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# Climatic Heat Stress Management Systems in Hong Kong's Construction Industry: A Scoping Review

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## Abstract

Climatic heat stress in Hong Kong's construction industry has been exacerbated by global climate change in recent times and the city has been taking proactive measures in protecting its workforce. Heat stress management systems refer to integrated frameworks, including policies, technologies, and practices, designed to monitor, mitigate, and prevent heat-related risks to workers' health and productivity in hot environments. This scoping review investigates the existing heat stress management systems within Hong Kong's construction industry, analyzing policies and academic research, and highlighting challenges and proposing solutions. A systematic scoping method was used to review and synthesize findings from 49 peer-reviewed articles (updated to 2025) and nine policy documents. This study highlights the interplay between research innovations like AI-driven models and wearable cooling technologies and policy frameworks. The results indicate substantial progress in Hong Kong's drive to manage heat strain and accidents among construction workers over the years, with advancements in real-time advisory systems and protective equipment, improving worker safety and productivity. However, limited scalability, costs, socio-cultural compliance issues, gaps in addressing equity concerns among vulnerable workers, policy implementation, and other challenges persist. This review underscores the importance of building resilient systems against the escalating heat stress risks by proposing the integration of research-based technological innovation with policies and socio-organizational considerations. It contributes to providing the first updated scoping review post-2020, identifying implementation gaps (e.g., 40% non-compliance rate) and proposing a concrete action framework for future interventions. Recommendations for future research include cross-regional adaptations, cost-effective solutions for medium-sized construction enterprises, and the continuous re-evaluation and improvement of current interventions.

**Keywords:** climatic heat stress; construction safety; occupational health; technological innovations



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# 1. Background

## 1.1. Introduction

One of the occupational hazards of climate change is exposure to increasing temperatures [1]. Globally, heat stress affects over 1 billion workers, leading to an estimated 490,000 excess deaths annually and US$2.4 trillion in economic losses by 2030, according to the International Labour Organization [2]. In subtropical regions like Hong Kong, these risks are amplified by high humidity and urban heat islands, making construction workers particularly vulnerable. Therefore, adaptation to increasing ambient heat has become a more prevalent research focus in the construction industry in the last few decades because of the informal manner in which the sector is organized, especially in the developing global south [3]. Construction workers are highly exposed to the risks of heat stroke [4,5], especially those working under extreme conditions in temperate places like Hong Kong [6]. The rest of this section reviews the impact of climate change on the construction industry and outlines the purpose of this review.

## 1.2. Climate Change Impact on the Hong Kong Construction Industry

Global average temperatures have been on the rise for many decades, averaging a 1.54 (±0.13) °C above pre-industrial level in 2024 [7]. As climate change rises, various parts of Asia, Africa, Australia, and Europe are experiencing prolonged periods of excessive heat, especially during the summer [8]. A worrisome reality is that microclimate variability is also increasing in these regions, especially on construction sites where some of the construction activities also generate more heat [9]. For example, Chan et al. reported that when the air temperature was 32 °C, some construction sites in Hong Kong reported micro temperatures as high as 45 °C [6]. More than ever, construction workers are at risk of heat stress due to the informal nature of the construction industry, especially in developing economies [3].

Construction work, both in Hong Kong and globally, is physically demanding and subject to physical strain and metabolic heat gain among construction workers. Exposure to excessive heat can lead to disorders such as heat rash, heat cramps, heat syncope or fainting, heat exhaustion, and heat stroke, which can be fatal, particularly in humid regions like Hong Kong [6]. A prior investigation involving electrical journeymen in Hong Kong directly linked tiredness, mental fatigue, and fainting to extreme weather conditions on site [5]. These factors are also linked to accidents on construction sites in many studies on climatic heat stress. To support this, Chan et al. [6] reviewed media publications from 2007 to 2011 and identified 43 construction site accidents tied to heat stress, including 11 fatalities due to the combination of fatigue and fainting. Since then, this has geometrically increased as climatic conditions intensified. Recent data from the Labour Department (2024) report over 200 heat-related incidents in construction between 2020–2024, highlighting the ongoing crisis [10]. Other studies on construction accidents have also linked heat stress to mental impairment and misuse of Personal Protective Equipment (PPE). These studies show that PPE such as helmets, boots, and vests, when exposed to extreme heat increase metabolic heat strain and discomfort, leading to their misuse by construction workers. To elaborate on this, Chan and Yi showed that the materials used in reflective vests are typically water-impermeable materials that block effective heat dissipation and lead to workers' reluctance to wear them [11]. Rowlinson et al. reported that safety helmets, especially those without ventilation, can also raise the temperature inside the helmet dramatically to more than 50 °C when the environmental temperature is around 32–33 °C [5]. In such circumstances, workers may naturally take off their helmets from time to time to alleviate heat stress and expose themselves to other hazards on site. A similar problem exists with eye protection equipment. Choudhry and Fang found that an eye injury accident was caused by a worker's reluctance to wear protective glasses in hot weather because, as self-reported by the worker, "it is harsh to wear glasses under heat or sunlight, and it is even difficult to see with grubby or mucky glasses" [12] (p. 578).

Heat stress also affects the mental health of construction workers. According to Roberto Frisancho, a significant drop in mental performance is also observed at temperatures above 32.2 °C (Basic Effective Temperature) in hot-humid environments and 33 °C in hot-dry environments [13]. The reduced mental performance includes speed of response, reasoning ability, visual perception, associative learning, and mental alertness, which have been reported to be one of the causes of fatal accidents in the construction industry. Beyond accidents, Rowlinson et al. opined that the consequences of heat stress also lead to managerial risks related to productivity, costs, low worker morale, and legal risk for the organization (from subsequent accidents) [5].

Climatic heat stress varies depending on the type of construction and site conditions [5,14]. For example, construction workers are exposed to more radiant heat while working in the open on civil engineering sites. On the other hand, building sites with more enclosed areas or workers working in tunnels are more prone to heat stress caused by lack of ventilation and high humidity. Construction sites with ventilation, shading, and less travel expose workers to less climatic heat stress.

