The impact of heat on occupational injuries, illnesses and associated economic costs in Australia

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Abbreviations

ABS: Australian Bureau of Statistics
AF: attributable fraction
AIC: Akaike Information Criterion
AN: attributable number
ANZSCO: Australian and New Zealand Standard Classification of Occupations
ARC: Australian Research Council
AU: Australian
BLUP: best linear unbiased prediction
BoM: (Australian) Bureau of Meteorology
CBD: central business district
CI: confidence interval
CMIP: Coupled Model Intercomparison Project
CO_2: carbon dioxide
CPI: Consumer price index
df: degrees of freedom
DLNM: distributed lag non-linear model
DMT: daily mean temperature
DMT_{3days}: daily mean temperature over the current and previous two days
DMT_{95}: 95th percentile of daily mean temperature
eCI: empirical confidence interval
ED: emergency department
EHF: Excess Heat Factor
EHI_{accl}: excess heat acclimitisation index
EHI_{sig}: excess heat significance index
GAM: generalised additive model
GCCSA: Greater Capital City Statistical Area
GCM: general circulation model
GDP: gross domestic product
GHG: greenhouse gas emissions
GLM: generalized linear model
GZN: Graff Zivin and Neidell
HI: heat index

Hothaps: High Occupational Temperatures Health and Productivity Suppression
LMIC: low- and middle-income country
OHI: occupational heat-induced illness
OHS: occupational health and safety
OI: occupational injury
OII: occupational injury or illness
PhD: Doctor of Philosophy
RCP: Representative Concentration Pathway
REML: restricted maximum likelihood
RR: relative risk
SSP: Shared Socioeconomic Pathway
SWA: Safe Work Australia
$T_{average}$: average air temperature
T_{max}: maximum air temperature
TOOCS: Type of Occurrence Classification System
UofA: University of Adelaide
US[A]: United States of America
WBGT: wet bulb globe temperature
WHS: workplace health and safety
WPI: whole person impairment

Abstract

Introduction: High temperatures have been associated with increased morbidity and impaired labor productivity in workers. Despite extensive relevant literature, there is limited understanding of the associated economic impact. This PhD aimed to analyse economic burden secondary to occupational heat stress and create an Australian national cost profile of heat-attributable occupational injuries and illnesses (OIIs) within Australia.

Literature review: Estimated retrospective and future heat-attributable occupational economic burdens are substantial. Predicted global costs from lost worktime were US\$607 billion annually from 2001-2020. This was projected to US\$1,069, US\$1,626, and \$3,286 billion worldwide following a 1, 2, and 4°C increase in global average temperature. In Australia from 2013-2014, annual costs of US\$6.2 (95% CI: 5.2 7.3) billion were estimated, 0.33% 0.47% of Australia's GDP. Estimated annual heat-related expenses from occupational injuries exceeded US\$1 million in Spain and Guangzhou, China and US\$250,000 in Adelaide, Australia. Low- and middle-income countries and countries with warmer climates had greater losses as a proportion of GDP.

Methodology: Climate and workers' compensation claims data were extracted representing OIIs from July 2005 to June 2018 in seven Australian capital cities: Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth, and Sydney. Daily maximum wet bulb globe temperature was used to measure the impact of temperatures above and below the mean. The Excess Heat Factor was used to define the presence, intensity, and duration of heatwaves. OIIs and associated costs were estimated separately per city with time series, distributed lag non-linear models and modelled using (quasi-)Poisson and Tweedie distributions, respectively. City-level estimates were pooled together with multivariate meta-analysis. Heatwave-attributable risks were projected to the 2030s and 2050s under RCP4.5 and RCP8.5.

Temperature-attributable OIIs: Heat-attributable and cold-preventable fractions of OIIs were 1.66% (95% eCI: 1.38-1.94) and 0.66% (95% eCI: 0.45-0.89%), respectively. These represented 38,540 heat-attributable OIIs and 15,409 cold-preventable OIIs. 1.53% (95% eCI: 0.77-2.27%) and 1.33% (95% eCI: 0.66-1.97%)

of costs were heat- and cold-attributable, respectively, with increased costs per OII during cold despite fewer OIIs. The associated financial burdens were AU$651 and AU$574 million, representing AU$94 million annually and AU$88.1 and AU$76.3 per worker, respectively.

Heatwave-attributable OIIs: 0.13% of OIIs (95%eCI: 0.11-0.16%) were heatwave-attributable, equivalent to 120 OIIs annually. These were associated with 0.25% of heatwave-attributable costs (95%eCI: 0.18-0.34%), equal to AU$4.3 million annually. By 2050, 0.17% (95%eCI: 0.10-0.27%) and 0.23% (95%eCI: 0.13-0.37%) of OIIs were heatwave-attributable under RCP4.5 and RCP8.5, respectively. Projected costs estimates under RCP4.5 and RCP8.5 were 0.13% (95%eCI: -0.27-0.46%) and 0.04% (95%eCI: -0.66-0.60), with significant associations observed with extreme heatwaves in 2030 (0.04%, 95%eCI: 0.02-0.06%) and 0.04% (95%eCI: 0.01-0.07), respectively. Attributable fractions were similar to baseline when assuming theoretical 100% climate adaptation.

Implications: OIIs and associated costs increase with both moderate and extreme heat. This morbidity and financial burden is substantial. Expenses are likely to be less than the costs secondary to labor productivity loss not associated with OIIs. Collectively, however, they portray a more detailed estimate of the economic impact secondary to heat in the workplace. Climate adaptation and mitigation are imperative to minimize future morbidity and costs.

Keywords

Attributable risk; Climate change; Cold; Compensation claims; Costs of injury and illness; Distributed lag non-linear model; Excess heat factor; Environmental economics; Environmental temperature; Global warming; Health and safety; Heat; Heat stress; Heatwaves; Labor productivity; Multivariate meta-analysis; Occupational health; Occupational illnesses; Occupational injuries; Time series; Tweedie distribution; Wet bulb globe temperature; Worker safety; Workplace heat exposure; Work-related illnesses; Work-related injuries.

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

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I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship.

Date: December 14, 2022

Signature:

COVID-19 impact

As with many higher degree research candidates during 2020 and 2021, the COVID-19 pandemic impacted my work. The major impact was a delay in the acquisition of the compensation claims data from Safe Work Australia. They compromised the primary outcome dataset for this research. Other direct impacts included: a closure of the University campus, moving personal belongings from campus to home, setting up a home office, communication with the University Ethics and Information Technology teams for discussion of options for remote access to my University computer and installation of Microsoft Remote Desktop. Ongoing indirect impacts include decreased efficiency from not working on campus alongside other researchers, no face-to-face contact with supervisors, adjusting to the COVID-situation and keeping updated on the COVID-situation both with regards to University and from a broader perspective.

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This research used workers' compensation claims data supplied by Safe Work Australia and has been compiled in collaboration with state, territory, and Commonwealth workers' compensation regulators. The views expressed are the responsibility of the author and are not necessarily the views of Safe Work Australia or the state, territory, and Commonwealth workers' compensation regulators.

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Publications during candidature

Publications contributing to this thesis

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- Borg MA, Xiang J, Anikeeva O, Ostendorf B, Varghese B, Dear K, et al. Current and projected heatwave-attributable occupational injuries, illnesses, and associated economic burden in Australia: a national time-series analysis.

Published datasets:

- Borg M. Public holidays in Australian capital cities from 2004 to 2023. The University of Adelaide; 2022. `https://adelaide.figshare.com/articles/dataset/Public_holidays_in_Australian_capital_cities_from_2004_to_2023/20732449`.
- Borg M. School holidays in Australian capital cities from 2004 to 2023. The University of Adelaide; 2022. `https://figshare.com/articles/dataset/School_holidays_in_Australian_capital_cities_from_2004_to_2023/20732173`.

Other publications

Published:

- Borg MA, Bi P. The impact of climate change on kidney health. Nature Reviews Nephrology. 2021;17(5):294-5.`https://dx.doi.org/10.1038/s41581-020-00365-4`.
- Yuan P, Xiang J, Borg M, Chen T, Lin X, Peng X, et al. Analysis of lifetime death probability for major causes of death among residents in China. BMC Public Health. 2020;20(1):1090.`https://dx.doi.org/10.1186/s12889-020-09201-7`.

- Han S-R, Wei M, Wu Z, Duan S, Chen X, Yang J, et al. Perceptions of workplace heat exposure and adaption behaviors among Chinese construction workers in the context of climate change. BMC Public Health. 2021;21(1).`https://dx.doi.org/10.1186/s12889-021-12231-4`.
- Liu J, Varghese BM, Hansen A, Borg MA, Zhang Y, Driscoll T, et al. Hot weather as a risk factor for kidney disease outcomes: A systematic review and meta-analysis of epidemiological evidence. Science of The Total Environment. 2021;801:149806.`https://doi.org/10.1016/j.scitotenv.2021.149806`.

Manuscripts submitted for publication

- Borg MA, O'Callaghan, ME, Moretti KL, Vincent AD. External validation of predictive models of sexual, urinary, bowel and hormonal function after surgery in prostate cancer subjects. Submitted to BMC Urology in June 2022.

Listed in Acknowledgements

- Fatima, SH, Rothmore, P, Giles, LC and Bi, P. Outdoor ambient temperatures and occupational injuries and illnesses: Are there risk differences in various regions within a city? Science of The Total Environment 2022; 826:153945. `https://dx.doi.org/10.1016/j.scitotenv.2022.153945`.

