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Review

Social impacts of occupational heat stress and adaptation strategies of workers: A narrative synthesis of the literature

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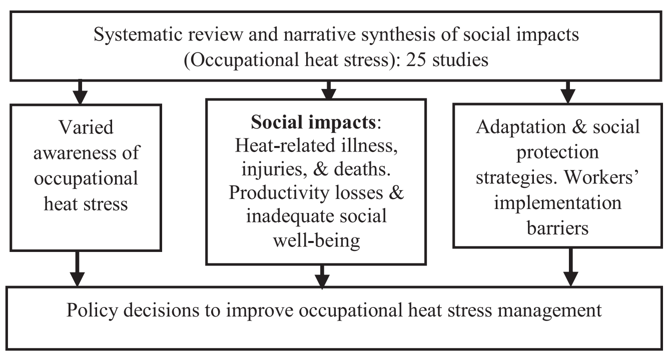
HIGHLIGHTS

- Workers possess varying but clear awareness of occupational heat stress, impacts and adaptation strategies
- Social impacts of heat stress include heat illnesses, injuries, deaths, productive losses, and inadequate social well-being
- Adaptation strategies in policy decisions are sustainable approaches to enhance adaptive capacity of workers
- Implementing adaptation strategies are important for policy decisions towards improving occupational heat stress

GRAPHICAL ABSTRACT



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ABSTRACT

Dimensions of risks and impacts of occupational heat stress due to climate change on workers' health and safety, productivity, and social well-being are significantly deleterious. Aside from empirical evidence, no systematic review exists for policy development and decision making in managing occupation heat stress impacts and adaptation strategies of workers. This study sought to synthesise evidence on the social impacts of occupational heat stress and adaptation strategies of workers. From a review of existing literature, eight categories were obtained from 25 studies and grouped into three syntheses: (1) awareness of occupational heat stress, (2) social impacts of occupational heat stress and (3) workers' adaptation to occupational heat stress due to changing climate. Awareness of occupational heat stress among workers varied and their social impacts were related to workers' health and safety, productivity and social well-being. Sustainable adaptation to occupation heat stress due to climate change hinges on financial resource availability. Adequate investment and research are required to develop and implement policies to combat the threat of rising temperature and climate change to enhance workers' adaptive capacity, boost resilience and foster sustainable development.

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Contents

1. Introduction

Excessive heat exposure due to intensifying temperature and climate change has emerged as one of the existential threats to humanity and the socio-economic, health, and environmental well-being of working populations (United Nations (UN), 2009). Hence, the global agenda for improving the well-being of people, as embodied in the 2030 Sustainable Development Goals (SDGs), reiterates the need for combating rising temperature and climate change impacts (SDG 13) (UN, 2015).

Intensive physical work in an environment of high heat exposure due to the temperature rising beyond 37 °C and inadequate rehydration creates heat stress-related morbidity and mortality (CDCP, 2008; Lucas et al., 2014; Parsons, 2014). Workers in the construction, agriculture, firefighting, armed forces, manufacturing, oil and gas, and mining industries are examples of workers at risk of adverse impacts related to heat stress (Lucas et al., 2014; Xiang et al., 2014a, 2014b). Climate change and occupational heat stress risks and impacts on working people prone to heat exposure include, but are not limited to, physiological, psychological, health and safety, socio-economic and productivity consequences (Dunne et al., 2013; Kjellstrom et al., 2016a; Lucas et al., 2014; Venugopal et al., 2016a; Xiang et al., 2016). Climate change-related occupational heat stress is a condition in which heat stress is induced by intensive physical work, rising temperature and climate change or is being exacerbated by intensive physical work, rising temperature and climate change (Kjellstrom et al., 2016a).

Climate change, occupational heat stress risks and associated impacts have engendered multidisciplinary research, cooperation, frameworks and protocols to combat its consequences for the world's population. Prior studies focusing on impact assessment of climate change, heat stress and adaptation have neglected social impact assessment (SIA) and focused mainly on environmental impact assessment (EIA) and health impact assessment (HIA) of climate change and heat stress on working people. Social impacts refer to the direct or indirect perceptual or physical effect of a phenomenon (e.g., policies, projects, natural and social risk) on the lives, culture, cohesion, political system, environment, health and well-being, rights, and fears of individuals, social units, and communities (Vanclay, 2003; Vanclay et al., 2015). SIA as conceptualised by Vanclay et al. (2015) focuses on resource and capital projects, a practice that Adusei-Asante (2017) has criticised. Current thinking in SIA is calling for the need to focus on policies and phenomena such as climate change and work-related heat stress to augment global efforts at combating rising temperature and climate change threats (Adusei-Asante, 2017; Kalkstein et al., 2009; Miller, 2014; Scheffran and Remling, 2013; UN, 2011).

Except for a few studies such as Miller (2014) and Venugopal et al. (2016a), there seems to be no specific empirical studies, systematic review or synthesis that have assessed the social impacts of occupational heat stress and adaptation strategies of workers. Accessible systematic reviews have tended to focus on adaptation to heat-related mortality and illness, and heat-related mortality and climate change other than on social impacts of climate change, occupational heat stress and adaptation strategies of workers (Boeckmann and Rohn, 2014; Huang et al., 2011). Considering the importance of systematic reviews to evidence-based policy making, there is a need for this review to collate findings from available published and unpublished studies.

Given the socio-economic and health implications of climate change and occupational heat stress, it is appropriate and timely to conduct this review to update and expand the literature on the risks and impacts of occupational heat stress due to climate change on workers' health and safety, productivity, and social well-being. It will also inform occupational heat stress adaptation and resilience planning and policies, the ongoing rising temperature and climate change-social impact discourse and future research needs. This review examines available evidence on social impacts of occupational heat stress driven by climate change and adaptation strategies of workers with emphasis on the research design and methodology, study setting, and significant findings based on three research questions: (1) What are workers' perceptions and experiences of occupational heat stress (RQ1)? (2) What are the effects of occupational heat stress on workers' health and safety, productivity, psychological behaviour, and social well-being (RQ2)? (3) What are the adaptation strategies of workers to occupational heat stress (RQ3)?