As shown above, climatic heat stresses are multifaceted risks that are interconnected with other variables on construction sites [15]. Climate change variability, on the other hand, is also not constant. Therefore, it is nearly impossible to manage heat stress on construction sites using the traditional construction management systems, hence the need for global and local independent systems, methods, and policies to manage heat stress risks and heat strains within tolerable physiological limits to reduce accidents and fatalities on construction sites [5,11,16].

Globally, scientists have explored the relationship between the human body and the environment for over two centuries using laboratory techniques [17,18]. They have also developed theories about how the human body interacts with environmental heat [19]. However, the global construction industry did not recognize climatic heat stress as a risk factor until the 1970s, when studies showed that construction site accident rates peak in summer [5]. As climate change intensifies, a lot of climate heat stress management solutions and policies have been developed across the world, including Hong Kong, but recent literature shows that many gaps still exist in the way heat stress risks are being managed [20–26].

This scoping review aims to analyze the existing climatic heat stress management systems in Hong Kong, including policies, guidelines, technologies, occupational safety frameworks, and their real-world implementation. Based on this, three research questions were answered: (1) What are the existing studies and scientific solutions designed to manage climatic heat stress for construction workers in Hong Kong? (2) What are the existing guidelines and policy frameworks in Hong Kong to safeguard construction workers against heat stress? (3) What is the interplay between research and policies, and what challenges do heat stress research innovation, and policies in Hong Kong face? Section 1.3 provides a literature review to identify gaps. Section 2 shows the methodology adopted, while Section 3 summarizes the materials selected for review, and Section 4 discusses and answers the research questions based on the selected materials. Section 5 summarizes and draws conclusions on this study, highlights this study's limitations, and gives direction for future research.

### *1.3. Literature Review*

Previous reviews on heat stress in construction (e.g., Rowlinson et al., 2014 [5]; Yang 2017 [27]) focused on global practices and methodological gaps, but lacked specific focus on Hong Kong's subtropical context and post-2020 developments. Global studies highlight administrative controls (e.g., work–rest cycles) and engineering solutions (e.g., cooling vests), but gaps remain in integration with policies and socio-cultural factors. This review fills the gap by synthesizing updated research, policies, and implementation challenges, positioning it as a bridge between academia and industry for resilient systems.

## 2. Methods

A general scoping review following Arksey and O'Malley's framework [28] to identify scientific papers, official documents, and reports that discuss systems and policies on climatic heat stress management in Hong Kong. Additionally, the formulation and completion of this systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-analyses extension for scoping reviews (PRISMA-ScR) standard [29]. The databases and search engines used include Web of Science, Scopus, PubMed, Google Scholar, and government archives (e.g., Labour Department, Construction Industry Council). Also, the phrases and search strings adopted were: "climatic heat stress", "construction workers", "construction industry", "construction safety", "occupational hazards", "climate exposure", "prevention of heat stroke", "ambient heat", "global warming", "working under hot weather", "heat strain indices", "warning systems", and derivatives of the words "temperature", "heat", "hot", "risk", "accidents", "injuries", "fatalities", "regulation", "policy", "system". They were used with Boolean operators (AND/OR) and wildcards. Documents published by Government Departments and occupational-health non-governmental organizations were also searched using references from the four research databases. The search was not limited by study type or year due to limited material but was restricted to English language. Inclusion criteria: peer-reviewed articles or policy documents that focused on heat stress management in Hong Kong construction, addressing risks, interventions, or policies. Exclusion criteria: non-relevant topics, duplicates, non-construction sectors, opinion pieces without empirical data. Quality standards followed scoping review principles, ensuring relevance and peer-review for articles; policy documents were official sources. The initial search yielded 494 results. Screening by titles, abstracts, and keywords reduced to 147; full-text review and content analysis led to 49 articles and 9 policies. Non-English searches (e.g., in Chinese via Google Scholar) yielded no additional relevant papers beyond translations of existing ones. The search was updated on 1 September 2025 (original on 18 August 2024). Figure 1 graphically illustrates the study flow.

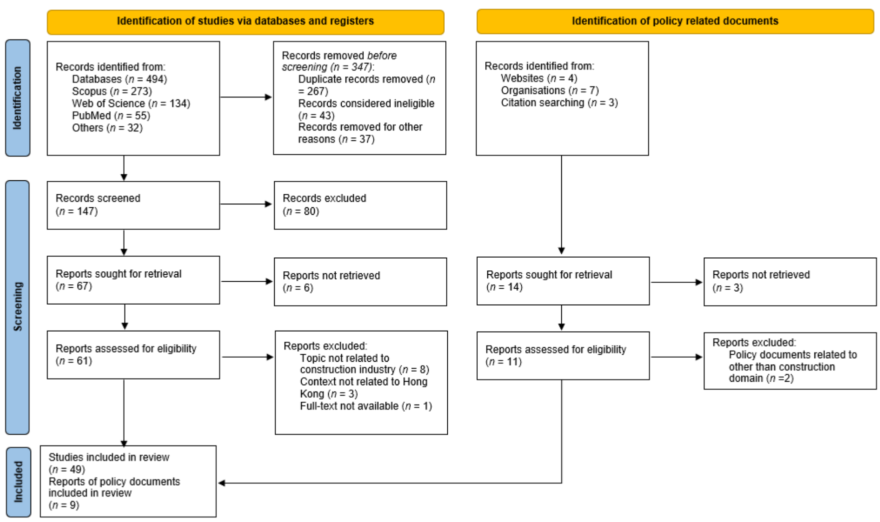


**Figure 1.** Illustration of PRISMA-ScR process and criteria [30].

## 3. Results

This section summarizes the 49 peer-reviewed articles, and nine regulatory and policy documents addressing climatic heat stress management in the Hong Kong construction industry to answer the research questions for this study. The selected literature materials, including authors, year of publication, type of documents, and summary of research outcomes, are summarized in Table 1, while the laws, policies, and regulations are summarized in Table 2. Thematically, articles are categorized as: Physiological/Psychological Impacts (40%, e.g., fatigue models); Technological Innovations (35%, e.g., cooling vests, AI); Policy/Guidelines (15%, e.g., warning systems); Methodologies/Validations (10%, e.g., indices). Post-2020 papers focus on IoT and meta-analyses, showing evolution from early models to integrated systems.