Presentations during candidature

International, with published journal abstracts:

- Borg M, Bi P, Xiang J, Anikeeva O, editors. 3F.004 Occupational heat stress and economic burden: evidence for workplace heat management policies. Virtual Pre-Conference Global Injury Prevention Showcase 2021; 2021 2021; Adelaide, Australia: BMJ Publishing Group Ltd. `https://dx.doi.org/10.1136/injuryprev-2021-safety.86`.
- Borg MA, Xiang J, Anikeeva O, Bi P. Occupational heat stress and economic burden: A review of global evidence. International Society for Environmental Epidemiology 33rd Annual Conference 2021. `https://ehp.niehs.nih.gov/doi/abs/10.1289/isee.2021.P-379`.
- Borg M, Bi P, Xiang J, Anikeeva O. 345 Occupational heat stress and economic burden: evidence to support development of workplace heat management policies. International Journal of Epidemiology. 2021; 50(Supplement_1):dyab168. 089. `http://dx.doi.org/10.1093/ije/dyab168.089`.
- Borg M, Xiang J, Anikeeva O, Bi P. The impact of apparent temperature on occupational injuries in Australia. Saf Health Work. 2022;13:S132. `https://doi.org/10.1016/j.shaw.2021.12.1165`.

National:

- Australian Meteorological and Oceanographic Society Science for Impact Conference.

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- 2021 South Australian Safety Symposium. Slides available online: `https://www.slideshare.net/safetyinstitute/uni-of-adelaide-matthew-borg-heat-stress-in-the-workplace-health-service-burden-and-labour-productivity-loss-in-australia`.
- SA State Population Health Conference 2021.
- 2022 Florey Postgraduate Research Conference.

Awards and Achievements

Associated with candidature:

- Faculty of Health and Medical Sciences Divisional Scholarship for my PhD candidature. Awarded by the University of Adelaide in 2019.
- Poster Abstract Award for my conference abstract presented at the International Society of Environmental Epidemiology 2021. Awarded by the International Society of Environmental Epidemiology in 2021.
- 2022 Kerry Kirke Student Award for public health work as a postgraduate student. Awarded by the Public Health Association of Australia in 2022.

Not associated with candidature:

- Masters of Biostatistics. Conferred in March 2021, graduated in May 2021.
- Biostatistics Collaboration of Australia star graduate: obtaining an overall score of at least 85% in the Masters of Biostatistics.
- Four university subjects completed during the time of candidature: Categorical Data Analysis, Survival Analysis and two Workplace Portfolio Projects.
- Certificate Graduate Statistician with the Statistical Society of Australia.

1

Introduction

1.1 Preface

This chapter outlines the research background informing this thesis. Subchapter 1.2 summarizes the potential impact of global warming, the negative health impacts of higher temperatures, and the associated effects on workers, and briefly describes the potential work-related economic impact. This forms the impetus for this thesis' overarching objectives and aims in Subchapter 1.3. The chapter concludes by briefly summarising the policy and practical implications (Subchapter 1.4) and stating the thesis structure (Subchapter 1.5).

1.2 Background

1.2.1 Global warming

Hot days and heatwaves are projected to increase in frequency, intensity, and duration with global warming (3,4). Global surface temperature increased in 2001-2020 by approximately 1°C compared to 1850-1900, and temperatures are increasing at an elevated rate (4). The extent of future increases is largely dependent on future greenhouse gas (GHG) emissions. Under a high GHG emissions scenario (SSP5-

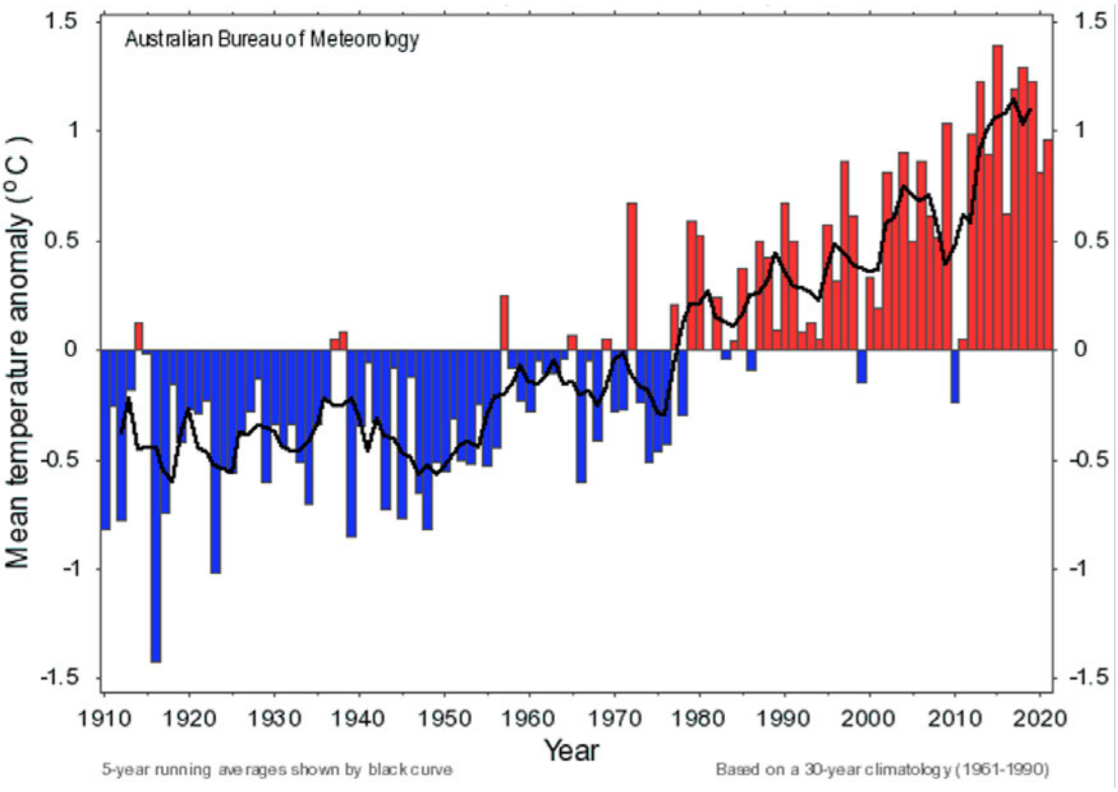

Figure 1.1: Mean yearly temperature anomalies in Australia from 1910 to 2020. Anomalies are shown per financial year (July to June). This figure was derived from the Australian Bureau of Meteorology webpage under the Creative Commons Attribution 4.0 International License.

8.5, a combination of Shared Socioeconomic Pathway [SSP]5 and Representative Concentration Pathway [RCP]8.5), global average temperatures were projected to increase by 3.3-5.75°C at the end of the 21st century (4). Relatively smaller increases are expected with climate mitigation and subsequent low GHG emission scenarios. Under a very low GHG emissions scenario (SSP1-1.9), the projected increase was instead 1.0-1.85°C (4).

Similar increases have been observed in Australia (Figure 1.1) (5). The Australian national average temperature in 2021 was 0.56°C higher than the 1961-1900 average (6). Projected temperature increases in 2090 compared to 1986-2005 ranged from 2.8 to 5.1°C under RCP8.5 and 0.6 to 1.7°C under RCP2.6 (7). Approximately similar increases were projected across Australian cities (5,7).

1.2.2 Heat-attributable health impacts

High ambient temperatures and heatwaves have been associated with increased morbidity and mortality, including increased emergency department (ED) and inpatient hospital admissions (3,8 11). In response to elevated heat, the body stimulates vasodilation (3). This leads to increased cardiac activity (elevated heat rate and stroke volume), increasing cardiac oxygen demand which can aggravate existing cardiac disease potentially leading to cardiac ischemia (3). Moderate dehydration (approximately 2% loss of body fluid) can impair physical and cognitive performance (12), which predisposes to accidents such as falls and injuries generally (13). Dehydration also predisposes to kidney disease (14), neuromuscular fatigue due to electrolyte imbalance, and exacerbation of pre-existing cardiovascular disease (increased cardiac activity is required to compensate for hypovolemia and subsequent decreased blood flow) (3,15).

Heat stress occurs when heat gain cannot be compensated by heat loss (16). This not only attenuates the aforementioned heat-related responses to greater degrees but also predisposes to mental illnesses (17) and heat-related illnesses that can damage the neurological, cardiovascular, renal, gastrointestinal, hepatobiliary, and pulmonary systems, sometimes permanently (3,9,10,12,18,19). Heat-related illnesses are the illnesses most commonly associated with heat stress (13,18). These include, in order of least to most severe, heat cramps, heat exhaustion, heat syncope, and heat stroke, the latter being life-threatening if not promptly treated (15,18). Mechanisms for the multisystem body dysfunction include, but are not limited to, dehydration, diverted blood flow towards skeletal muscle and away from other organs, and heat-induced pathophysiological processes such as inflammation (3,12,15). More deaths have occurred due to heatwaves than all other natural disasters combined (20). With global warming, an increase in heat-attributable health impacts is highly likely (3,4). This will pose significant health challenges to the most vulnerable groups such as the elderly, children, migrants, and people with pre-existing medical conditions (3,11,18). This thesis will focus on the health and wellbeing of workers in the context of climate change.

