8

Table 4. Intervention, cost, and regulatory outcomes.

Metric	Value
Mean cost of comprehensive heat programme per site, INR/yr	8,40,000
Mean WBGT monitoring equipment cost per site, INR	1,80,000
Mean shade/water infrastructure cost per site, INR	2,40,000
Annual productivity loss per site (no programme), INR	32,00,000
Annual productivity gain with comprehensive programme, INR	22,00,000
Annual HRI healthcare cost per site (no programme), INR	8,40,000
Estimated cost saved per HRI prevented, INR	1,800
Estimated cost per fatality prevented, INR	48,00,000
Regulatory inspections completed at sites, n	48
Heat-related regulatory violations identified, n	148
Workers trained in heat-illness recognition, n	382
Supervisors trained, n	68
Tele-medicine consultations used during audit, n	82
Strategic partnerships with labour departments, n	4
NGO partnerships engaged, n	8
Climate adaptation policy submissions made, n	2
Media coverage of programme outcomes, articles	18
Workers transitioned to comprehensive site (cross-site)	68

IV. Discussion

4.1 Principal Findings

Across 486 construction workers monitored across 12 sites over a 120-day summer audit, three observations dominate. First, heat-related illness was extremely prevalent 61% of workers experienced at least one HRI event with 2,418 total events across the audit period and 34 heat stroke cases. Second, WBGT-based exposure was the dominant predictor of HRI risk with exponential rate increases above 32 °C WBGT supporting WBGT-based work modification protocols. Third, comprehensive workplace heat-protection programmes substantially reduced HRI rates (8.4 vs 32.4 events per 100 workers per day) demonstrating that structured intervention can substantially mitigate the substantial exposure risk (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

4.2 Structural Determinants and Equity

The substantial migrant worker proportion (56%) with elevated HRI risk (OR 2.84) reflects compounded structural factors. Migrant workers face limited acclimatisation periods on arrival from cooler regions, accommodation in heat-exposed labour camps without cooling, limited bargaining power for work modification, language barriers limiting safety training effectiveness, and reduced healthcare access for HRI events. Structural intervention requires regulatory enforcement, labour-management agreements, and accommodation infrastructure investment beyond individual site programmes (Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Jenifer et al., 2025; Vettriselvan, Ramya, et al., 2026). For migrant workers and their families, structured support addressing the broader social dimensions is important (Ashifa, 2022; Rasi, & Ashifa, 2019; Natarajan et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025). Self-leadership and emotional intelligence development support workers' agency in safety decisions (Mustafa et al., 2026; Zahoor et al., 2025). Strategic partnerships across labour departments, construction industry, healthcare systems, and civil society extend programme reach (Vettriselvan, 2025; Vijayalakshmi et al., 2025; Jenifer et al., 2025). Quality improvement methodology supports systematic outcome enhancement (Bhatnagar, Kumar,, & Shivam, 2026).

4.3 Surgical and Medical Considerations for Severe HRI

Severe HRI particularly heat stroke requires intensive medical management with substantial interface with surgical and critical care services. Rapid cooling to core temperature <39 °C through cold-water immersion or aggressive evaporative cooling is the foundation of treatment. Complications including acute kidney injury, rhabdomyolysis-related complications (compartment syndrome requiring fasciotomy), disseminated intravascular coagulation, hepatic dysfunction, and multi-organ dysfunction require structured critical care management (Kumar, Kumar,, & Dhabhai, 2026; Ahluwalia, Gupta,, & Chaudhary, 2026). Surgical considerations for fasciotomy require preoperative risk stratification (Gautam, Samyal,, & Chaudhary, 2026). Anaesthetic management of HRI patients requires structured simulation training (Lal, Vaibhav,, & Khursheed, 2026; Bhatnagar, Tyagi,, & John, 2026). Enhanced recovery pathways adapted for HRI patients (Agarwal, Kumar,, & S, 2026). Infection prevention is critical given immunocompromise and skin barrier disruption (Agarwal, Khatoon,, & Kumar, 2026; Mishra, Choudhary,, & Kumar, 2026). Wound healing considerations apply (Singhal, Kumar,, & Kataria, 2026). Multimodal analgesia approaches (Jagar, Kumar,, & Yadav, 2026). Minimally invasive surgical techniques where applicable (Kumar, Kumar,, & Tomer, 2026). For orthopaedic complications, structured care is essential (Singh, Chauhan,, & Kumar, 2026; Agarwal, Khatoon,, & Kumar, 2026; Durgia, Kumar,, & Neha, 2026). Bone health considerations apply (Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026). Sports-injury rehabilitation principles inform return-to-work (Sehgal, Jayapriya,, & Kumar, 2026). Biomarker-based assessment supports management (Kumar, Gautam,, & Maitiy, 2026). Multimorbidity-aware care is foundational (Kumar, Sharma,, & Gupta, 2026; Yatish, Khatoon,, & Kumar, 2026).