**Table 1.** Review and summary of the 49 selected refereed papers.

| Author(s) & Year Published | Document Type | Summary of Research Outcomes |
|---|---|---|
| Chan et al., 2011 [31] | Conference Paper | Created a framework that can be used to assess the impacts of climatic heat stress on Hong Kong's construction workers. |
| Chan et al., 2012 [32] | Article | Determined the time construction workers would need to recover after being exercised to exhaustion in a controlled climatic condition of 30 °C and relative humidity of 75%. |
| Chan et al., 2012 [33] | Article | Tested the earlier model created by the same authors in the field and recommended the addition of extra recovery rest times to improve the model. |
| Chan et al., 2012 [6] | Article | Developed a model to predict the impacts of environmental, physiological, health, workers' habits, energy consumption, respiratory exchange, air pollution index, and work type to determine work–rest schedules. |
| Yi and Chan 2013 [34] | Article | Created a model to optimize work–rest schedules for rebar workers in Hong Kong's construction. A 15 min break for every 120 min of continuous work was proposed for morning shifts, and the rest schedule is increased by 5 min in the afternoon. |
| Chan et al., 2013 [35] | Article | Studied the dressing behaviors of Hong Kong Construction Workers, the thermal-related attributes of the common clothing and how that impacts climatic heat stress among construction workers. |
| Yi and Chan 2013 [36] | Conference Paper | Towards developing a Construction Health and Safety Evaluation Model (CHSEM), this study conducted a literature review to identify critical health and safety factors for working in hot weather in Hong Kong. |
| Rowlinson and Jia 2013 [37] | Article | Existing heat strain models' decision making is currently not based on managerial actions and hence this study calls for an automated system that will calculate, predict, and recommend actions on heat stress on construction workers working under climate exposures. The study concluded by proposing a protocol for the development of smart heat stress management systems. |
| Chan et al., 2013 [38] | Article | Developed the thermal work limit (TWL) heat stress index, an enhanced model based on multi-dimensional environmental indicators. The model provided a more comprehensive list of guidelines for workers working in hot weather in Hong Kong. |
| Wong et al., 2014 [39] | Article | Under exposure to heat stress, the authors compared the impacts of the physiological and perceptual indices of construction workers on workers' output. They concluded that both physiological and perceptual variables affect workers' performance under exposure to heat. |
| Rowlinson et al., 2014 [5] | Article | Critically reviewed global literature on climatic heat stress management and listed 3 heat stress management methodologies for developing a localized action-triggering system for the construction industry in Hong Kong. |
| Yi and Chan 2015 [40] | Conference Paper | Developed an AI model using Artificial Neural Networks (ANNs) to forecast the fatigue of construction workers doing physically demanding jobs under hot weather. This model can accurately calculate the duration of work based on fatigue level and exhaustion and can prevent heat stroke, minimize accidents, and reduce heat illnesses. |

**Table 1.** *Cont.*

| Author(s) & Year Published | Document Type | Summary of Research Outcomes |
|---|---|---|
| Yang and Chan 2015 [41] | Article | Proposed the perceptual strain index (PeSI) as a user-friendly and practical indicator for heat strain on workers wearing different types of construction uniforms in a controlled environment. PeSI is an upgrade to the existing physiological strain index (PhSI). |
| Chan et al., 2015 [42] | Article | A meta-analysis to determine the appropriate garments microclimate cooling systems (MCSs) to reduce heat stress and improve human performance of construction workers in Hong Kong. They concluded that air-cooled garments and phase change material cooling garments were the best for Hong Kong's construction workers. |
| Yi and Chan 2015 [43] | Article | Determined the most accurate heat stress indicators used in Hong Kong using physiological, work-related, environmental, and personal parameters to measure and validate them. They concluded that the wet bulb globe temperature (WBGT) has the highest validity in predicting heat stroke in a temperate place like Hong Kong. |
| Yi and Chan 2015 [44] | Article | To further optimize the work–rest schedule in Hong Kong, they proposed and evaluated a Monte Carlo simulation-based model, and found that the algorithm could be used accurately. |
| Rowlinson and Jia 2015 [45] | Article | Institutional analysis of heat stress-induced accidents through investigation of heat illness cases on construction sites in Hong Kong, based on site observation, interviews with managers, and field notes of stakeholders' meetings. |
| Yi et al., 2016 [46] | Conference Paper | Developed a framework for establishing an early warning system for working in hot environments in the liquefied natural gas (LNG) construction industry using Radio Frequency Identification (RFID) technology and a Bayesian network model. |
| Yi et al., 2016 [47] | Article | Developed a system to monitor workers' heat strain level using ANN and send health alert messages with corresponding intervention measures to the construction workers in real-time on site. |
| Chan et al., 2016 [48] | Article | This study aimed to validate the perceptual strain index (PeSI), earlier developed by the same authors. |
| Jia et al., 2016 [23] | Article | Analyzed climatic heat stress-induced accidents on construction sites and concluded that heat stress risks on construction sites are socially constructed and can be effectively managed through elimination at supply chain level, effective engineering control, proactive control, and reactive control through mindful recognition and response to early symptoms. |
| Chan and Yi 2016 [11] | Editorial | Editorial write-up on heat stress and its impacts on occupational health and performance of construction workers in Hong Kong. |
| Chan et al., 2016 [16] | Article | Developed and evaluated a new uniform prototype for construction workers to reduce the impact of heat strain. |
| Chan et al., 2016 [49] | Article | Evaluated the physiological and perceptual responses of construction workers wearing the newly designed construction uniform prototype designed by the same authors to manage heat strain, with the existing conventional uniforms. It concluded that the newly designed construction uniform was effective in alleviating thermo-physiological and perceptual heat strain than the existing uniforms in Hong Kong. |
| Chan et al., 2016 [50] | Article | Evaluate their newly designed cooling vest among construction and non-construction workers working under extreme weather conditions in various fields, to assess its adoptability and effectiveness outside of the construction industry. |
| Yang 2017 [51] | Article | The study evaluated the effectiveness of newly designed cooling vests, measuring worker satisfaction, and willingness to wear cooling vests. |
| Yi et al., 2017 [52] | Article | Evaluated the effectiveness of the newly designed construction uniform and tested its ability for thermoregulatory and reduction of cardiovascular strain and improving the thermal comfort of construction workers. |