1.2.3 Occupational heat stress

Workers are more predisposed to heat stress. The reasons for their elevated risk can be summarized in relation to the fundamental factors of body heat balance: metabolic heat, clothing, hydration, air temperature, radiant temperature, humidity, air movement, and solar radiation (Table 1.1) (15,16,21). Human physical activity requires metabolic energy, most of which is converted into heat (15). Working during the warmest hours of the day (usually the afternoon (22)), reduced access to air conditioning, and radiant workplace-generated heat for process heat (such as furnaces) increase heat gain from the surrounding environment (13,16,21,23). Overly warm work clothing (formal attire and especially protective clothing or equipment such as overalls and gloves) can impede the heat-protective measures of air conduction and sweat evaporation from the skin (15,21). Workers may have potentially less access to adequate hydration (13,16,21). Working conditions can involve impeded air movement because of reduced or no access to ventilation (13,16,21,23) or working in confined spaces (24,25). Collectively, workers are more likely to gain more heat and have barriers to compensate for this heat, predisposing to a net gain in body temperature and consequent health impacts (3,16). Work-attributable muscle and mental fatigue further aggravate impaired physical and cognitive performance from excessive heat (3,26). Workers may also be less likely to seek medical attention if they are afraid of its impact on their work and/or their relationships with their employer(s) and by extension their employment, especially among small businesses (27).

Workers have been associated with increased occupational illnesses/injuries (OIIs) in response to higher temperatures/heatwaves and consequent adverse morbidity and mortality outcomes (3,13). A previous systematic review observed a 1.005% increase in occupational injuries (95% CI: 1.001 to 1.009) in response

Table 1.1: Fundamental factors of body heat balance and potential adverse work impacts

Environmental?	Factors	Potential work-related issues
No	Metabolic heat	Metabolic energy generated through physical work converted into heat
	Clothing	Workplace mandated clothing, especially protective clothing or equipment
	Hydration	Potential less access to hydration
Yes	Air temperature	Working in warmest hours of the day
	Radiant temperature	Workplace-generated heat; reduced access to air conditioning
	Humidity	Evaporated sweat trapped by clothing and protective equipment
	Air movement	Less ventilation, working in confined-spaces, clothing-induced air resistance
	Solar radiation	Working outside; increasing heat exposure from sunlight

to heat stress (28). To the best of the author's knowledge, only one study has previously estimated the impact of projected temperatures on OIIs, and only in Adelaide (29). This study predicted large and likely but non-statistically significant heat-attributable increases in OIIs. In the 2090s, projected increases were 9.19% (95%CI: -1.60 to 15.64%) and 10.32 (95%CI: -1.62 to 17.54%) under RCP4.5 and RCP8.5, respectively (29). OIIs are also associated with decreased labor productivity from sick leave, temporary or permanently decreased capacity to work, and both time and resources spent overseeing potential compensation payments and hiring replacement staff (21,23,30,31).

Arguably the greatest impact on labor productivity loss is the heat-attributable impairment in work performance that applies to the general working force instead of only being correlated with OIIs (23,26). High heat, even without morbidity, can result in increased work breaks, a reduced rate of work or workers taking days off work (3,23,32). Productivity loss is expected to worsen with global warming in most countries (21,23,33). In the hottest month of the year, global labor productivity was estimated to decrease by 6 to 10%, and this was projected to increase by 20 to 37% by 2100 and up to 61% by 2200 (34). In Australia, 70% of workers reported decreased productivity during heat, and 7% of workers reported missing at least one workday a year due to heat (32).

Occupational heat stress is an international workplace health and safety (WHS) issue. Workers in low-, middle-, and high-income countries are all at risk, though those in low- and middle-income countries (LMICs) are at greater risk, especially in the future (10,23). LMICs are often warmer, have a greater proportion of workers in higher risk industrial sectors, have less access to healthcare, air conditioning and WHS regulations, and are less able to substitute laborers with mechanisation of work (3,10,14,21,23,33,35). A systematic review identified an association between heat and elevated OIIs across a range of climate zones, although no studies were identified in tropical regions (36).

In terms of occupational factors, employees at greater risk of heat stress include outdoor workers, those with physically demanding jobs, those who work close to heat-generating sources and those who require personal protective clothing or equipment (13,23). These include miners and workers in the agriculture, construction, and manufacturing industries, particularly in LMICs (13,23,37,38). However, increases in temperature compared to mean exposure were not always associated with an increased risk in OIIs for outdoor workers (28,39,40), and most studies assessed heat-induced labor productivity loss as a function of wet bulb globe temperature (WBGT) (23,26), which generally has higher values when measured outdoors compared to indoors (41). Both indoor and outdoor workers have been identified to be at risk of occupational heat stress (13,28,39). Other risk factors include males, younger workers (aged <25 or <35 years old), older workers (aged >55 years old), and those employed by businesses with fewer employees, although not all studies found associations with these risk factors (13,28,36,39).

1.2.4 Economic costs from heat

Extreme heat has been associated with increased healthcare expenses covered by governments and/or patients and their families (42). Healthcare expenses include those from health services such as ambulance, hospitalisations, and allied health for both morbidity and mortality, out-of-pocket expenses such as over-the-counter medications, intangible costs from anxiety and pain, and indirect costs from workers requiring sick leave or reduced work hours (42,43). Injury and illness severity are correlated with greater costs, such as prolonged hospital stays (42). Similarly, illnesses generally incur more costs than injuries (44), likely because illnesses are longer-lasting in nature and thus more likely to be associated with on-going costs.

(Heat-attributable) OIIs are not only associated with the aforementioned costs but also workers' compensation payouts, associated administrative and potential legal costs, and indirect costs from labor productivity loss (31,32). Given that a previous study estimated a total cost of $118,540 per OII in New South Wales, Australia, from 2000 to 2001 (45), heat-attributable OIIs potentially represent considerable economic burden. Heat-induced labor productivity loss, regardless of its association with OIIs, can result in decreased worker incomes or increased industrial costs to maintain the same level of production (21,23). Heat-related occupational expenses represent preventable costs (46) that are likely to increase with global warming (3). Despite the relatively large literature on occupational heat stress, there is comparatively less research into the associated economic burden (13).

1.3 Objectives and aims

The overall objective of this thesis was to analyze economic burden secondary to occupational heat stress. The underlying aims were to:

- Summarize existing estimates on previous heat-attributable economic burden, including associated risk factors;
- Create, for the first time, a national Australian profile of temperature-attributable OIIs and their associated economic burden;
- Investigate the relationships between OII-associated costs and apparent temperature, including differences in the relationships between OIIs and their costs;
- Explore higher risk groups for increased heat-attributable OII-associated costs and if they were identical to those of OIIs; and

- Estimate OII-associated costs attributable to extreme heat and the potential impact of global warming.

1.4 Policy and practical implications

The policy and practical implications of this thesis are to provide scientific evidence to:

- Support the creation of more accurate estimates of occupational heat stress by reviewing estimates from existing literature and estimating costs secondary to heat-attributable OIIs, a topic under which there has been limited research;
- Support heat adaptation measures aimed at workers to provide both a morbidity and economic benefit;
- Support climate mitigation in terms of workers' outcomes;
- Guide whether workplace adaptation measures to cold and especially high temperatures are likely to be effective for both morbidity and financial expenses; and
- Determine if certain worker or OII characteristics are associated with greater temperature-attributable OII-associated costs and thus if they should be prioritized with workplace adaptation measures.

1.5 Thesis outline

This is a thesis by publication. Subchapter 2.3 of Chapter 2, and Chapters 4 and 5 are written as individual publications. Chapters 3 and 6 refer to aspects shared between the studies.

Chapter 2 details a comprehensive review of current knowledge about the economic impacts of occupational heat stress. This pools existing findings together for collective interpretation and identifies gaps in current research regarding occupational heat stress and economic burden, which were used to guide the subsequent studies of this project. Chapter 3 provides an overview of the study design and methodology for the subsequent studies including a description of an overarching approach to implementing these studies. Chapter 4 describes a study evaluating the impact of heat and cold on OIIs and their associated costs in seven capital Australian cities: Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth, and Sydney. Chapter 5 explores the impact of heatwaves on OIIs and their associated costs, projected future findings, and the potential benefit of long-term climate adaptation in the seven aforementioned cities. Chapter 6 summarizes, discusses, and concludes the main findings from Chapters 4 and 5 whilst outlining relevant recommendations and referencing previous studies discussed in Chapter 2.

2

Occupational heat stress and economic burden: A review of global evidence

2.1 Preface

This chapter updates on previous literature estimating both retrospective and projected estimated economic burden from occupational heat stress. Subchapter 2.3 contains a peer-reviewed and published review on this topic. Subchapter 2.4 lists relevant epidemiological studies published after the publication of the review, identified using the same search strategy. These new studies' findings and their impact on current knowledge regarding work-related economic burden, including any impact on pre-existing research gaps, are briefly summarized. Subchapter 2.5 summarizes the information covered in this chapter.

Although Chapter 4 explores the exposure-relationship with OII-associated costs and cold temperatures, the effect of occupational cold stress on economic burden was not explored in the published literature review. A preliminary literature search only identified one study exploring this (31). To briefly summarize the findings specific to cold temperatures, this study observed an annual cost of €49.89 million from cold-attributable occupational injuries across Spain from 1994 to 2013

(31). Although large, this was notably less than the cost from heat-attributable injuries (€319.39 million).

2.2 Statement of Authorship

This subchapter includes signed forms detailing the contribution of all authors involved in this study pertaining to subchapter 2.3 and the Chapter 2 Supplementary Material.