2. Materials and methods

This review was guided by the philosophy of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) and the Joanna Briggs Institute (JBI) framework for systematic review, synthesis, and reporting (JBI, 2014; Moher et al., 2015; Popay et al., 2006). A systematic review and synthesis of the literature were adopted in this study because it is scientific and provides the basis for describing the patterns, similarities and differences among the results of the included studies based on well-defined selection criteria (JBI, 2014; Petticrew and Roberts, 2008; Popay et al., 2006). The mixed-methods approach was employed to provide answers to enhance understanding of the research questions. The use of the textual approach to narrative synthesis was informed by the heterogeneous nature of findings from multiple studies on risks and impacts of occupational heat stress and adaptation strategies of workers in the context of rising temperature and climate change. Synthesising empirical qualitative and quantitative evidence is warranted because there is a mutual interest in aggregating empirical studies (Dixon-Woods et al., 2005; Noblit and Hare, 1988). Moreover, mixed method studies are amenable to the narrative method of synthesis and the most suitable in systematic reviews in which the studies were not exactly similar to warrant meta-analysis (Mays et al., 2005). Narrative synthesis allows the combination of various types of evidence from multiple studies of different nature to answer a range of different research questions (Gough et al., 2017; Petticrew and Roberts, 2008).

The concept of Population, Intervention, Comparator Context Outcome (PICO) informed the scoping of the review (Cooke et al., 2012). The scope covered: workers of both sexes above 18 years; workers' perceptions and experiences of occupational heat stress and adaptation strategies; effects of occupational heat stress on workers' health and safety, productivity, psychological behaviour, and social well-being based on a series of inclusion and exclusion criteria (Table 1).

2.1. Search criteria

The authors conducted a systematic search of Web of Science, PubMed, Science Direct, Google Scholar, ProQuest, Taylor and Francis Online, and the reference lists of included studies for evidence of peer-reviewed published studies in English from 2007 to 2017 to provide a contemporary outlook. 'Assessment', 'perceptions', 'experiences', 'social impact', 'climate change', 'occupational heat stress', 'health and safety', 'productivity', 'psychological behaviour', 'social well-being', 'adaptation strategies', and 'workers' were search terms used as part of the search strategy. The assessment process was guided by the JBI critical appraisal checklist for systematic reviews and research syntheses (Supplemental Table 1) (JBI, 2014). Five researchers independently assessed the quality of included studies and any differences resolved through consensus. The search process yielded 25 studies based on the selection criteria out of 23,352 studies identified (Fig. 1).

2.2. Characteristics of included studies

Descriptive characteristics of included studies were illustrated by the name of the author(s), year of publication, study location, study design, population and sample size, methods, data analysis, and conclusions. The studies were organised according to the research questions and methodology. Some studies addressed either one or a combination of two or three research questions. Tables 2 to 6 provide an overview of the 25 included studies. Of the 25 studies, five addressed Research Question 1 (RQ1), eight answered RQ2, four focused on RQ1 and RQ2, seven addressed RQ1 and RQ3, while one centred on RQ1, RQ2, and RQ3. However, 17 studies were on issues related to RQ1 (Tables 4, 5 & 6), 13 studies were associated with RQ2 (Tables 3, 4 & 6), and eight studies focused on issues based on RQ3 (Tables 5 & 6).

Table 1
Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Studies using quantitative, qualitative and mixed-method approaches	Comments, letters, editorials, viewpoints, reviews, reports, and correspondence
Peer-reviewed journal publications of original studies in English	Studies published in other languages except for English
Studies on workers' perceptions and experiences of occupational heat stress, and adaptation strategies	Studies on climate change-related storms, rainfall, drought, cyclones, and rising sea levels other than climate change-related temperature, humidity, air movement, and heat radiation
Studies measuring ambient temperature at work and resting environment of workers	Studies unrelated to objectives, population, intervention/exposure, outcome, and context of the study
Studies assessing the effect of occupational heat stress on workers' health and safety, productivity, psychological behaviour, and social well-being	Studies on the effect of climate change and heat stress on people, communities, plants, animals, and crops, other than workers' health and safety, productivity, psychological behaviour, and social well-being
Studies on barriers of workers to occupational heat stress adaptation	Studies using only secondary data without primary data
Studies in the local and international context	Studies on mitigation to climate change and occupational heat stress

Regarding research methodology, 19 out of the 25 selected studies used quantitative techniques, three employed qualitative techniques, and three studies applied the mixed methods approach. The quantitative studies used descriptive, cross-sectional, cohorts, comparative, evaluative, correlational, and experimental research designs. They also applied descriptive statistics, trend analysis, bivariate logistical regression, and multivariate logistical regression as methods of data analysis. The qualitative studies used narrative, exploratory observation, and case study research designs while thematic and interpretive phenomenology were used as the techniques of data analysis. Cross-sectional survey, quantitative, qualitative, and grounded theory research designs as well as a combination of STATA, thematic analysis, descriptive, trend, qualitative, and quantitative analysis were used in the mixed method studies as methods of data analysis.

Geographically, the study locations of the 25 articles, varied widely across countries from the continental regions of Asia, Africa, North America, and Central America. Out of the included studies, 14 articles were from India, Thailand, China and Nepal in Asia (56%), four studies were from the States of Florida, California, Georgia, and Carolina in North America (12%), three papers were from Costa Rica and Nicaragua in Central America (16%), three studies from Australia (12%), and one from South Africa (4%) (Fig. 2). These are tropical and sub-tropical regions with moderate to high risk of heat exposure (Hyatt et al., 2010; Lucas et al., 2014). Based on the selection criteria, it appears no primary studies, other than reports and reviews, focusing on occupational heat stress were found from Europe. This may be due to its low risk of heat exposure, adequate adaptation capacity, and technological advancement. However, there have been occasions of injuries and deaths related to heat waves in Europe. For instance, in 2003 excess mortality of 30,000 deaths occurred in France as part of the more than 70,000 deaths during the extreme heat wave event in Europe (Robine et al., 2008). An analysis of the period of publication of the included studies showed that seven articles were published between 2007 and 2011, while 18 studies were published from 2012 to 2017. This indicates an increasing trend of interest by researchers on issues related to occupational heat stress due to climate change and adaptation in the last decade.