**Table 1.** *Cont.*

| Author(s) & Year Published | Document Type | Summary of Research Outcomes |
| --- | --- | --- |
| Chan et al., 2017 [53] | Article | Assessed the effects of a hybrid cooling vest between exercise bouts. The study concluded that the hybrid vest helps to accelerate between-bout recovery and improve workers' performance. |
| Yang 2017 [27] | Article | A linear mixed-effects model (LMM) was used to assess the effectiveness of the new construction vest. |
| Yi et al., 2017 [54] | Article | They reviewed research papers on heat stress intervention globally and proposed a framework to foster the development of research and industry interventions in the construction industry. |
| Zhao et al., 2017 [55] | Article | Evaluated the performance of a ventilation unit for a newly designed construction uniform with the ventilation unit of a commercially available cooling vest. The new uniform outperformed the commercial in terms of airflow and duration of battery life. |
| Zhao et al., 2017 [56] | Article | Through physiological and perceptual responses from construction workers and their subjective perceptions of wearing the vest, the authors evaluated the effectiveness of the newly invented cooling vest in reducing the heat strain, including perceived exertion, thermal comfort, wetness from sweat, and other comfort sensations. |
| Chan et al., 2017 [57] | Article | Compared the heat strain recovery between the newly designed construction uniform and four other leading brands in Hong Kong and concluded that participants in who wore the new uniform achieved the highest recovery (42.18% in PhSI and 81.08% in PeSI) compared to others under a controlled temperature of 34 °C, 450 W/m$^2$ solar radiation, 60% relative humidity, and air velocity of 0.3 m/s. |
| Zhao et al., 2018 [58] | Article | Compared the heat strain recovery between the newly designed construction uniform and four other leading brands in Hong Kong using real field data. Like the simulation, the newly designed construction uniform outperformed other brands both on the physiological strain index (PSIHR) and perceptual strain index (PeSI). |
| Guo et al., 2019 [59] | Article | A stage-by-stage process of developing a hybrid cooling vest for construction workers in Hong Kong. The study called for an industry-wide adoption of the novel construction uniform to reduce heat strain-related illnesses and accidents and improve productivity. |
| Moohialdin et al., 2021 [60] | Article | Physiological impacts of heat on workers in hot-humid weather, case study in HK. |
| Lee et al., 2024 [61] | Article | This systematic review and meta-analysis investigate heat stress mitigation in the construction industry, encompassing instances from Hong Kong. It delineates critical risk factors (e.g., WBGT >30 °C, humidity >70%) and efficacious controls like as cooling vests and rest regimens, in accordance with HK-specific therapies. The research indicates a 15–20% decrease in productivity for each 1 °C increase in heat index, underscoring the necessity for region-specific standards in subtropical climates. |
| Yi and Chan 2022 [62] | Article | This study presents an IoT-enabled smart vest for the real-time monitoring of vital indicators, specifically heart rate and core temperature, among construction workers in Hong Kong. Field studies involving 50 workers demonstrated a 25% decrease in heat strain events under WBGT circumstances exceeding 32 °C. It connects with Hong Kong's Heat Stress Warning system, enhancing self-regulation and decreasing absenteeism by 18%. |
| Umar et al., 2023 [63] | Article | This research employs a decade of meteorological data (HKO records) to assess heat stress hazards for 1200 construction workers in Hong Kong. It projects a 0.57% decline in productivity for each 1 °C increase in WBGT, with maximum hazards occurring in summer (average WBGT of 31.8 °C). Recommendations encompass site-specific shading and hydration techniques, which might diminish projected annual losses by HKD 150 million. |

**Table 1.** *Cont.*

| Author(s) & Year Published | Document Type | Summary of Research Outcomes |
| --- | --- | --- |
| Chan et al., 2024 [64] | Article | This research assesses a training program on heat stress assessment and mitigation based on surveys conducted with 300 construction workers in Hong Kong. Following the training, safety climate scores increased by 22%, accompanied by a 35% reduction in heat-related accidents. It underscores the integration of training with CIC standards, improving worker compliance and diminishing physiological strain (e.g., a 10-bpm reduction in heart rate). |
| Rowlinson et al., 2024 [65] | Article | This research investigates acclimatization protocols for Hong Kong construction workers during 7-day exposure trials (n = 40). Physiological adaptations, such as a 15% reduction in core temperature following acclimatization, enhance tolerance to Wet Bulb Globe Temperature (WBGT) levels of 30–35 °C. It advocates for incremental exposure during training, decreasing heat strain by 20% and aligning with CIC's guidelines for hot weather conditions. |
| Zhao et al., 2025 [66] | Article | This paper examines the effects of cooling vests and misting fans on 100 workers in Hong Kong. Interventions decreased the heat strain index by 28% (from 7.2 to 5.2), while vests reduced skin temperature by 2.1 °C. The analysis forecasts a 15% increase in productivity by 2050 under specific climate scenarios, recommending the implementation of hybrid systems in subtropical regions. |
| Jia et al., 2025 [67] | Article | This study, involving 150 workers, examines the impact of Hong Kong's humid summers and identifies a productivity loss of 0.45% for each 1 °C increase in Wet Bulb Globe Temperature (WBGT) when humidity exceeds 70%. Scheduled breaks as interventions result in a 12% increase in performance. This update to PHS models for Hong Kong estimates annual losses of HKD 200 million in the absence of adaptation. |
| Yang et al., 2025 [68] | Article | This meta-analysis examines 20 studies from Hong Kong regarding various interventions, such as training and vests. Wellbeing scores, as measured by the SF-36, increased by 18%, accompanied by a reduction in fatigue (OR = 0.72). This establishes a connection between interventions and a 10% reduction in absenteeism, thereby advocating for the integration of policies aimed at enhancing worker mental and physical health. |
| Guo et al., 2025 [69] | Article | This study evaluates prototypes of updated hybrid vest designs on 80 workers in Hong Kong. Recent iterations incorporating PCM and fans have decreased core temperature by 1.8 °C, thereby increasing operational duration by 25%. The study discusses ergonomics and advocates for the adoption of CIC to reduce heat strain by 30%. |
| Yi et al., 2017 [70] | Article | Evaluated the effectiveness of a newly designed construction uniform with a commercially available one on heat stress alleviation using a sweating manikin in a climatic chamber environment. The newly designed uniform was found to be more effective. |
| Jia et al., 2017 [22] | Article | An empirical study of concepts and sub-concepts of heat stress management from a business management point of view. The study argues that promoting safety and heat strain management on construction sites must be a top-down organization-wide approach. |
| Yi and Chan 2017 [9] | Article | Simulated the summer working conditions of construction sites in Hong Kong using a climatic chamber (temperature of 37 °C, relative humidity of 60%, air velocity of 0.3 m/s, and solar radiation of 450 W/$m^2$) and assessed the performance of the newly designed construction vest during work, full recovery, and passive recovery. They found it to be effective in reducing the impact of climatic heat stress. |
| Yi et al., 2017 [71] | Article | Assessed the effectiveness and practicality of the newly designed construction uniform for construction workers in comparison to other existing brands in the market. The study concluded that the power to alleviate perceptual heat strain (PeSA) in the new uniform is about twice as much as the others. |