Statement of Authorship

Title of Paper	Occupational heat stress and economic burden: A review of global evidence
Publication Status	☒ Published ☐ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details	Borg MA, Xiang J, Anikeeva O, Pisaniello D, Hansen A, Zander K, et al. Occupational heat stress and economic burden: A review of global evidence. Environmental Research. 2021;195:110781. https://doi.org/10.1016/j.envres.2021.110781

Principal Author

Name of Principal Author (Candidate)	Matthew Anthony Borg		
Contribution to the Paper	Conceptualisation; Methodology design; Visualisation; Writing drafting manuscript; Reviewing and editing the manuscript;		
Overall percentage (%)	85%		
Certification	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	4/11/2022

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

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2.3 Occupational heat stress and economic burden: A review of global evidence

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Review article

Occupational heat stress and economic burden: A review of global evidence

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ABSTRACT

Background: The adverse effects of heat on workers' health and work productivity are well documented. However, the resultant economic consequences and productivity loss are less understood. This review aims to summarize the retrospective and potential future economic burden of workplace heat exposure in the context of climate change.

Methods: Literature was searched from database inception to October 2020 using Embase, PubMed, and Scopus. Articles were limited to original human studies investigating costs from occupational heat stress in English.

Results: Twenty studies met criteria for inclusion. Eighteen studies estimated costs secondary to heat-induced labor productivity loss. Predicted global costs from lost worktime, in US$, were 280 billion in 1995, 311 billion in 2010 (≈0.5% of GDP), 2.4–2.5 trillion in 2030 (>1% of GDP) and up to 4.0% of GDP by 2100. Three studies estimated heat-related healthcare expenses from occupational injuries with averaged annual costs (US$) exceeding 1 million in Spain, 1 million in Guangzhou, China and 250,000 in Adelaide, Australia. Low- and middle-income countries and countries with warmer climates had greater losses as a proportion of GDP. Greater costs per worker were observed in outdoor industries, medium-sized businesses, amongst males, and workers aged 25–44 years.

Conclusions: The estimated global economic burden of occupational heat stress is substantial. Climate change adaptation and mitigation strategies should be implemented to likely minimize future costs. Further research exploring the relationship between occupational heat stress and related expenses from lost productivity, decreased work efficiency and healthcare, and costs stratified by demographic factors, is warranted.

Key messages. The estimated retrospective and future economic burden from occupational heat stress is large. Responding to climate change is crucial to minimize this burden. Analyzing heat-attributable occupational costs may guide the development of workplace heat management policies and practices as part of global warming strategies.

1. Introduction

Heat stress in humans is defined as heat exceeding the level that can be tolerated without physiological impairment (Kjellstrom et al., 2016). Some workers are susceptible to heat stress due to increased ambient temperatures and workplace heat exposure, potential metabolic heat production from physical work, and clothing or personal protective equipment that reduces heat convection and sweat evaporation (Hanna et al., 2011; Kjellstrom et al., 2016; Parsons, 2014). Two systematic reviews have associated high temperatures with an increased rate of occupational injuries (OIs) (Binazzi et al., 2019; Bonafede et al., 2016). These OIs include both occupational heat-induced illnesses (OHIs)

Abbreviations: OHI, Occupational heat-induced illness; OI, Occupational injury; $T_{average}$, Average air temperature; T_{max}, Maximum air temperature.

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ranging from heat rash to life-threatening heat stroke (Xiang et al., 2014a, 2015) and those not directly caused by heat such as bone fractures resulting from injuries sustained while working in the heat (Binazzi et al., 2019; McInnes et al., 2017; Otte Im Kampe et al., 2016; Varghese et al., 2018, 2019).

Occupational heat stress can burden the economy (Dell et al., 2008, 2014; Xiang et al., 2014b, 2014c) as illustrated in Fig. 1. Heat-induced dehydration can impair physical and mental performance; this can compromise occupational safety, predisposing to OIs, and reduce work efficiency (Chi et al., 2005; Murray, 2007; Xiang et al., 2014a). A meta-analysis estimated a decrease in work productivity by 30% in either indoor or outdoor industries during heat stress conditions with a 2.6% productivity decline for each degree above 24 °C wet bulb globe temperature (WBGT) (Flouris et al., 2018). Productivity loss can also be caused by [1] workplace policies that reduce worktime (or increase break time) during high temperatures for occupational safety (Kjellstrom, 2016); [2] sick leave from OIs due to heat (Milton et al., 2000); and [3] reduced workforce secondary to resignations from jobs

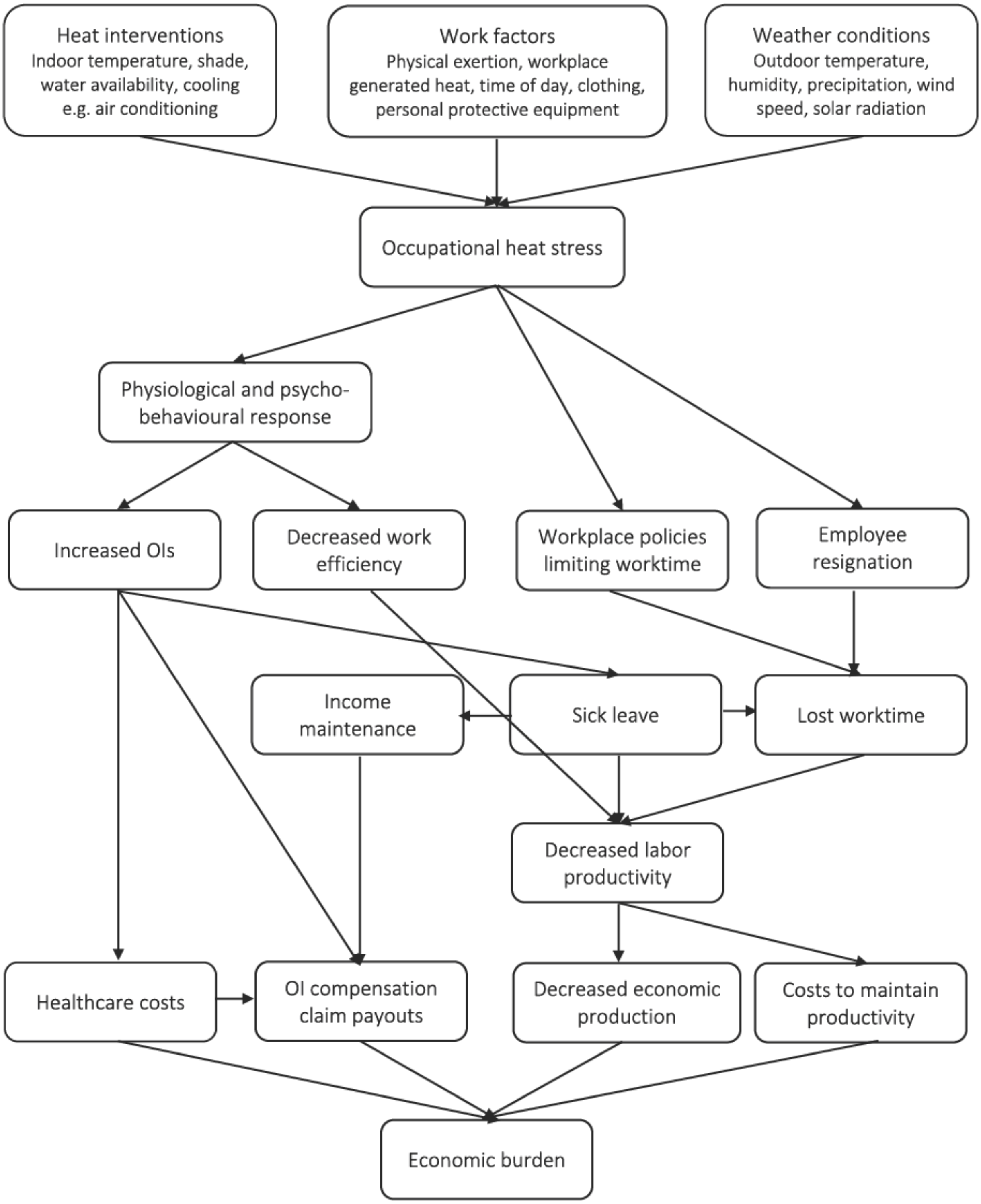

Fig. 1. Schematic illustration of economic burden related to occupational heat stress.

associated with high heat stress (Dunne et al., 2013; Heal and Park, 2016; Milton et al., 2000). Decreased labor productivity leads to less economic production and/or costs to maintain production such as overtime payments and replacement staff. Following OIs, additional expenses can arise from healthcare costs and income maintenance due to sick leave, which may be paid through injury compensation claims. As an example, studies in Adelaide, Australia, observed a 0.2% increase in daily OI compensation claims per 1 °C increase in daily maximum air temperature (T_{max}) below 37.7 °C (Xiang et al., 2014c); and a 6.2% increase in these claims during heatwaves (defined as $\geq$3 consecutive days with daily $T_{max} \geq 35$ °C) compared to non-heatwave periods (Xiang et al., 2014b). The same authors observed an even greater (12.7%) increase in claims for OHIs following a 1 °C increase in daily T_{max}; and 4–7 times during heatwaves compared to non-heatwave periods (Xiang et al., 2015).

Hot days are projected to increase in duration, frequency and intensity with global warming (Intergovernmental Panel on Climate Change, 2015). Worldwide average surface temperatures have increased by 0.85 °C (0.65 °C–1.06 °C) between 1880 and 2012 (Intergovernmental Panel on Climate Change, 2015). Projected changes are greatest in low- and middle-income countries and those with warmer climates (Kjellstrom et al., 2009b, 2016). This will affect labor productivity. There is extensive literature investigating the association between heat stress and decreased work-related productivity (Flouris et al., 2018; Levi et al., 2018), and labor productivity has been projected to decrease by up to 27% by the 2080s in Southeast Asia, the Caribbean, and Andean and Central America (Kjellstrom et al., 2009c).