2.3. Abstraction of findings from included studies

The findings of each study were used as the basis for data extraction for categorisation and narrative synthesis using tables and figures where appropriate (JBI, 2014; Popay et al., 2006). The value of extracted data of included studies was determined by using JBI's interpretation of degree of evidence (Supplemental Table 2) (JBI, 2014). Abstraction of data from the 25 included studies (Supplemental Tables 3 to 27) was presented according to their findings, an illustration of evidence and degree of evidence.

3. Results

3.1. Narrative synthesis and categorisation of findings from included studies

The results of the data abstraction process yielded 121 findings which were grouped into eight categories and then synthesised into three themes based on observed emerging patterns, similarities and differences. The findings were categorised as: perceptions of occupational

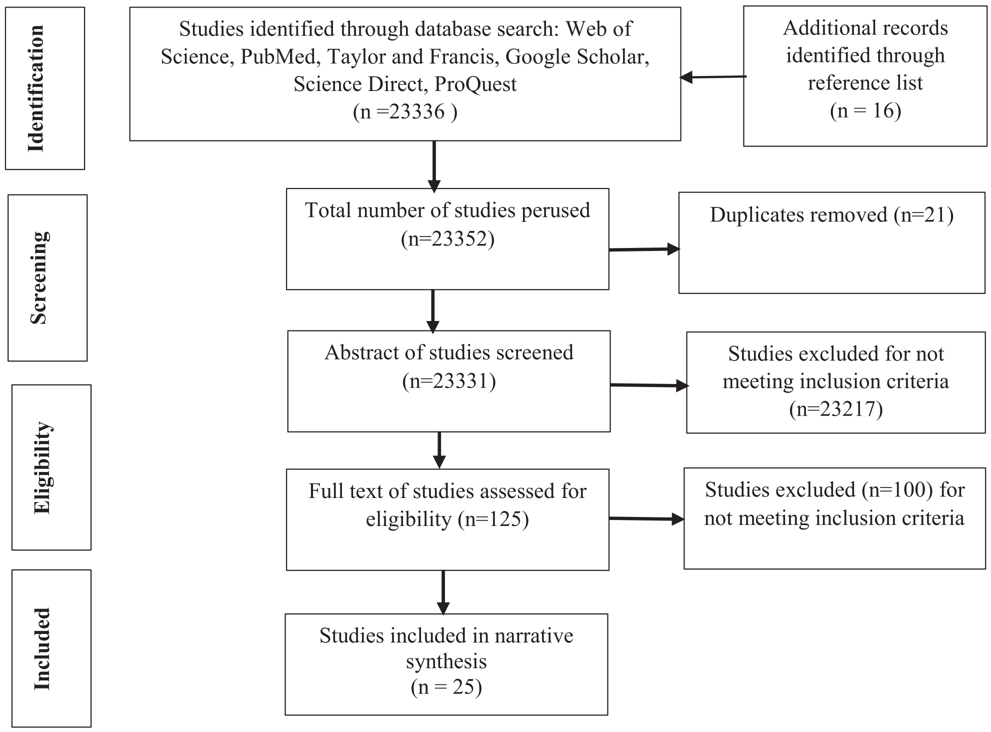

Fig. 1. Flowchart illustrating a summary of included studies.

heat stress risk; experiences of occupational heat stress risk; magnitude of heat exposure risk; health and safety effects of occupational heat stress; productivity effects of occupational heat stress; social well-being effects of occupational heat stress; adaptation strategies to occupational heat stress; and barriers to implementation of occupational heat stress adaptation. The eight categories were then synthesised into three themes: (1) workers' awareness of occupational heat stress; (2) social impacts of occupational heat stress; and (3) adaptation to occupational heat stress.

3.1.1. Synthesis One: workers' awareness of occupational heat stress

Workers' awareness of occupational heat stress constitutes Synthesis One. It is the result of aggregating three categories with similar attributes of describing workers' awareness of occupational heat stress (Fig. 3).

Table 2
Details of papers addressing workers' perceptions and experiences of occupational heat stress.

Author, year & title	Study location	Study design	Population/sample size	Methods	Data analysis	Author(s) conclusions
Balakrishnan et al. (2010). Case studies on heat stress related perceptions in different industrial sectors in southern India	India	Case study	242 manufacturing workers	Questionnaires and Wet Bulb Globe Temperature (WBGT) index	Correlation analysis	Given the potential implications of future climate change-related increases in ambient heat stress that are likely to translate into workplace exposures in developing country settings
Crowe et al. (2013). Heat exposure in sugarcane harvesters in Costa Rica	Costa Rica	Descriptive study design	105 harvesters	WBGT and non-participatory observation	Descriptive analysis using WBGT data, metabolic rate and threshold limit values	Sugarcane harvesters are at risk of heat stress for the majority of the work shift. Immediate action is warranted to reduce such exposures
Flocks et al. (2013). Female farmworkers' perceptions of heat-related illness and pregnancy health	Central Florida	CBR approach using narrative interviews	35 female farmworkers	Focus group discussion	Thematic analysis	Participants believe that heat exposure can adversely affect general, pregnancy, and fetal health, yet feel they lack control over workplace conditions and that they lack training about these specific risks
Crowe et al. (2010). Heat exposure in sugarcane workers in Costa Rica during the non-harvest season	Costa Rica	Exploratory observational study	45 sugarcane workers	WBGT	Descriptive analysis	It is therefore important to take action to decrease current and future heat-related risks for sugarcane workers in both harvest and non-harvest conditions and in all sugarcane growing regions in Costa Rica. It is also necessary to improve guidelines and occupational health standards for protecting worker health and productivity in the tropics
Stoecklin-Marois et al. (2013). Heat-related illness knowledge and practices among California hired farm workers in The MICASA study	California	Comparative study design	467 hired farm workers	Structured interviews questions	Statistical analysis using multivariate survey logistic regression	The study suggests important areas to target for heat illness prevention in farmworker population, and that gender-specific approaches may be needed for effective heat illness

Table 3
Details of papers addressing effects of occupational heat stress on workers' health and safety, psychological behaviour, productivity and social well-being.