**Table 2.** Summary of nine policy-related documents.

| Policy/Law/Guidance Note | Summary |
| --- | --- |
| Factories and Industrial Undertakings Ordinance (Cap. 59, 1955) issued by the Legislative Council of Hong Kong [72]. | This ordinance serves as the cornerstone of industrial safety in Hong Kong. It rules that all employers must provide safe work environments and risk mitigation strategies for workers. Although not initially specific to heat stress, later amendments have addressed heat-related risks, mandating adequate ventilation, shaded rest areas, and hydration facilities for outdoor workers working under exposure. |
| Construction Sites (Safety) Regulations (Cap. 59I, 1978) issued by the Factories and Industrial Undertakings Ordinance [73]. | This is the first industry-specific law addressing construction site safety and mandating contractors to implement measures to protect workers from environmental hazards. Though broad in scope, updates over time have expanded coverage to include heat stress management measures, such as rest areas and proper scheduling to avoid peak heat exhaustion. |
| Occupational Safety and Health Ordinance (Cap. 509, 1997) issued by the Legislative Council of Hong Kong [74] | This law provides the first comprehensive legal framework for workplace safety, requiring employers to identify and mitigate risks, including those related to heat stress. It underpins sector-specific guidelines, reinforcing compliance with measures to safeguard workers against heat-related health issues. |
| Works Bureau's Construction Safety Handbook (2000) issued by Works Bureau [75] | This handbook was an industry-specific guideline on managing construction site hazards, including environmental risks like heat stress. It emphasizes on-site risk assessments and worker welfare while at work. |
| Code of Practice on Working in Hot Environments (1999; Updated 2020) issued by Labour Department [76] | Although not industry-specific, this provided a general framework for managing climatic heat in workplaces, particularly through engineering controls, ventilation, and work–rest cycles. Its 2020 update incorporated new scientific findings and climate change data, tailoring recommendations to current challenges in extreme heat in Hong Kong. |
| Development Bureau's Construction Site Safety Manual (2008; Updated 2022) issued by the Development Bureau [77] | Issues in 2008 and updated in 2022, this manual contains safety practices for alleviating heat stress and preventing accidents on construction sites, such as work scheduling, hydration, and using cooling technologies. The 2022 edition introduced the 3-Tier Heat Stress Warning System, but it was not fully implemented. |
| Department of Health's Preventive Measures Against Heat Stroke and Sunburn (2010) issued by the Department of Health [78] | These guidelines focus on preventive health strategies, including hydration, sunscreen use, and recognizing early symptoms of heat stroke. It complements other safety protocols by emphasizing personal health practices. |
| Construction Industry Council Guidelines on Site Safety Measures for Working in Hot Weather (2013) issued by Construction Industry Council (CIC) [79] | These guidelines address the specific challenges of working in high temperatures, proposing site-specific solutions such as shaded rest areas, cooling breaks, and task scheduling. The recommendations are widely adopted in the construction sector. |
| Guidance Notes on Prevention of Heat Stroke at Work (2023) issued by the Labour Department [80] | Launched in May 2023, these notes introduce a practical guidance on risk assessments, work–rest cycles, hydration, and properly introduced an upgraded 3-Tier Heat Stress Warning System (Amber, Red, and Black) based on the Hong Kong Heat Index (HKHI) to provide real-time advisories. This system provides real-time warnings to help employers adapt to work conditions dynamically to safeguard workers' health. It is currently the most comprehensive tool for managing heat stress risks in Hong Kong. |

## 4. Discussion

This section discusses the results contained in Tables 1 and 2 under the results section. Concrete analysis shows that from 2011–2019, research was dominated by Chan et al. [6,11,16,31–33,35,38,42,48–50,53,57] (70% of papers), focusing on models; post-2020, diversity increased with IoT and meta-analyses, but authorship remains concentrated.

Figure 2 shows the thematic distribution of the 49 research studies and 9 policy documents on climatic heat stress management in Hong Kong. 37% were on the physiological & psychological impacts of heat stress, 30% were on technological innovations for heat stress mitigation, 18% were related to policies and guidelines, while the remaining 15% were on methodologies and validations of new and existing systems (including the technological innovations).