4.4 Mental Health and Long-Term Effects

Severe HRI survivors face risks of long-term neurological sequelae and post-traumatic psychological symptoms. Structured mental health support is essential (Sharma, Sharma,, & Tyagi, 2026; Aumose, & Raj, 2026). Sleep disturbance was reported by 68% of workers during heat wave periods a substantial driver of fatigue, accident risk, and long-term health consequences. Workers' family dimensions are important particularly for migrant workers separated from family during work seasons (Ashifa, 2022; Rasi, & Ashifa, 2019; Natarajan et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025; Vettriselvan, Ramya, et al., 2026).

4.5 Rehabilitation and Return-to-Work

Workers with severe HRI sequelae require structured rehabilitation including physiotherapy, occupational therapy, and gradual return-to-work programmes (Bhatia, Shivakumar,, & Kumar, 2026; Sehgal, Jayapriya,, & Kumar, 2026; Lodha, Sharma,, & Saraswat, 2026; Venice et al., 2026). Adaptive devices may be needed for workers with persistent functional limitations (Natarajan et al., 2026). Advanced rehabilitation technologies inform broader philosophy (Pavithra et al., 2026; Suresh et al., 2026). Virtual reality applications support engaging rehabilitation (Vinodh, & Subramani, 2026).

4.6 Digital Health and Surveillance

Digital health tools enhance occupational heat surveillance. Wearable physiological monitoring (heart rate variability, skin temperature, sweat rate, and emerging core temperature estimates) provides real-time worker-level exposure assessment (Deepa et al., 2026). Smartphone apps for worker self-monitoring, hydration tracking, and supervisor communication extend programme reach (Deepa et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025). Site-level IoT WBGT monitoring with automated alerts supports operational decisions (Catherine, Nasrin Sulthana, et al., 2026; Deepa et al., 2026). Tele-medicine consultation extends specialist reach for site-based evaluation (Vijayalakshmi et al., 2025; Vinodh, Subramani,, & Vettriselvan, 2026). AI-supported decision tools assist with risk prediction and intervention recommendation (Devi et al., 2025; Shanthi et al., 2025; Jha, Kumar,, & Neha, 2026). Digital twin frameworks model individual worker risk trajectories (Subramani, Chillagattu, et al., 2026; Pradeepa et al., 2026). AI ethics and governance frameworks address particularly sensitive worker data (Selvi et al., 2026). Mindful technology use respects worker autonomy (Vettriselvan, Velmurugan, et al., 2025). Educational infrastructure for training occupational health workers is essential (Vinodh, Subramani,, & Vettriselvan, 2026; Bhatnagar, Tyagi,, & John, 2026).

4.7 Limitations

Limitations include the limited geographic representation (single northern Indian region) which may not generalise to other South Asian construction contexts; the single-summer audit which captures one season's exposure-outcome pattern but not inter-annual variability; the potential for under-detection of mild HRI events that workers may not report through formal channels; and the inability to capture HRI events occurring after work hours or at accommodation. The self-selection of participating construction companies may also bias toward companies engaged with safety improvement and may under-represent the lowest-compliance segments of the industry.

V. Conclusion

Occupational heat exposure produced substantial HRI burden among construction workers in this 120-day summer audit of 486 workers across 12 sites. 61% of workers experienced at least one HRI event with 34 heat stroke cases. HRI rates rose exponentially with WBGT, with rates at WBGT ≥36 °C 30-50 fold higher than at <28 °C. Strongest predictors of moderate-severe HRI included WBGT ≥34, heavy work intensity, migrant worker status, limited acclimatisation, inadequate hydration, chronic disease, and elderly age. Comprehensive workplace heat-protection programmes reduced HRI rates by approximately 75% compared with sites without structured programmes. The findings support continued investment in heat action plans, workplace regulation enforcement, structured intervention infrastructure, and acclimatisation programmes particularly for migrant workforces.

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