Author, year & title	Study location	Study design	Population/sample size	Methods	Data analysis	Author(s) conclusions
Tawatsupa et al. (2013). Association between heat stress and occupational injury among Thai worker: findings of the Thai cohort studies	Thailand	Cohort studies	58,495 workers	Mail out health questionnaires	Logistic regression using STATA version 12	The study provides useful evidence linking heat stress to occupational injury in tropical Thailand and identifies factors that increase heat exposure
Tawatsupa et al. (2012). Association between occupational heat stress and kidney disease among 37,816 workers in the Thai cohort studies (TCS)	Thailand	Cohort studies	37,816 workers	Self-reported questionnaires	Logistic regression	There is an association between self-reported occupational heat stress and the self-reported doctor diagnosed kidney disease in Thailand. There is a need for occupational health interventions for heat stress among workers in tropical climates
Sett and Sahu (2014). Effects of occupational heat exposure on female brick workers in West Bengal, India	India	Evaluative study design	120 brick moulders and carriers	WBGT and questionnaires	Statistical analysis using *t*-test and ANOVA	High heat exposure in brickfields during summer caused physiological strain in both categories of female brickfield workers
Luo et al. (2014). Exposure to ambient heat and urolithiasis among outdoor workers in Guangzhou, China	China	Correlational case-control study design	190 cases and 760 control shipbuilding workers	2003–2010 health check data	Conditional logistic regression	Significant association between exposure to ambient heat and urolithiasis among outdoor working populations
Langkulsen et al. (2010). Health impact of climate change on occupational health and productivity in Thailand	Thailand	Descriptive cross-sectional study	21 workers	WBGT and questionnaires	Descriptive and trend analysis	Climate conditions in Thailand potentially affect both the health and productivity in occupational settings
Sahu et al. (2013). Heat stress, cardiovascular stress and work productivity in rice harvesters in India: Implications for a climate change future	India	Comparative study design	124 rice harvesters	WBGT and an interviewer-administered questionnaire	Trend and Statistical analysis using a *t*-test	High heat exposure in agriculture caused heat strain and reduced work productivity. This reduction will be exacerbated by climate change and may undermine the local economy
Krishnamurthy et al. (2017). Occupational heat stress impacts on health and productivity in a steel industry in Southern India	South India	Cross-sectional study design	84 steel worker	WBGT and structured questionnaires	Statistical analysis	High heat exposures and heavy workload adversely affect the workers' health and reduce their work capacities. Health and productivity risks in developing tropical country work settings can be aggravated by temperature rise due to climate change, without appropriate interventions
Tawatsupa et al. (2010). The association between overall health, psychological distress, and occupational heat stress among a large national cohort of 40,913 Thai workers	Thailand	Cohort studies	40,913 workers	Self-reported questionnaires	Descriptive statistical analysis	This association between occupational heat stress and worse health needs more public health attention and further development of occupational health interventions as climate change increases Thailand's temperatures

Category One describes workers varied perceptions of occupational heat stress risk. Thirteen findings were grouped into Category One. Findings from category one indicated that although workers' awareness of trends of weather patterns varied widely, occupational heat stress risk is perceived as a seasonal condition associated with symptoms (e.g., dehydration, skin rashes, and itchy skin) (Balakrishnan et al., 2010), and occupational heat stress risk is recognised as an issue of serious concern in summer (Venugopal et al., 2016b). Also, heat stress is perceived by workers to affect productivity and ability to work due to dehydration, lack of insulation (deficiency in reducing heat loss or gain), and inadequate ventilation (Balakrishnan et al., 2010), workers' perceptions of heat stress concerns was moderate to severe and was related to age and work that require heavy physical efforts (Xiang et al., 2016). Similarly, management is conscious of heat stress risk as evident in the routine assessment and monitoring, management knowledge of heat stress risk is on account of several heat-related worker incidents during summer month, and workers' perceived provision of water, electrolytes, and fans as ways of controlling heat stress (Balakrishnan et al., 2010) (Supplemental Fig. 1).

Category Two describes workers' experiences of occupational heat stress. The review yielded 16 findings in this category. For example, studies reported experiences of heat stress conditions (e.g., fainting, tension, and irritation, nausea, hot and dry skin, cramps, and confusion) among workers (Fleischer et al., 2013; Pradhan et al., 2013). Furthermore, widely prevalent heat-related issues among workers were fatigue and sweating excessively (Krishnamurthy et al., 2017). Experiences of occupational heat stress were also reported in other studies as heat stress resulted in various occupational injuries (Tawatsupa et al., 2013). Heat stress conditions were common among males, labourers, low income and low education workers (Tawatsupa et al., 2010). Workers' experiences of heat-related health effects were headaches, dehydration, and heat stroke (Lao et al., 2016). Heat-related training was received by almost half of the workers, and workers within ages of 25 and 54 years with experiences of heat-related illness or injury had a positive attitude towards heat-related training (Xiang et al., 2016) (Supplemental Fig. 2).

Category Three relates to the magnitude of heat exposure risk of workers. This category resulted from aggregation of 33 findings. Findings on the magnitude of heat exposure risks were identified as being higher during peak hot months, when the average temperature reached over 39 °C and when environmental conditions in selected factories were too hot for continuous work in summer months (Pradhan et al., 2013). Heat stress exposure values at most locations of industrial units exceeded recommended levels (Tawatsupa et al., 2012), and values of Wet Bulb Globe Temperature (WBGT) increased sharply in most mornings at about 7:00 am to 12:00 noon (Crowe et al., 2013). Similarly, working conditions of four out of five study sites were within the likelihood of ‘extreme caution’ or ‘danger’ of heat stress conditions

Table 4
Details of papers addressing workers' perceptions and experiences of occupational heat stress risk and effects of occupational heat stress on workers' health and safety, psychological behaviour, productivity and social well-being.