To the best of our knowledge, the literature linking occupational heat stress to economic burden has yet to be comprehensively summarized. Although a literature review in 2019 identified ten studies that linked heat stress with increased healthcare costs from ambulance call-outs, emergency department visits and hospitalizations (Wondmagegn et al., 2019), it did not focus on costs associated with occupational heat stress. Day et al. (2019), Kjellstrom et al. (2016), and Orlov et al. (2019) discussed occupational costs from heat stress in the context of labor productivity loss but only briefly (Day et al., 2019; Kjellstrom et al., 2016; Orlov et al., 2019). This review aimed to summarize the literature investigating the associations between occupational heat stress and economic burden, encompassing costs of decreased productivity, and heat-related healthcare expenses from OIs. Both retrospective and potential future economic costs were reviewed.

2. Methods

2.1. Search strategy

A search strategy combining controlled vocabulary (MeSH, EMTREE) and keywords was created for PubMed, Embase and Scopus to identify peer-reviewed scientific journal articles (Appendix A). Search term protocols included three categories of search terms: "heat", "work", and either "medical costs" or "productivity", combined using the Boolean operator "AND" (Wee and Banister, 2016). Terms within each category, and the categories of "medical costs" and "productivity", were combined using the Boolean operator "OR." The wildcards "*" and "?" were used for particular keywords such as "labo*" to capture "labor," "laborer", "laborers", using American or British English spelling. Searches were not limited by year of publication. Potentially relevant articles identified by backward reference searching, including grey literature, were retrieved using Google Scholar.

2.2. Inclusion and exclusion criteria

The studies selected in this review met the following criteria:

- Written in English.
- Published from database inception to October 18, 2020.
- Limited to human populations.
- Publications with original research results on estimated costs secondary to occupational heat stress were included. Studies with results on costs without providing figures for total expenses, cost per capita, or costs as a proportion of economic output were excluded.
- Studies devoted solely to the effect of cold temperatures, without considering hot temperatures, were excluded.
- Studies devoted solely to non-occupational costs, without considering occupational costs separately, were excluded.
- Studies devoted solely to labor productivity loss without reference to associated costs were excluded.
- Conference abstracts, commentaries, editorials, and letters to the editor were excluded.
- Peer-reviewed articles without an abstract were excluded.

The search results were imported into an Endnote library. Relevant peer-reviewed studies were identified by a four-step process: [1] removing duplicates using the Endnote function of "find duplicates; " [2] screening titles; [3] reviewing abstracts of articles that were difficult to judge by screening their titles; and [4] reviewing the full-texts (Fig. 2).

All monetary figures were converted to United States Dollars (US$) as per previous reviews evaluating economic burden (Bahadori et al., 2009; Wondmagegn et al., 2019) using the exchange rate on September 14, 2019 from Google Finance (Reuters, 2019). The figure conversion for 1 US$ with the currencies for studies included in this review are shown in Appendix B.

3. Results

Twenty studies were included in the final review (15 peer-reviewed and five grey literature articles). These studies and their main cost estimates are summarized in Table 1 (retrospective results) and Table 2 (future estimates). One included study, Takakura et al. (2018), was a follow-up study to another included 2017 publication by the same authors using the same data. Studies were from China (n 2), Australia (n 2), Canada (n 1), Germany (n 1), India (n 1), Italy (n 1), Malaysia (n 1), Spain (n 1), USA (n 1), multiple European cities or countries (n 3), and global data across multiple continents (n 6).

The metrics for estimating occupational heat exposure included WBGT (n 12), T_{max} (n 3), $T_{average}$ (average air temperature, n 2), perceived temperature (n 1), and heatwaves (n 3), with two studies utilizing self-reported results without using a heat metric.

Thirteen studies estimated retrospective costs and ten estimated future costs, with three studies estimating both. Three studies investigated health-care costs, all retrospective and in relation to OIs. Eighteen studies investigated costs from heat-induced labor productivity loss including retrospective (n 10) and future (n 10) costs. The included mechanisms for estimating decreased productivity were assumed lost worktime from recommended work/rest ratios during heat stress (n 8), reduced work efficiency estimated from exposure-response functions (n 4), self-reported reduced work efficiency (n 2), self-reported missed worktime (n 2), costs related to maintaining production (n 1), and long-term lost incomes following OIs (n 1). Two studies assumed predefined estimates for the value of productivity loss.

3.1. Retrospective costs from heat stress

3.1.1. Costs associated with decreased labor productivity

Two studies estimated retrospective costs from worktime lost due to recommended altered work/rest ratios based on heat exposure. One study estimated retrospective global costs in 1995 to be $280 billion annually (Kjellstrom et al., 2019), and another estimated costs in 2010 to be $311 billion annually, ≈0.5% of global GDP (DARA, 2012). A manufacturing worksite in Ontario, Canada, with approximately 200 outdoor laborers, retrospectively estimated costs in summer from 2012 to 2018 (Vanos et al., 2019) and showed that approximately 1% of

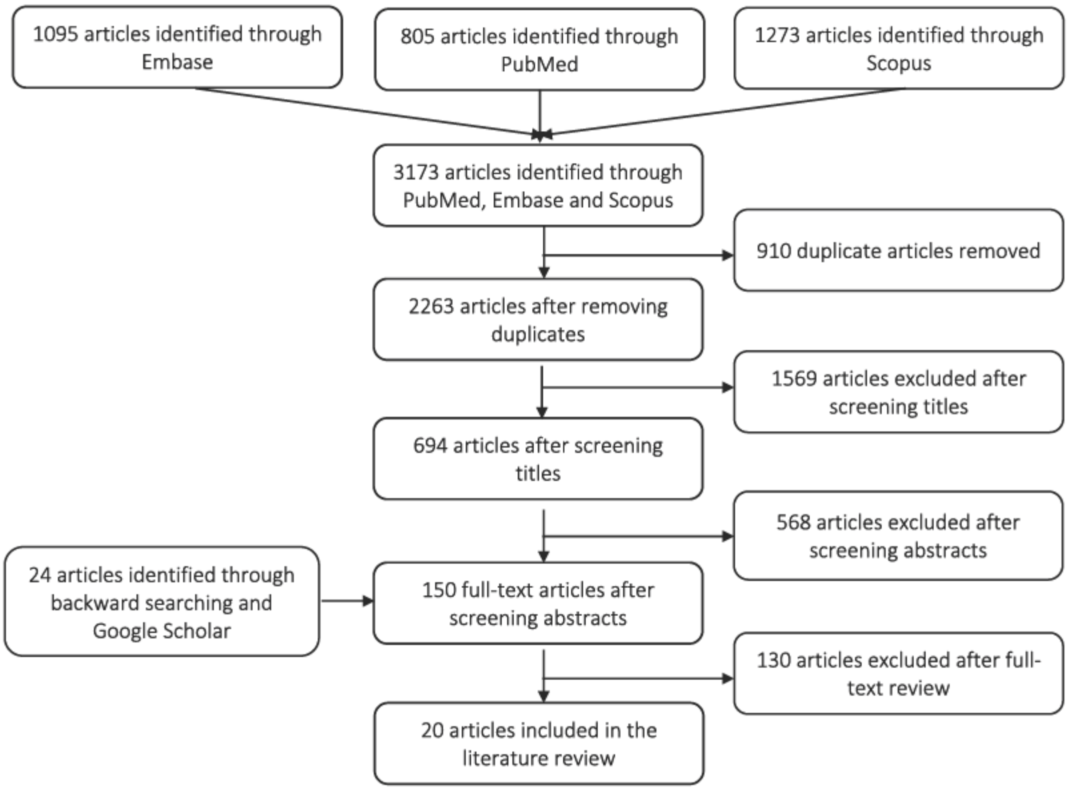

Fig. 2. Selection process for study inclusion.

annual work hours (21.8 h per worker), were lost annually, resulting in an average $827 annual loss per worker, totaling approximately $166, 316.

An exposure-response function was derived from the High Occupational Temperature Health and Productivity Suppression (Hothaps) program (Kjellstrom et al., 2009a), using data from previous epidemiological data sets (Sahu et al., 2013; Wyndham, 1969), to predict heat-induced work efficiency loss using WBGT and work intensity (Brode et al., 2018; Kjellstrom et al., 2018). Using this function (hereafter: the Hothaps function), a wine and honey farm in Florence, Italy estimated hourly costs of $6.3 in 18 outside workers across the summers of 2017 and 2018, or $6667 in total (Morabito et al., 2020). The estimated costs across all wine workers in Florence (≈2500 workers) was $888,889. Using the same function, Orlov et al. (2019) estimated costs in agricultural and construction workers during the months of August 2003, July 2010, and July 2015 in 10 European countries (Austria, Croatia, Cyprus, France, Germany, Greece, Hungary, Italy, Spain, and Switzerland) (Orlov et al., 2019). Heatwaves occurred during these months, and these countries were estimated to have the largest heat-induced efficiency loss (Orlov et al., 2019). The mean costs per capita were $4.9 (August 2003), $3.7 (July 2010), and $4.4 (July 2015). Costs were approximately twice as large when estimated using ISO guidelines instead of an exposure-response function (Orlov et al., 2019). The costs estimated by Morabito et al. (2020) were also increased by a factor of 1.4 when using a similar exposure-response function based on ISO guidelines (Morabito et al., 2020).