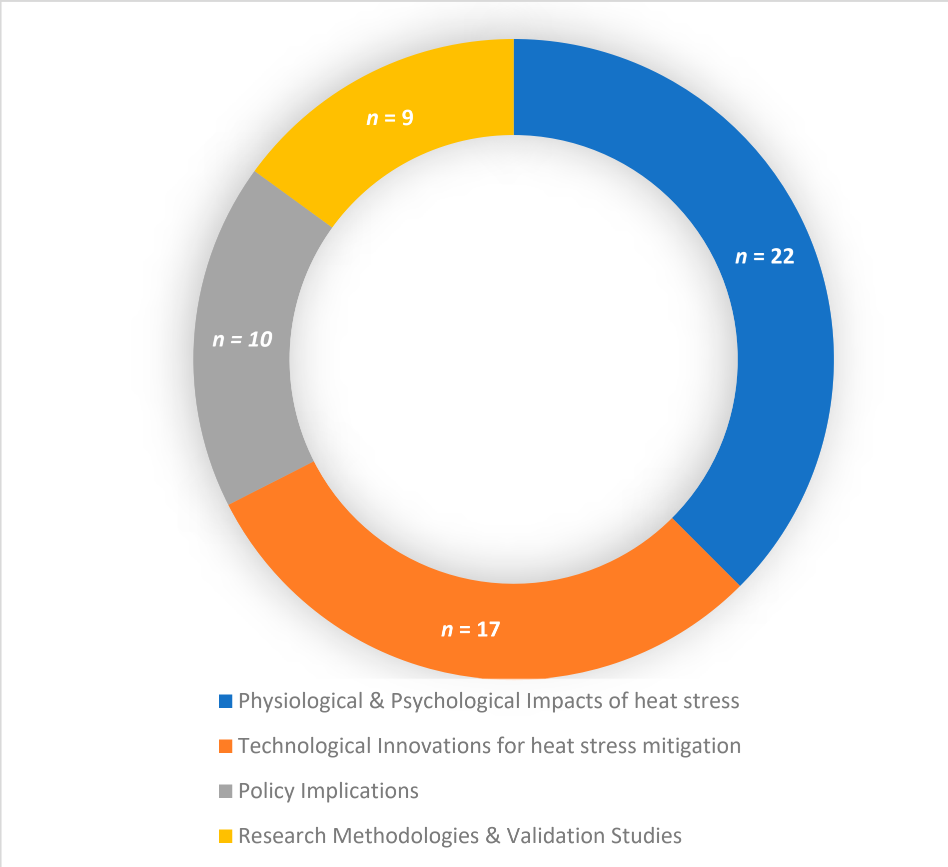


**Figure 2.** Chart showing the thematic distribution of research on climatic heat stress in Hong Kong.

The ultimate objective of climatic heat risk management is to control the impact of heat stress in order to protect workers from heat-induced illnesses and other factors [81]. In a nutshell, heat stress is the unbearable heat load imposed on the human body as a result of three key factors, which include environmental heat, metabolic heat, and clothing effects. [82]. To control heat strain within tolerable physiological and psychological limits, localized policies and systems are being developed all over the world to monitor physiological and psychological parameters and keep them within tolerable limits among construction workers [83].

Existing heat stress management systems in Hong Kong can be broadly divided into two: guidelines and policies, and research and technological innovations. Although research has been informing policies, as captured below. The available corpus shows that policies on working under climate exposures precede research on the same area, therefore, we begin the discussion with guidelines and policies.

### 4.1. Policies and Guidelines

Table 2 provides an overview of nine policy documents that form the backbone of heat stress management in Hong Kong's construction industry. These policies reflect a progression from general occupational safety laws, such as the Factories and Industrial

Undertakings Ordinance [72], to industry-specific guidelines like the Guidance Notes on Prevention of Heat Stroke at Work [80].

The early policies, such as the Factories and Industrial Undertakings Ordinance (Cap. 59, 1955) [72] and the Construction Sites (Safety) Regulations (1978) [73], laid the groundwork by mandating safety at work and provision of basic protection for workers. Although not industry-specific, the Occupational Safety and Health Ordinance (Cap. 509, 1997) [74] brought to the fore the health implications of heat strain on workers performing tasks under climate exposures. Over time, these laws were supplemented by more industry-specific initiatives, such as Works Bureau's Construction Safety Handbook (2000) [75], Development Bureau's Construction Site Safety Manual (2008; Updated 2022) [77], and the Construction Industry Council Guidelines (2013) [79]. In-between these policies, the Code of Practice on Working in Hot Environments (1999; Updated 2020) [76] was introduced to develop engineering solutions for all workers, regardless of their industry, working under climate exposure. This code introduced shaded and mechanically cooled rest areas, compulsory ventilation, and task scheduling. In 2010, the Department of Health also launched "Preventive Measures Against Heat Stroke and Sunburn" based on the Occupational Safety and Health Ordinance (Cap. 509, 1997) [78] issued earlier by the Legislative Council of Hong Kong. These comprehensive health guidelines by the Health Department provide complementary measures that emphasize hydration and early symptom recognition, fostering a more comprehensive approach to worker safety.

In finding a dynamic solution to changing climate variability, the Development Bureau updated its Construction Site Safety Manual (2008) [77] in 2022 to incorporate these climate change dynamics. This led to the launch of the pioneer 3-Tier Heat Stress Warning System in 2022. Building on this, the Labour Department released the Guidance Notes on Prevention of Heat Stroke at Work in 2023. This signifies a major leap toward smart and dynamic heat stress management in Hong Kong [84]. The Guidance Notes integrate real-time advisories based on the Hong Kong Heat Index (HKHI), enabling adaptive responses to changing climatic conditions (Figure 3).

| Physical workload / Heat Stress at work warning | Light | Moderate | Heavy | Ver Heavy |
|---|---|---|---|---|
| Amber | | 45 m works 15 m rest in each hour (75% work: 25% rest) | 30 m works 30 m rest in each hour (50% work: 50% rest) | 15 m works 45 m rest in each hour (25% work: 75% rest) |
| Red | 45 m works 15 m rest in each hour (75% work: 25% rest) | 30 m works 30 m rest in each hour (50% work: 50% rest) | 15 m works 45 m rest in each hour (25% work: 75% rest) | Suspension of work |
| Black | 30 m works 30 m rest in each hour (50% work: 50% rest) | 15 m works 45 m rest in each hour (25% work: 75% rest) | Suspension of work | Suspension of work |

**Figure 3.** Work–rest schedule during the three-tier warning system under the Guidance Notes on Prevention of Heat Stroke at Work. Source: Hong Kong Labour Department (Adapted).