Author, year & title	Study location	Study design	Population/sample size	Methods	Data analysis	Author(s) conclusions
Delgado-Cortez (2009). Heat stress assessment among workers in a Nicaraguan sugarcane farm	Nicaragua		22 sugarcane workers	data loggers and data collection sheet	Descriptive statistics and Chi-square analysis	Productivity improved with the new rehydration measures. Awareness among workers concerning heat stress prevention was increased
Venugopal et al. (2016b). Occupational heat stress profiles in selected workplaces in India	India	Experimental study design	442 workers	WBGT and questionnaires	Statistical analysis using Z-test a chi-square for bivariate	Reducing workplace heat stress benefits industries and workers via improving worker health and productivity. Adaptation and mitigation measures to tackle heat stress are imperative to protect the present and future workforce as climate change progresses
Dutta et al. (2015). Perceived heat stress and health effects on construction workers	Gandhinagar-Western India	A cross-sectional survey using mixed method approach	219 construction workers	WBGT, focus group discussion and survey questionnaires	Thematic analysis using grounded theory approach for qualitative data and descriptive statistical analysis and trend analysis	This study suggests significant health impacts on construction workers from heat stress exposure in the workplace, showed that heat stress levels were higher than those prescribed by international standards and highlights the need for revision of work practices increased protective measures, and possible development of indigenous work safety standards for heat exposure
Venugopal et al. (2016a). The social implications of occupational heat stress on migrant workers engaged in public construction: a case study from Southern India	India	Both quantitative and qualitative studies	142 migrant workers	WBGT and questionnaires	Quantitative and qualitative analysis	In an increasingly warmer global climate and with increasing construction demand, stronger policies to prevent morbidity/mortality among vulnerable migrant workers in the construction sector are imperative. Better health, literacy rates, and decreased crime statistics among migrant community are potential positive implications of protective policies

(Langkulsen et al., 2010). Furthermore, workers' exposure to heat levels of WBGT per hour were 26–32 °C and air temperatures (30–38 °C), exceeding international standards (Sahu et al., 2013), with WBGT values (90%) also exceeding recommended threshold values (27.0 °C–41.7 °C) for heavy and moderate workloads (Krishnamurthy et al., 2017). Also, workers' exposure to heat stress settings was above approved American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs) for heavy workloads (Venugopal et al., 2016a). Factors with the potential of affecting workers' level of heat exposure included personal protective equipment (PPE), relative humidity, access to cold water and shade, type of work, and location of work (Lao et al., 2016) (Supplemental Fig. 3).

3.1.2. Synthesis Two: social impacts of occupational heat stress

Social impacts of occupational heat stress due to climate change constitute Synthesis Two. It is the outcome of combining Categories Four, Five, and Six (Fig. 4).

The remaining categories (4, 5 & 6) emanated from aggregating 37 findings of included studies. Category Four centred on the mixture of 25 findings related to the health and safety effects of occupational heat stress on workers. Some findings of studies in category four included the following: occupational injury risks decrease with age for both sexes, but increases with lower income, physical workload, sleeping fewer hours, existing disease and fast work pace (Tawatsupa et al., 2013). Also, heat stress-related occupational injury was worse for males, younger aged workers with lower income and physical jobs, and occupational injury effect was experienced by more males and females exposed to heat stress than those unexposed (Tawatsupa et al., 2013). The associated effect of heat stress on the incidence of kidney disease for men with experience of heat exposure is significant (Tawatsupa et al., 2012). Similarly, workers' reported adverse health impact of heat stress (e.g., excessive sweating, nausea, prickly heat, infection, headaches, dehydration, increased thirst, tiredness, itchy skin, burning eyes, backache, leg pains, and nose bleeds). These were attributed to climate-related hot and dry conditions (Crowe et al., 2013; Flocks et al., 2013; Venugopal et al., 2016a; Ayyappan et al., 2009) (Supplemental Fig. 4).

Category Five describes the productivity effects of occupational heat stress on workers. Eleven findings were grouped to form category five. Examples of findings in this category were that supervisors perceive work as strenuous and tiring in hot environment resulting in reduced productivity and optimal performance (Mathee et al., 2010), productivity losses were in the range of 10 to 60% of the construction and pottery workers (Langkulsen et al., 2010), farm workers' productivity increased with improved hydration (Delgado-Cortez, 2009). Workers exposed to direct heat reported significant production losses as compared to workers exposed to indirect heat ($\chi^2 = 26.13$, df $= 1$, $p = 0.001$) (Krishnamurthy et al., 2017). Furthermore, heat stress impact on productivity losses was stated by 69% of workers as inability to finish task on time, absenteeism and wage loss due to illness (Venugopal et al., 2016a), and workers perceive heat to impede work efficiency, slow work pace and affect productivity (Lao et al., 2016) (Supplemental Fig. 5).

Effects of occupational heat stress on social well-being are the sixth and last category of Synthesis Two. The findings in category six showed that heat stress impact on workers' social lives was limited time for

Table 5
Details of papers addressing workers' perceptions and experiences of occupational heat stress risk and adaptation strategies.

Author, year & title	Study location	Study design	Population/sample size	Methods	Data analysis	Authors' conclusion
Pradhan et al. (2013). Assessing climate change and heat stress response in the Tarai Region of Nepal	Nepal	Case study household survey	120 household factory workers	Data loggers, questionnaire and observation checklist	Comparative analysis of quantitative data	More quantitative measurement of workers' health effect and productivity loss will be of interest for future work
Xiang et al. (2015). Perceptions of workplace heat exposure and controls among occupational hygienists and relevant specialists in Australia	Australia	Cross-sectional research design	180 occupational hygienists	Questionnaire	Descriptive analysis using STATA and Excel	The findings suggest a need to refine occupational heat management and prevention strategies
Fleischer et al. (2013). Public health impact of heat-related illness among migrant farmworkers	Georgia	Cross-sectional survey research design	405 farmworkers	In-person interview	Statistical analysis using logistic regression	Migrant farmworkers experienced high levels of HRI symptoms and faced substantial barriers to preventing. Heat-Related Illness may be reduced through appropriate training of workers on HRI prevention, as well as regular breaks in shaded areas these symptoms
Mirabelli et al. (2010). Symptoms of heat illness among Latino farm workers in North Carolina	Carolina	Cross-sectional study	300 farm workers	Interviewer-administered questionnaires	Descriptive statistical analysis using log-binomial regression	These findings suggest the need to improve the understanding of working conditions for farm workers and to assess strategies to reduce agricultural workers' environmental heat exposure
Ayyappan et al. (2009). Work-related heat stress concerns in automotive industries: a case study from Chennai, India	India	Quantitative research design		WBGT	Descriptive statistical analysis	The study re-emphasises the need for recognising heat stress as an important occupational health risk in both formal and informal sectors in India. Making available good baseline data is critical for estimating future impacts
Xiang et al. (2016). Workers' perceptions of climate change related extreme heat exposure in South Australia: a cross-sectional survey	Australia	Cross-sectional research study	479 workers	Questionnaire survey	Bivariate and multivariate analysis	Need to strengthen workers' heat risk awareness and refine current heat prevention strategies in a warming climate. Heat education and training should focus on those undertaking physically demanding work outdoors, in particular, young and older workers with low education
Lao et al. (2016). Working smart: An exploration of council workers' experiences and perceptions of heat in Adelaide, South Australia	Australia	A qualitative case study design	32 council male workers	Focus groups	Thematic analysis and interpretative phenomenological analysis	The results showed the importance of workplace management and training, and an understanding of the need for workers to be able to self-pace during hot weather