A self-reported questionnaire survey from 2013 to 2014 estimated that 7% of Australia's workforce annually missed workdays due to heat at a cost equating to $845 per person ($58 per person across the Australian workforce) (Zander et al., 2015). Moreover, 70% of Australian workers reported reduced work efficiency from heat stress on at least one day yearly, costing $932 annually per person ($656 per person across the entire workforce). Another self-administered questionnaire survey from 2017 to 2018 estimated that 88% of Malaysia's urban workers had decreased work efficiency on at least one day annually (Zander and Mathew, 2019). Per worker, this was associated with a mean cost of $196 (SD: $434, median cost: $62). Considering the Malaysian workforce size in January 2018 of 14, 670, 500 (both urban and rural workers) (Mahidin, 2018), this likely represents a large economic burden to Malaysia. A questionnaire survey in Bhubaneswar and Sambalpur, two cities in Odisha, India, estimated lost wages from lost summer worktime during heatwave days compared to non-heatwave days for low-income urban outdoor workers in the informal sector (Das, 2015). The estimated annual cost was $7.7 per worker per heatwave day resulting from an average loss of 1.19 work hours. Applying this estimate to all the aforementioned workers in Odisha results in a loss of about $5 million. In the Australian, Malaysian, and Indian surveys, the causes of missed workdays and decreased efficiency, such as feeling unwell or work policy, were not investigated.

Martínez-Solanas et al. (2018) estimated costs associated with maintaining production and long-term lost incomes of $65.79 and $54.64 million, respectively, following an increase in OIs during high temperatures in Spain from 1994 to 2013 (Martínez-Solanas et al., 2018). This study based its cost estimates on a previous study estimating costs from OIs (Abiuso and Serra de La Figuera, 2008). Two studies estimated costs by assuming the percentage loss in productivity during heat stress. Decreased labor productivity during a 14-day heatwave in Nanjing, China, in 2013, caused an estimated economic cost of $3.88 billion, 3.43% of Nanjing's annual gross value of production (GVP) (Xia et al., 2018). This productivity loss comprised assumed worktime losses of 12% (indoor industries) and 75% (outdoor industries), and 250, 11.9, and 8.4 working days lost per heat-related death, hospital cardiovascular admission, and respiratory admission in 2013, respectively. Hübler et al. (2008) estimated costs of heat-induced labor productivity loss in Germany (2004) using predefined loss values of 3% and 12% from Bux (2006) (Hübler et al., 2008). With losses of 3% and 12%, the costs were $600 million (0.03% of GDP) and $2.7 billion (0.11% of GDP), respectively.

Table 1
Overview of studies estimating retrospective economics costs from occupational heat stress. All monetary figures were converted to United States Dollars using the exchange rate on September 14, 2019.

Study	Location	Time period	Study design	Heat and cost metrics	Statistical analysis	Main cost estimates
DARA 2012 (DARA, 2012). Grey literature	Global: 192 countries	2010	Ecological	*Heat:* WBGT (°C) *Cost:* GDP from labor productivity loss, estimated by lost hourly worktime	Global/sub-regional scale model to project labor productivity loss, estimated based on ISO and NIOSH WBGT thresholds.	$314 billion annually, ≈0.5% of global GDP. GDP cost per country was more significant in low- and middle-income countries and those with warmer climates.
Das, 2015 (Das, 2015)	Bhubaneswar and Sambalpur, Odisha, India	25th April – May 20, 2013	Prospective cohort questionnaire	*Heat:* Heatwave days based on T_{max} *Cost:* Income lost from worktime lost in summer during heatwvave days compared to non-heatwave days	Costs were estimate using lost worktime obtained from survey responses multiplied by average hourly income. Only low-income urban outdoor workers in the informal sector were used for analysis.	$7.77 annually per worker during heatwaves, 0.12% of their annual income. Applying this estimate to all 644,000 low-income urban outdoor workers in Odisha's informal sector gives combined cost of $5 million.
Hübler et al., 2008 (Hübler et al., 2008)	Germany	2004	Ecological	*Heat:* perceived temperature (°C) *Cost:* GDP from labor productivity loss, assumed as 3% or 12% loss on days with perceived temperature $\geq 32^\circ$	Macroeconomic model using GDP in 2004, number of days where perceived temperature $\geq 32^\circ$ and associated labor productivity loss.	$600 million (0.03% of GDP) or $2.7 billion (11% of GDP) with labor productivity loss of 3% and 12%, respectively.
Kjellstorm et al., 2019 (Kjellstrom et al., 2019). Grey literature	Global	1981–2010	Ecological	*Heat: WBGT (°C)* *Cost:* GDP from labor productivity loss, estimated by decreased work efficiency	Hothaps exposure-response function to estimate worker efficiency loss based on WBGT. Loss measured as the number of full-time jobs lost is multiplied by GDP earned by worker.	$280 billion annually. GDP cost per country was more significant in low- and lower-middle-income countries and those with warmer climates.
Ma et al., 2019 (Ma et al., 2019)	Guangzhou, China	2011–2012	Ecological	*Heat:* WBGT (°C) *Cost:* Insurance payouts from OI claims attributable to days where WBGT > 25 °C	Daily time-series analysis using quasi-Poisson regression with distributed lag non-linear model.	$1.63 million during time period. On days where WBGT >25 °C, OI insurance payouts increased by 4.1% (95% CI: 0.2–7.7%).
Martínez-Solanas et al., 2018 (Martínez-Solanas et al., 2018)	Spain	1994–2013	Ecological	*Heat:* T_{max} (°C) *Costs:* Cost from heat-attributable OIs with at least one day of sick leave, divided into health costs, labor productivity loss (maintaining production and long-term lost incomes), and costs of pain and suffering	Distributed lag nonlinear models for association between daily T_{max} and number of daily OIs, with pooled estimates from multivariable meta-regression.	$354.88 million annually. Costs from pain and suffering: $203.30, maintaining production: $65.79, long-term lost incomes: $54.64, and health costs: $31.18.
Morabito et al., 2020 (Morabito et al., 2020)	Wine and honey farm in Florence, Italy	Summer 2017 and 2018	Retrospective cohort	*Heat: WBGT (°C)* *Cost:* GDP from labor productivity loss, estimated by hourly decreased work efficiency.	Exposure-response functions (Hothaps and ISO) to estimate heat-induced worker efficiency loss based on WBGT. Loss is the product of productivity loss (%) and workers' salaries. 18 workers	$6.3 hourly per worker ($6667 total) using Hothaps function, equal to $888,889 in total across all wine workers (≈2500) in Florence. Costs increased by ~ 1.4 when using the ISO function.
Orlov et al., 2019 (Orlov et al., 2019)	10 European countries	August 2003, July 2010, and July 2015	Ecological	*Heat: WBGT (°C)* *Cost:* GDP from labor productivity loss, estimated by hourly decreased work efficiency.	Hothaps exposure-response function to estimate worker efficiency loss based on WBGT. Loss inputted in computable general equilibrium model to estimate cost for outdoor (agricultural and construction) workers.	Mean per capita costs of $4.9 (August 2003), $3.7 (July 2010), and $4.4 (July 2015). Equivalent to $120 + $61 (August 2003), $84 + $41 (July 2010) and $132 + $72 per agricultural + construction worker. Costs were approximately doubled when estimated using ISO guidelines instead of the Hothaps function.
Vanos et al., 2019 (Vanos et al., 2019)	Manufacturing workplace in Ontario, Canada	2012–2018	Retrospective cohort	*Heat:* WBGT (°C) *Cost:* GDP from productivity loss in outdoor laborers, estimated by lost hourly worktime per summer	Estimated worktime lost based on ACGIH WBGT thresholds and associated hourly wages. ≈200 workers	$166,316 total, based on 21.8 h lost per worker annually (≈1% of annual work hours). Cost of $827 per worker.
Xia et al., 2018 (Xia et al., 2018)	Nanjing, China	5th – August 18, 2013	Ecological	*Heat:* Heatwave based on T_{max} and $T_{average}$ (°C) *Cost:* GVP from labor productivity loss during a heatwave, estimated by lost worktime	Supply-driven IO model derived from a traditional Leontief IO model. Working time loss of 12% and 75% assumed for indoor and outdoor industries,	$3.88 billion, 3.43% of Nanjing's GVP in 2013. Most costs were indirect. Economic loss per industry: manufacturing: 63.1%, service: 14.3%, construction:

(*continued on next page*)

Table 1 (*continued*)

Study	Location	Time period	Study design	Heat and cost metrics	Statistical analysis	Main cost estimates
					respectively. Additionally, each heat-related death, cardiovascular hospital admission and respiratory hospital admission was treated as 250, 11.9 and 8.4 working days lost, respectively.	10.7%, agriculture: 7.6%, energy supply: 3.3%, mining: 0.9%.
Xiang et al., 2018 (Xiang et al., 2018)	Adelaide, Australia	2000–2014	Ecological	*Heat:* T_{max} (°C) and heatwave periods based on T_{max} *Cost:* Daily compensation claims for OHIs. Claim amounts were given based on number of lost workdays and employee medical expenditure	Daily time series model with restricted cubic splines models to estimate crude associations between T_{max} and costs. Linear regression to estimate association between heat and log-transformed costs.	$4,139,890 for all OHI claims from 2000 to 2014. Average cost of $9452 per OHI claim. A 1 °C increase in T_{max} above 32.9 °C was associated with a 41.6% increase (95% CI: 29.3%–55.1%) in medical costs.
Zander et al., 2015 (Zander et al., 2015)	Australia	2013–2014	Prospective cohort questionnaire	*Heat:* N/A *Cost:* Lost income from decreased labor productivity yearly, estimated as the sum of missed workdays and reduced work efficiency	Non-parametric Kruskal-Wallis tests and multiple comparison tests. Workers reported their incomes and perceived productivity loss from heat stress on an online survey. 1726 survey respondents.	$6.2 (95% CI: 5.2–7.3) billion, 0.33%–0.47% of Australia's GDP, equal to $655 per worker. This included costs of $58 and $656 per person from missed workdays and reduced work efficiency, respectively, with some money saved from workers carrying out additional compensatory work.
Zander and Mathew, 2019 (Zander and Mathew, 2019)	Urban Malaysia	2017–2018	Prospective cohort questionnaire	*Heat:* N/A *Cost:* Lost income from decreased work efficiency yearly	Non-parametric Kruskal-Wallis tests and multiple comparison tests. Workers reported their incomes and perceived productivity loss from heat stress on an online survey. 514 survey respondents.	$196 mean cost per worker (SD: $434), and $62 median cost per worker (9.5% of median annual income).