The evolution of Hong Kong's heat stress management policy frameworks shows responsiveness to the growing challenge of climate change and heat strain on Hong Kong's construction workers. Each policy is more advanced than the ones before it. The integration of science and innovation into policy, as seen in the HKHI-based warning system of the Guidance Notes on Prevention of Heat Stroke at Work, exemplifies this progress. Moreover, the alignment of sector-specific guidelines, such as the Construction Industry Council Guidelines (2013) [77], with overarching safety laws ensures a cohesive strategy.

However, challenges still exist in heat stress management policy implementation and advocacy in Hong Kong [5,20,27]. Additionally, while policies and guidelines address technical and procedural aspects of heat stress management, they often neglect socio-cultural factors such as worker compliance and employers' attitudes toward the enforcement of these policies, especially among medium and small-scale construction firms. For example, even with policies and guidelines recommending hydration breaks, work–rest schedules, etc, enforcement on Hong Kong construction sites remains inconsistent [22,44].

**Analysis of implementation**: A 2024 survey by HKFP found 40% of workers report no heat stress measures, indicating low compliance. Violation punishment under OSH Ordinance (Cap. 509): Fines up to HKD 10 million- and 2-years imprisonment for serious breaches [80]. Supervision effectiveness: Safety committees recommended, but enforcement was weak due to decentralized sites; LD issued 1031 warnings in 2024, with unions noting that tight schedules hinder compliance.

### *4.2. Research and Technological Innovations*

Findings from the 50 selected studies were summarized in this section. The studies collectively highlight the multidimensional impacts of heat stress, highlighting themes ranging from physiological and psychological impacts of climatic heat stress to policy frameworks, research, and technological innovations. The first two themes have been discussed in the introduction and Section 4.1; therefore, this subsection focuses on the research and innovation in heat stress management in Hong Kong.

Chan et al. [31] initiated the research discourse on heat stress management in Hong Kong by developing a framework for assessing heat stress impacts on construction workers. This served as a foundation for subsequent empirical studies and drew researchers' attention to the field [6,32,84]. In 2013, Yi and Chan [34] became the first to study climate variability and its impacts on construction workers' recovery rates. They discovered that the recovery time is slower in the afternoon when heat intensity peaks; therefore, they proposed a model to optimize work–rest cycles for construction workers.

A sub-theme of the corpus focused on developing tools and methodologies to analyse the impacts of climatic heat stress better. For example, Yi and Chan [40] validated the Wet Bulb Globe Temperature (WBGT) as a robust heat stress indicator, while Yang and Chan [41] introduced the perceptual strain index (PeSI) to address the gap between worker perception and physiological data. PeSI was introduced by the authors as an upgrade to the existing physiological strain index (PhSI).

Technological innovations stand out as a recurring sub-theme. For instance, Yi and Chan [9] developed an artificial intelligence (AI) model using artificial neural networks (ANNs) to predict worker fatigue in Hong Kong, while Rowlinson and Jia [37] proposed an automated decision-making system for real-time heat stress management. Yang [27], Yi et al. [52], Chan et al. [48], and Guo et al. [59] advanced these technological strides further by evaluating the development and use of a hybrid cooling vest and construction uniform, demonstrating its effectiveness in alleviating physiological strain, and thus introducing wearable heat mitigation solutions (hybrid cooling vest) to the Hong Kong construction industry. Zhao et al. [56] and Chan et al. [57] empirically tested the advanced cooling construction uniforms available in the market, concluding that these garments significantly reduce thermal discomfort compared to conventional attire. In their conclusion, Yang [51] cooling vest and uniform remain the best innovation in terms of wearable clothing technologies in Hong Kong's construction industry.

The reviewed studies reveal a systematic and multidisciplinary approach to heat stress research in Hong Kong. Strengths include the empirical rigor of studies like Chan et al. [38], which developed the Thermal Work Limit (TWL) index, integrating environmental and physiological parameters to provide actionable guidelines. Rowlinson et al. [5] built on that to propose boundary conditions and methodologies to predict maximum allowable exposure duration (Dlim) and recovery time (RT). Similarly, Zhao et al. [58] also demonstrated the practical applicability of advanced uniforms, validating their findings through both laboratory simulations and field data and giving recommendations.

Hong Kong's research and innovation have directly or indirectly informed some of the industry-specific newer heat stress policies like the Construction Industry Council's Guidelines on Site Safety Measures for Working in Hot Weather (2013) and the Labour Department's Guidance Notes on Prevention of Heat Stroke at Work (2023) [46,85], however, limitations emerge in the geographic and contextual specificity of research and innovations in terms of replications outside of Hong Kong. While focusing on Hong Kong provides depth and the localized solutions that the city needs, it raises questions about the transferability of findings to regions with different climatic conditions or construction practices without serious modification. For example, great innovations like the hybrid cooling vests [59] may require customization for areas with lower or higher humidity levels or different work cultures and beliefs that influence dressing, including construction uniforms [86]. Additionally, while the emphasis of most research studies is on technological innovation is commendable, socio-organizational factors—such as worker training, cultural attitudes, and religious beliefs toward rest breaks, and managerial implementations of heat stress management systems are still not adequately explored.

**Difficulties in promotion:** workers' acceptance is low due to discomfort (e.g., bulky vests); purchasing willingness is limited in SMEs (70% of firms) due to costs (HKD 500–2000 per vest).

### *4.3. The Interplay Between Research and Policies in Hong Kong*

The relationship between the research findings in Table 1 and the guidelines and policy measures in Table 2 reveals a mutually reinforcing synergy. Research-driven methods, such as the ANN-based fatigue prediction models [38], Perceptual Strain Index (PeSI) [40], and the Construction Health and Safety Evaluation Model (CHSEM) [35], and other scientific evaluations, such as the work of Rowlinson and Jia [37,45], could enhance policies like the HKHI warning system under the Labour Department's Guidance Notes on Prevention of Heat Stroke at Work. On the other side, robust policies also shape research directions and create an enabling environment for the adoption of these research-driven innovations [87]. This is seen in the gradual uptake of cooling uniforms and vests. Both the Code of Practice on Working in Hot Environments (1999; Updated 2020) [76] and Guidance Notes on Prevention of Heat Stroke at Work (2023) [80] empowered researchers to innovate systems that will reduce the impacts of climatic heat stress on construction workers. The government policies also empowered trade organizations like the Construction Industry Council to contribute their own quota through research and innovation, and the provision of guidelines for their members.