family care, household chores, and family disagreement due to fatigue, physical violence and interpersonal issues (Venugopal et al., 2016a) (Supplemental Fig. 6).

3.1.3. *Synthesis Three: adaptation to occupational heat stress due to climate change*

Adaptation to occupational heat stress is the focus of Synthesis Three and was derived from the aggregation of 22 findings into Category Seven and Eight (Fig. 5).

Category Seven covers workers' adaptation strategies to occupational heat stress. It is derived from the aggregation of 18 findings. This is exemplified by analogous findings such as workers adapted coping measures such as fan, a shift in working time, wearing thin clothes and drinking water (Pradhan et al., 2013). Also, workers' recognised heat protection strategies as drinking enough water, taking breaks, working at sites with less sun exposure, wearing a wide-brimmed hat, and use of fan and sunblock (Flocks et al., 2013) (Supplemental Fig. 7). Heat adaptation measures were also identified as access to drinking water, heat stress training, rescheduling work time, provision of a central cooling system, electric fans use, and cease work in extreme heat (Xiang et al., 2015). The provision of hydration breaks, improving ventilation and installing air cooling devices were the range of approved improvements in heat stress exposure locations (Ayyappan et al., 2009). Also, personal coping strategies to heat exposure were self-pacing, wearing sun protective gear, drinking water, taking breaks, slowing down, work self-efficacy and modifying work practices, and the policy at helping workers to cope with heat exposure include provision of water, air-conditioned vehicles and PPEs (Lao et al., 2016).

Finally, Category Eight consists of four findings combined to describe the barriers to implementation of occupational heat stress adaptation.

Table 6
Details of paper simultaneously addressing workers' perceptions and experiences of occupational heat stress risk, effects of occupational heat stress on workers' health and safety, behaviour, productivity and social well-being and adaptation strategies.

Author, year & title	Study location	Study design	Population/sample size	Methods	Data analysis	Authors' conclusion
Mathee et al. (2010). Climate change impacts on working people (the HOTHAPS initiative): findings of the South African pilot study	South Africa	Grounded theory	151 workers	Focus group discussion and interviews	STATA for quantitative data analysis and thematic analysis for qualitative data	People working in sun-exposed conditions in hot parts of South Africa currently experience heat-related health effect, with implications for their well-being and ability to work and that further research is warranted

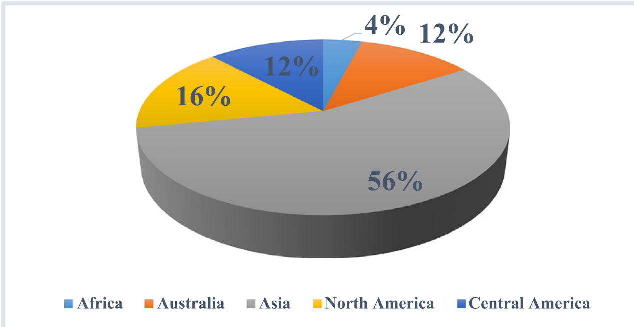

Fig. 2. Continental location of included studies.

Findings that typify category eight were identified as inadequate coping measures against heat stress due to poor housing designs (Pradhan et al., 2013) and insufficient resources for protecting workers from heat stress (Dutta et al., 2015). It also includes lack of awareness, lack of management commitment, lack of training, lack of financial resources, low compliance, and lack of heat-related guidelines (Xiang et al., 2015). Similar barriers to heat illness prevention at work were a lack of prevention training, no regular breaks, no access to shade or medical attention (Fleischer et al., 2013) (Supplemental Fig. 8).

4. Discussion

This study is the first and most recent systematic review and narrative synthesis examining the social impacts of occupational heat stress and adaptation strategies of workers in the face of rising temperature and climate change. The process culminated in aggregating 121 findings into eight categories and three syntheses based on patterns of significant similarities and differences. It was guided by the need to find evidence-based answers to three review questions related to workers' perceptions, social impacts, and adaptation strategies to occupational heat stress.

4.1. Workers' awareness of occupational heat stress

Evidence-based understanding of how workers perceive and experience heat stress risks based on the magnitude of workplace heat exposure may be useful in improving heat exposure risks management and occupation health and safety policies in the context of rising temperature and climate change. In this review, clear but varied awareness of heat stress, experiences of heat stress, and high magnitudes of heat exposure risks were reported among cohorts of workers, managers and key stakeholders (e.g., Balakrishnan et al., 2010; Mathee et al., 2010; Stoecklin-Marois et al., 2013; Xiang et al., 2015, 2016). This finding is consistent with the results of other studies in various industries in which varied awareness and experiences of heat-related morbidity and mortality as well as the magnitude of heat exposure risks were observed among workers, employers and other stakeholders (Jacklitsch, 2017; Lam et al., 2013; Singh et al., 2015). Also, excessive heat exposure in changing climate has been perceived and remained a significant concern for workers' health and safety, productivity, and workplace environmental conditions (Kjellstrom et al., 2016b; Lucas et al., 2014).