Acronyms; ACGIH: American Conference of Governmental Industrial Hygienists, CI: confidence interval, GDP: gross domestic product, GVP: gross value of production, Hothaps; High Occupational Temperatures Health and Productivity Suppression; IO: industrial-total output, ISO: International Organization for Standardization, NIOSH: National Institute for Occupational Safety and Health, OHI: occupational heat-induced illness, OI: occupational injury, $T_{average}$: average air temperature, T_{max}: maximum air temperature, WBGT: wet bulb global temperature.

3.1.2. Healthcare costs from OIs

Three studies estimated healthcare costs from heat stress: all in relation to OIs. Two estimated daily OI claims and payouts – one investigated all OIs (Ma et al., 2019), and the other only included OHIs (Xiang et al., 2018). In metropolitan Adelaide, Australia, from 2000 to 2014, there were 438 OHI claims (Xiang et al., 2018). These resulted in costs of $4,139,890, equivalent to $9452 per claim. The authors observed a J-shaped curve relationship between daily T_{max} and OHI insurance claim costs (Xiang et al., 2018). Above a threshold of 32.9 °C, a 1 °C increase in daily T_{max} was associated with a 41.6% increase in costs (95% CI, 29.3%–55.1%). Xiang et al. (2018) observed no statistically significant differences for cost per claim between heatwave and non-heatwave periods ($7978 vs $8606, respectively, P-value 0.14). This study excluded costs from OIs that were not OHIs, omitting OIs that could potentially have been caused by heat (Otte Im Kampe et al., 2016; Spector et al., 2019). In Guangzhou, China from 2011 to 2012, when WBGT exceeded 25 °C, OI insurance payouts increased by 4.1% (95% CI: 0.2–7.7%) and the number of OI claims increased by 4.8% (95% CI: 2.9–6.9%) (Ma et al., 2019). This represented $1.63 million in total. Martínez-Solanas et al. (2018) estimated heat-related health costs of $31.18 million from treatment and rehabilitation for OIs in Spain from 1994 to 2013 (Martínez-Solanas et al., 2018). This study also estimated expenses of $203.3 million from pain and suffering (level of disability). The components for expenses of pain and suffering were not specified, but typically these can include additional health costs such as medications and disability-specific aids (Mitra et al., 2017).

3.2. Projected future costs from labor productivity loss

The ten studies that projected future costs from occupational heat stress estimated labor productivity loss using recommended work/rest ratios, except for Kjellstrom et al. (2019) and Orlov et al. (2020) who estimated decreased work efficiency instead (Kjellstrom et al., 2019; Orlov et al., 2020), and Hübler et al. (2008) who assumed the value of productivity loss during heat stress (Hübler et al., 2008). Eight studies projected costs using future climate scenarios with high greenhouse gas concentration scenarios. These scenarios, from highest to lowest concentrations, were RCP8.5, SRES A2, and SRES A1B (Intergovernmental Panel on Climate Change, 2007a; Intergovernmental Panel on Climate Change, 2007b; Intergovernmental Panel on Climate Change, 2015) with RCP8.5 representing no climate mitigation. Five studies compared costs under one of these scenarios to those under either the RCP2.6, SRES 1 B or ENSEMBLES E1 scenario, scenarios with lower predicted greenhouse gas concentrations due to higher levels of climate mitigation (Intergovernmental Panel on Climate Change, 2007a; Intergovernmental Panel on Climate Change, 2007b; Intergovernmental Panel on Climate Change, 2015; Kjellstrom et al., 2019; Orlov et al., 2020; van der Linden and Mitchell, 2009). Takakura et al. (2017 and 2018) and Orlov et al. (2020) also projected shared socioeconomic pathways (SSPs), where each of the five SSPs pose different challenges for climate mitigation and adaptation (O'Neill et al., 2013; Van Vuuren and Carter, 2014). These projected climate and socioeconomic scenarios are described in Appendix C.

Table 2

Overview of the ten (ecological) studies estimating projected future economics costs from occupational heat stress.

Study	Location	Time period	Heat and cost metrics	Projection scenarios	Statistical analysis	Main cost estimates
Costa and Floater 2015 (Costa and Floater, 2020). Grey literature	Antwerp, Bilbao and London	2081–2100	*Heat:* WBGT (°C) *Cost:* Annual GVA from labor productivity loss, estimated by lost hourly worktime	*Climate:* RCP8.5	Constant elasticity of substitution production functions per industrial sector using hourly productivity loss, estimated with ISO WBGT thresholds. Calculated annual lost for year in time period with maximal productivity loss.	Annual GVA loss of 0.4% in London ($2111 million), 2.1% in Antwerp ($2778 million) and 9.5% in Bilbao ($777 million). GVA was observed to monotonically decrease with increasing WBGT.
DARA 2012 (DARA, 2012) Grey literature	Global: 192 countries	2030	*Heat:* WBGT (°C). *Cost:* GDP from labor productivity loss, estimated by lost hourly worktime	*Climate and socioeconomic:* SRES A2	Global/sub-regional scale model to project labor productivity loss, estimated based on ISO and NIOSH WBGT thresholds, using 2010 as the baseline year.	$2.5 trillion annually, ≈1.2% of GDP. This compromised the majority of costs secondary to climate change in 2030 (2.1% of GDP). GDP loss (%) was larger in low- and middle-income countries and those with warmer climates.
Hsiang et al., 2014 (Hsiang et al., 2020). Grey literature	USA	2020–2099	*Heat:* T_{max} (°C) *Cost:* GDP from labor productivity loss, estimated by lost worktime	*Climate:* RCP8.5	Integrated assessment model using labor productivity loss, estimated using regression equations with variables for environmental factors, occupational activities, day of the week, seasonal occupational trends and US county.	Projected costs ranged from $0.1 to $22 billion in 2020–2039, $10 to $52 billion on 2040–2059, and $42 to $150 billion from 2080 to 2099 (0.3%–0.9% of GDP) annually.
Hübler et al., 2008 (Hübler et al., 2008)	Germany	2071–2100	*Heat:* perceived temperature (°C) *Cost:* GDP from assumed labor productivity loss of 3% or 12% on days with perceived temperature ≥ 32°	*Climate and socioeconomic:* SRES A1B and B1	Macroeconomic model using GDP and wage share in 2004, number of days where perceived temperature ≥ 32° and associated labor productivity loss.	Under SRES A1B, almost $2.2 billion with 3% productivity loss and almost $8.9 billion with 12% productivity loss annually. Under SRES B1 with 12% productivity loss, cost decreases from almost $8.9 billion to $4.7 billion annually.
Kjellstorm et al., 2019 (Kjellstrom et al., 2019). Grey literature	Global	2011–2040	*Heat: WBGT (°C)* *Cost:* GDP from labor productivity loss, estimated by decreased work efficiency	*Climate:* RCP2.6 *Socioeconomic:* National industrial-specific estimates of employment-to-population ratio	Hothaps exposure-response function to estimate worker efficiency loss based on WBGT. Cost estimated from estimated loss multiplied by GDP earned by worker.	$2.4 trillion annually. GDP cost per country was larger in low- and lower-middle-income countries and those with warmer climates. Costs estimated under RCP6.0, though not reported, were stated to be similar to those under RCP2.6 since projected temperatures only differed after 2030.
Kovats et al., 2011 (Kovats et al., 2011). Grey literature	Europe	2011–2100	*Heat:* WBGT (°C) *Cost:* GDP from labor productivity loss, estimated by lost hourly worktime	*Climate and socioeconomic:* SRES A1B and E1	Global/sub-regional scale model to project labor productivity loss, estimated based on ISO and NIOSH WBGT thresholds. Costs calculated using productivity loss, GDP/capita and baseline labor distributions across agriculture, industry and services sectors for each country.	Under SRES A1B, $41 – $84 million in 2020s, $132 – $359 million in 2050s, and $330 to $826 million in 2080s annually. Under E1 scenario, yearly costs increased to $61 - $123 in 2020s, and reduced to $68 - $159 million in 2050s and $68 - $161 million in 2080s.
Orlov et al., 2020 (Orlov et al., 2020)	Global	2011–2100	*Heat: WBGT (°C)* *Cost:* GDP from labor productivity loss, estimated by decreased work efficiency	*Climate and socioeconomic:* RCP2.6 with combined SSP1 and SSP4 scenario, and RCP8.5 with SSP5	Hothaps exposure-response function to estimate worker efficiency loss based on WBGT. Loss inputted in computable general equilibrium model to estimate cost. Air-conditioning and mechanization were assumed for indoor and outdoor industries, respectively.	Under RCP2.6, GDP loss of 0.5% by 2050 and 2100. Under RCP8.5, GDP losses of 0.7% by 2050 and 1.4% by 2100, or 0.7% and 1.8% without the assumption of mechanization, respectively. The non-mechanization 2100 costs estimated by ISO guidelines instead of the Hothaps function were 0.9% (RCP2.6) and 2.4% (RCP8.5).
Roson et al., 2016 (Roson and Sartori, 2016)	Global	N/A	*Heat:* WBGT (°C) *Cost:* GDP from labor productivity loss, estimated by lost hourly worktime	*Climate:* 3 °C increase in monthly average WBGT	Assumed linear labor productivity losses when WBGT >26 °C, >28 °C and >30° for agricultural, manufacturing and service sectors, respectively, with minimum productivity of 25%. Estimated cost was product of productivity loss and sectoral share of labor income.	With 3 °C increase in WBGT, mean GDP cost of 0.1779% per country, larger in low- and middle-income countries and those with warmer climates.
Takakura et al., 2017 (Takakura et al., 2017)	Global	2100	*Heat:* WBGT and $T_{average}$ (°C) *Cost:* GDP from labor productivity loss,	*Climate:* RCP2.6, RCP4.5, RCP6.5 and RCP8.5	Asia-Pacific integrated model/computable general equilibrium model with variables for air-conditioning device use, future	GDP losses were 2.8%, 2.6% and 4.0% with RCP8.5, and 0.48%, 0.46% and 0.49% with RCP2.6, under SSP1, SSP2 and SSP3,