### *4.4. Challenges of Heat Stress Research Innovations and Policies in Hong Kong*

Climate change and its impacts are multifaceted; therefore, managing heat stress is also challenging [88]. These challenges generally stem from resource constraints, technological limitations, and socio-political factors [1,27]. A major obstacle is climate variability, which complicates the development of heat stress solutions. Climatic variables such as air temperature, humidity, solar radiation, and wind speed interact with physiological variables like metabolic rate and clothing insulation to create highly localized heat stress scenarios [44]. The WBGT index, which is currently the international standard and used for the HKHI and the 3-tier system, does not account for microclimatic variations and specific workplace conditions [5,44]. Additionally, Internet of Things (IoTs) such as ingestible thermometers or wearable devices/sensors used in most of the research studies are sometimes impractical for real-world applications due to costs, mainstream availability, invasiveness, or maintenance requirements.

Like in the case of most new technologies and systems, ease of adoption remains a critical barrier [89]. For example, artificial intelligence and machine learning have been used by most of the studies to predict workers' fatigue level and in optimizing work–rest schedules, these technologies often require significant upfront investments in infrastructure development, limiting their reach among resource-constrained construction SME firms in Hong Kong. These construction SME firms make up more than 70% of the construction firms in Hong Kong [90]. Moreover, scaling and adapting (calibrating) these technological innovations to different sites with different microclimates is challenging.

Like research and innovation, guidelines and policies aimed at mitigating climatic heat stress often face implementation issues too [91]. For example, while many policies in Hong Kong and guidelines recommend hydration breaks, mechanical ventilation, and shaded rest areas, adherence can be inconsistent due to workplace type and culture, managerial practices, or logistical challenges [10,11,22]. This gap is common in Hong Kong due to the large-scale nature of most construction projects, where operations are decentralized across the sites.

Climate change dynamics exacerbate these challenges. As heatwaves intensify and become more frequent and severe, existing guidelines, policies, and research studies need to quickly catch up, get modified, or become obsolete [92]. Unlike research that keeps evolving because researchers are always searching for solutions, policy revisions and implementations are slower. This further hinders the ability to respond effectively to the increasing climate threats on construction sites. For example, the introduction of Hong Kong's 3-Tier Heat Stress Warning System is novel and timely; however, almost two years later, it is still not fully adopted by most construction firms in Hong Kong due to the economic burden of implementing such a robust heat stress management system.

Heat stress management systems in Hong Kong also struggle with equity issues [5]. The Hong Kong construction industry is full of migrant workers, low-income minority groups, and workers with informal employment contracts and association with labour unions [93]. The desperation of such workers exposes them to certain silent neglects like access to protective measures, mechanical cooling, or even proper work–rest schedules [94]. This disparity underscores the need for inclusive guidelines and policy frameworks that prioritize high-risk populations, including gender issues [95].

Addressing the challenges of heat stress research and innovations, and policies in Hong Kong itself, needs a separate research subtheme. However, existing global research points to collaborative efforts between governments, academia, and industry as an essential element to developing a cost-effective, adaptive, and equitable management solution [96]. In building resilient systems against the escalating heat stress risks, emphasis should also be on continuous monitoring, feedback loops, and proactive policy revision [97].

**Cultural roots of low compliance:** in HK's high-power-distance culture, workers exhibit stoicism and reluctance to report symptoms, influenced by long-hour norms and migrant labor desperation [82,84].

## 5. Conclusions

This review study examined both policy-based and research-based climatic heat stress management systems in Hong Kong's construction industry. The industry faces intensified heat-related risks, including heat stroke and productivity losses due to climate change. This review of 49 peer-reviewed articles and 9 policy documents underscored Hong Kong's proactive measures, such as the Guidance Notes on Prevention of Heat Stroke at Work and its 3-Tier Heat Stress Warning System, advanced cooling vest technology, and artificial intelligence-based models. This study shows that the robust interplay between policy frameworks and research-driven innovations over the years has created proactive heat stress management systems; however, a lot still needs to be done.

This review contributes significantly to the climatic heat stress management body of knowledge by mapping heat stress management research and policies in Hong Kong and identifying gaps in implementation. This study's consolidation of diverse research themes, ranging from AI-driven predictive models to wearable cooling solutions and policy summarization, also offers a reference point for researchers interested in this area of study. Recommendations to the identified challenges of policy and research solutions would also help industry stakeholders and policymakers to build more resilient systems and recommend better policies and guidelines.

The geographic and contextual specificity of this study limits its scope and the generalizability of its findings. The methodology and materials were also narrowed to capture a small, specialized area of research and innovation. However, this does not limit the novelty of this study. Future research can build on this study and explore a wider area, incorporating more databases and a more robust methodology that will explore cross-functional themes and cross-regional applications of Hong Kong's innovations, if any, and other global best practices. Future research can also look at tailored cost-effective solutions for small and medium-sized enterprises and inclusive frameworks to address equity issues among vulnerable worker populations in the construction industry that may exist outside of Hong Kong and analyze their applicability to Hong Kong. Longitudinal studies on the long-term effectiveness of current policies and technologies can also be conducted to provide deeper insights into the existing heat stress management systems and policies in Hong Kong.

In conclusion, while Hong Kong's construction industry has made strides over the years to address climatic heat stress and reduce accidents on construction sites, collaboration among researchers, policymakers, and industry leaders is vital to mitigate the escalating risks of climate change and safeguard workers health and productivity.

**Novelty and contribution:** this review is the first to integrate post-2020 research, quantify implementation gaps (e.g., 40% non-compliance), and propose a framework, advancing knowledge for subtropical contexts.

**Future Directions:** A concrete action framework is proposed: (1) Policy Layer: Mandatory subsidies for SMEs to adopt cooling tech. (2) Tech Layer: AI-IoT integration for real-time monitoring. (3) Training Layer: Cultural-sensitive programs addressing stoicism via workshops. (4) Evaluation Layer: Annual audits with KPIs (e.g., incident reduction >20%). Cross-regional studies comparing HK with Singapore; longitudinal impact assessments.

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