The extent of workers' awareness and experiences of occupational heat stress, impacts and adaptation strategies can significantly define the attitude and collective effort of all stakeholders in acting conscientiously to manage the vulnerability and impact of occupational heat exposure risks. The vulnerability principle states that the extent of severity of climate change and heat exposure hazards define the extent of exposure of individuals, and the magnitude of adaptation to climate change and heat exposure stressors to individuals determine vulnerability levels (Davidson et al., 2003; Ford et al., 2006; Kelly and Adger, 2000). Hence, the severity and magnitude of occupational heat stress impact on workers and adaptation strategies may depend on workers having adequate knowledge and awareness of perceived and actual vulnerabilities, adaptive capacity and resilience planning. The varying heat stress risks awareness and experiences, and high magnitude of heat exposure may serve as the basis to inform policy decisions, future research, and the development of information, training and education on heat stress risks. These measures can boost workers' adaptive capacity and resilience planning for effective occupational heat stress management. It also holds the potential for managing the threats and worsening impacts of heat stress in the context of rising temperature and climate change on workers' health and safety, productivity, and social well-being.

4.2. Social impacts of occupational heat stress

The use of the SIA framework mostly in the assessment of resource and capital projects (Vanclay, 2003; Vanclay et al., 2015), other than concerns related to social impacts of policies, occupational heat exposure and climate change have been criticised (Adusei-Asante, 2017; Kalkstein et al., 2009; Miller, 2014; Scheffran and Remling, 2013; UN, 2011). Accordingly, the reported range of social impacts resulting from occupational heat stress on workers vulnerable to heat exposure included physical, mental, behavioural, health and safety, socio-economic and productivity consequences (Costello et al., 2009; Dunne et al., 2013; Hanna et al., 2011; Kjellstrom et al., 2009; Smith et al., 2014; Venugopal et al., 2016a; Xiang et al., 2014a, 2014b).

Similarly evidence from the review revealed the significant influences of occupational heat stress on the health, safety, productivity and social well-being of outdoor and indoor workers across a range of different industrial settings across the world (Ayyappan et al., 2009; Flocks et al., 2013; Tawatsupa et al., 2012; Venugopal et al., 2016b). Results of the review on impacts of occupational heat stress on health and safety of workers resonate with various studies (e.g., Acharya et al., 2018; Arbury et al., 2014; Kjellstrom and Crowe, 2011; Xiang et al., 2014a, 2014b) where heat-related illnesses and injuries of workers were attributed to occupational heat exposure factors. For instance, the 20 cases of heat illness and deaths among workers in the United States (U.S.) during the 2012–2013 review of Occupational Safety and Health Administration (OSHA) were attributed to heat exposure with a heat index in the range (29.0 °C–41.0 °C) (Arbury et al., 2014). Heat-related illnesses, injuries and deaths among workers reflect the prevalence of work-related heat exposure factors, individual-related vulnerability factors and worsened by climate change-related heat exposure factors such as rising temperature, high humidity, air speed, and radiant heat.

Furthermore, multiple studies (e.g., Delgado-Cortez, 2009; Krishnamurthy et al., 2017; Langkulsen et al., 2010; Lao et al., 2016;

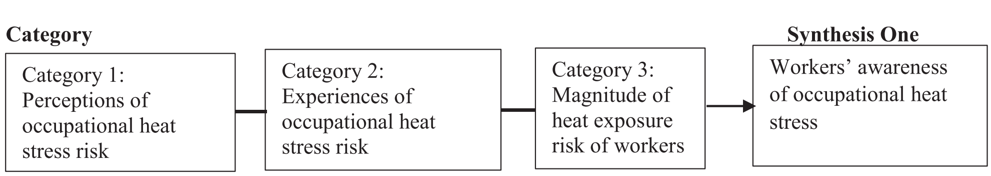

Fig. 3. Synthesis One: workers' awareness of occupational heat stress.

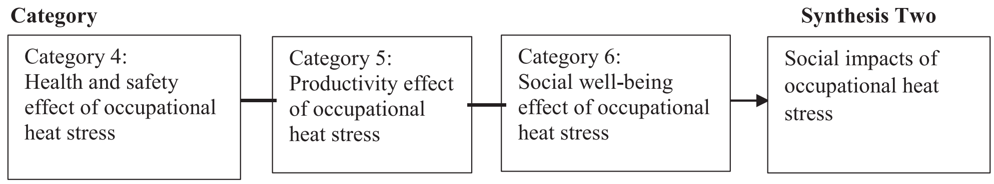

Fig. 4. Synthesis Two: social impacts of occupational heat stress.

Mathee et al., 2010; Sahu et al., 2013; Venugopal et al., 2016a) in this review have demonstrated that, occupational heat stress results in reduced productivity in a variety of workplaces and industries including construction (Venugopal et al., 2016a), agriculture (Delgado-Cortez, 2009; Sahu et al., 2013), and manufacturing (Krishnamurthy et al., 2017). Findings of the review relating to productivity impacts on workers corroborate other studies showing declines in productivity due to working under increasing heat exposure reported across a range of countries and regions (e.g., Dunne et al., 2013; Kjellstrom et al., 2016a; Kjellstrom et al., 2016b; Gibson and Pattisson, 2014; Singh et al., 2015), have continually been shown to decrease due to working under rising heat exposure conditions in a variety of workplaces and countries including, but are not limited to, Australia, U.S., Indonesia, Malaysia, China, Qatar, India, South Africa, and Bangladesh. Productivity losses, absenteeism, reduced work pace, and performance efficiency will be exacerbated by projected rise in temperature and climate change. For instance, international analysis of labour productivity loss over 1975–2200 showed that during the warmest period, there might be work capacity reduction (37% based on Representative Concentration Pathways [RCP]8.5 and 20% based on RCP4.5) in most humid months (Dunne et al., 2013). Also, reduction in work capacity and absenteeism caused by heat stress led to individual economic losses of US$655, and an overall financial loss of US$6.2 billion (Zander et al., 2015). Also, global analysis centred on national Gross Domestic Product (GDP) and annual mean temperatures indicated that countries would lose 23% of their GDP to rising temperatures and climate change by 2100 (Burke et al., 2015).

In addition, heat stress effect on workers' social lives and well-being as indicated in the review included inadequate time for task such as family care and household chores, as well as an increase in family breakdown due to fatigue, physical violence and interpersonal disputes (Venugopal et al., 2016a). The effect of extreme heat on workers' social lives and well-being also results in income erosion and loss of employment due to heat-related morbidity, absenteeism and productivity loss, thereby affecting workers' social network relationship with their families and co-workers, and access to community services (Venugopal et al., 2016a). Similarly, extreme heat events have been shown to present multi-stress vulnerabilities that affect people including their health and well-being, financial situation, mobility, social relations, and access to basic services (Miller, 2014; Bolitho and Miller, 2017). However, there is paucity of knowledge and research-based evidence on the social impact dimensions and the nexus between climate change-related heat exposure and its consequences on health, safety, productivity, and economic output, and adaptation strategies for workers' social lives, their families, coworkers, social units, and wider communities (Kjellstrom et al., 2016a; Miller, 2014; UN, 2011; Venugopal et al., 2016a). It is essential for the factors of social impacts of occupational heat stress to find expression in the letter and spirit of policy decisions and SIA frameworks at the global, national and local levels to reduce workers' vulnerability, boost adaptive capacity and resilience planning (Miller, 2014).

4.3. Adaptation of workers to occupational heat stress

Occupational heat stress based on rising temperature due to climate change has substantial socio-economic and health ramifications on working populations. Devoting significant resources in incorporating and enforcing mitigation, adaptation and social protection strategies in policy decisions are sustainable ways to reduce vulnerability, enhance resilience and adaptive capacity of working people to ensure viable well-being (Spector and Sheffield, 2014; Venugopal et al., 2016a; Venugopal et al., 2016b; Xiang et al., 2016). The need for mitigation, adaptation and social protection policies as preventive and control measures have been informed by protocols, frameworks, and targets to reduce vulnerability, risks, and sensitivity to climate change and heat stress, and to enhance resilience and adaptive capacity of workers (Brechin, 2016; IPCC, 2014; Rhodes, 2016; UNFCCC, 2006; WMO and WHO, 2015).

Accordingly, several studies (e.g., Ayyappan et al., 2009; Flocks et al., 2013; Lao et al., 2016; Pradhan et al., 2013; Xiang et al., 2015) in the review addressed a variety of issues related to workers' coping and adaptation to occupational heat stress and barriers to adaptation strategies. The use of coping and adaptation strategies as suitable options for decreasing and managing risks, vulnerabilities and sensitivity to occupational heat stress impacts on workers' health, productivity, and social lives are diverse (Davies et al., 2009; Kjellstrom et al., 2016a; Venugopal et al., 2016a). Generally, interventions of occupational heat stress from the perspective of coping mechanisms, adaptation, and social protection strategies as encapsulated in the review include engineering solutions, administrative controls, and consistent education and training regimes. It can also be reinforced by implementing such regulations and policies, ensuring a shift in structures of economies to non-outdoor work, provide compensations for productive losses, and social protection for workers (Frimpong et al., 2015; Kjellstrom et al., 2016b; Lucas et al., 2014; Lundgren et al., 2013; UN, 2011).

However, workers encounter barriers (e.g., inadequate housing designs, inadequate resources, lack of awareness, absence of management commitment, lack of prevention training, low compliance, lack of heat stress guidelines, lack of regular breaks, and the limited access to shade or medical attention) in implementing adaptation strategies to occupational heat stress (Dutta et al., 2015; Fleischer et al., 2013; Pradhan et al., 2013; Xiang et al., 2015). Similarly, the 20 cases of heat illness and fatalities in the U.S. during the 2010–2013 review were linked to poor approach to heat illness risk identification in prevention programme, inadequate or no heat illness prevention programme, inadequate water

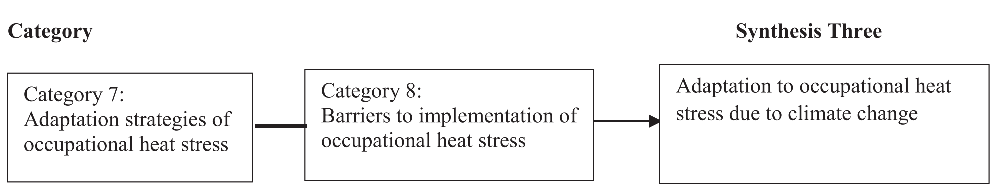

Fig. 5. Synthesis Three: adaptation to occupational heat stress as a result of climate change.

management, failure to provide shaded rest areas, and no acclimatisation programme (Arbury et al., 2014). The capacity to overcome the barriers to adaptation and risks to heat stress due to rising temperature and climate change depends on technological advancement and resource availability, especially in tropical developing countries. Policy analysts, decision makers, industrial hygienists, social risk and environmental health scientists ought to significantly consider these barriers in policy decisions and work with concerted effort to improve heat-related occupational safety and health administration and policies.

5. Conclusions

Workers' perceptions and experiences of occupational heat stress and adaptation strategies, epitomised as a natural and seasonal phenomenon, are clear but varied. The social impacts of occupational heat stress are associated with both perceived and actual risks and impacts on workers' health and safety, productivity and social well-being. Sustainable adaptation and social protection strategies to occupational heat stress depend on financial resource availability and cooperative effort to overcome the barriers to adaptation. The severity of occupational heat stress due to climate change depends on workers' sensitivity and vulnerability to heat exposure as well as the extent of adaptive capacity and resilience planning. The current synthesis shows that in the last decade, there has been inadequate research on social dimensions and impacts of occupational heat stress and adaptation strategies of workers in the context of rising temperature and climate change, especially in Europe and Africa (Lundgren et al., 2013). However, Africa is the region characterised by higher risk for negative occupational health outcomes than Europe because of lower adaptive capacity, increasing poverty and inadequate technological advancement to combat rising temperature and climate change. Studies of this nature are required among workers in such regions to highlight the state of knowledge to inform occupational heat stress adaptation and resilience policies for sustainable development. It will also be useful to integrate relevant knowledge-based evidence on social impacts of occupational heat stress into policy decisions, further development of the SIA framework, and inform the ongoing climate change social impact analysis aimed at combating intensifying temperature and climate change.

Conflict of interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2018.06.255.

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