(continued on next page)

Table 2 (*continued*)

Study	Location	Time period	Heat and cost metrics	Projection scenarios	Statistical analysis	Main cost estimates
			estimated by lost hourly worktime, compared to 2005	*Socioeconomic:* SSP1, SSP2 and SSP3	climate and socioeconomic projections, and future worktime reduction based on future ISO and NIOSH WBGT thresholds.	respectively. Each 1 °C increase in $T_{average}$ associated with losses of 0.63%, 0.58% and 0.93% under the aforementioned SSPs, respectively.
Takakura et al., 2018 (Takakura et al., 2018)	Global	2090s	*Heat:* WBGT and $T_{average}$ (°C) *Cost:* GDP from labor productivity loss, estimated by lost hourly worktime, compared to 2005	*Climate:* RCP2.6, RCP4.5, RCP6.5 and RCP8.5 *Socioeconomic:* SSP2	As per Takakura et al., 2017, but with a small modification to better describe the diurnal variation of WBGT.	GDP losses were 2.8% (1.7–3.8%) and 0.44% (0.41–0.92%) under RCP8.5 and RCP2.6, respectively. With work shifts up to 3 h earlier in day, losses decreased to 1.6% (1.0–2.4%) and 0.14% (0.12–0.47%), respectively. Losses of 0.48%, 0.68%, 1.2% and 1.7% with increases in $T_{average}$ by 1.5 °C, 2.0 °C, 3.0 °C and 4.0 °C, respectively.

All monetary figures were converted to United States Dollars using the exchange rate on September 14, 2019. Acronyms; GDP: gross domestic product, GVA: gross value added, Hothaps; High Occupational Temperatures Health and Productivity Suppression; ISO: International Organization for Standardization, RCP: representative concentration pathway, SRES: Special Report on Emissions Scenarios, $T_{average}$: average air temperature, T_{max}: mean air temperature, WBGT: wet bulb global temperature.

3.2.1. *Projected global costs*

Four studies projected heat-related workplace costs globally. Both Kjellstrom et al. (2019) and the international organization "DARA" estimated an annual global cost of $2.4–2.5 trillion in 2030 (under RCP2.6 and SRES A2, respectively), ≈1.2% of GDP (DARA, 2012; Kjellstrom et al., 2019). This is a large increase over DARA's baseline 2010 cost estimate of $311 billion annually. Kjellstrom et al. (2019) estimated similar costs in 2030 using RCP6.0 instead of RCP2.6, noting that temperatures under both RCPs only notably differed after 2030. Takakura et al. (2017) projected global GDP losses by 2100 were approximately 5.5–8 times larger under RCP8.5 compared to RCP2.6 (Takakura et al., 2017). Under SSP1, SSP2 and SSP3, these estimated losses under RCP8.5 were 2.84%, 2.62%, and 3.96%, respectively, and under RCP2.6 were 0.48%, 0.46%, and 0.49%, respectively (Takakura et al., 2017). The results were similar in the authors' subsequent 2018 study using the SSP2 scenario, with a model improvement to better estimate the diurnal variation of WBGT (Takakura et al., 2018). Orlov et al. (2020) projected global GDP losses of 0.5% by 2050 and 2100 under RCP2.6 and a combined SSP1 and SSP4 scenario, and 0.7% (1.4%) by 2050 (2100) under RCP8.5 and SSP5 (Orlov et al., 2020). Roson et al. projected that a 3 °C increase in WBGT and its associated labor productivity decrease in the agriculture, manufacturing and services sectors would collectively cause a mean GDP cost of 0.18% globally (Roson and Sartori, 2016). This study did not project socioeconomic or other weather variables.

Three studies projected relationships between global temperature increases and costs. Takakura et al. (2017) projected an approximately linear relationship between global $T_{average}$ rises and GDP loss based on decreased work-rest ratios from WBGT thresholds (Takakura et al., 2017). For each 1 °C increase in global $T_{average}$, GDP losses of 0.63%, 0.58%, and 0.93% were estimated under SSP1, SSP2, and SSP3 scenarios, respectively. However, the same authors in their subsequent study observed a curvilinear instead of a linear relationship, with progressive increases in GDP following incremental increases in global $T_{average}$ (Takakura et al., 2018). Based on this relationship, under SSP2, global $T_{average}$ increases of 1.5 °C, 2.0 °C, 3.0 °C, and 4.0 °C would decrease GDP in 2090 by 0.48%, 0.68%, 1.2%, and 1.7%, respectively (Takakura et al., 2018). Costa and Floater (2015) observed a non-linear (monotonically decreasing) relationship with WBGT and gross value added (GVA, the economic value of produced goods and services minus intermediate consumption) (Costa and Floater, 2020).

3.2.2. *Projected costs according to region*

In the USA, Hsiang et al. (2014) projected annual, direct costs for labor productivity loss with 67% confidence intervals (Hsiang et al., 2020). Under RCP8.5, these costs ranged from $0.1 to $22 billion from 2020 to 2039, $10 to $52 billion from 2040 to 2059, and $42 to $150 billion from 2080 to 2099 (0.3%–0.9% of GDP). In Germany, by 2071–2100 under SRES A1B, labor productivity losses of 3% and 12% would lead to estimated annual costs of almost $2.2 billion and $8.9 billion, respectively (Hübler et al., 2008). Under SRES B1 and a productivity loss of 12%, the cost in 2071–2100 would decrease from almost $8.9 to $4.7 billion.

Costa and Floater (2015) projected, in the hottest year in the period 2081–2100 under RCP8.5, a GVA loss of 0.4% in London ($2111 million), 2.1% in Antwerp ($777 million), and 9.5% in Bilbao ($2778 million) (Costa and Floater, 2020). The authors reasoned that the percentage loss of GVA was less in London compared to Antwerp and Bilbao because of a colder climate and a larger proportion of service workers; the service sector is associated with decreased occupational heat exposure and labor intensity compared to other sectors (Costa and Floater, 2020). Kovats et al. (2011) estimated projected costs from reduced worktime in Europe to be $41 – $84 million in the 2020s, $132 – $359 million in the 2050s, and $330 – $826 million in the 2080s under the SRES A1B scenario (Kovats et al., 2011). Under the E1 scenario, these costs increased to $61 – $123 million in the 2020s and reduced to $68 – $159 million in the 2050s and $68 – $161 million in the 2080s. The costs in the 2080s were approximately five times larger under SRES A1B than under ENSEMBLES E1. Lower values within these cost range reflect lower projected agriculture-to-service worker ratios compared to the ratio in 2000, with the highest limit representing no change in the ratio. Decreased costs were projected in Northern and Western Europe compared to Southern and Eastern Europe. This was also concluded to be because of a colder climate and a higher workforce proportion of service workers in Northern and Western Europe (Kovats et al., 2011).

Estimated costs as a proportion of GDP were larger in low- and middle-income countries and regions with warmer climates (DARA, 2012; Kjellstrom et al., 2019; Orlov et al., 2020; Roson and Sartori, 2016; Takakura et al., 2017). DARA estimated that in these areas, such as West and Central Africa, GDP loss due to occupational heat stress may be up to 6% instead of a global approximate 1.2% loss (DARA, 2012). Similarly, Kjellstrom et al. (2019) estimated GDP losses of 1.5% and 4.0% in low- and lower-middle-income countries, respectively, 2.3% in Asia and the Pacific and 1.8% in Africa (Kjellstrom et al., 2019). Roson et al. (2016), following an increase in global $T_{average}$ by 3 °C, estimated the highest GDP losses in West Africa including Nigeria (8.21%), Ghana, (7.61%), Cote d'Ivoire (7.35%) and Togo (6.79%), followed by Southeast Asia (6.47%). Takakura et al. (2017) observed the highest GDP loss rates in India and South-East Asia (14.3%–17.3% and 4.6%–6.9% under RCP8.5, respectively, with the ranges reflecting different SSPs) (Takakura et al., 2017). Sub-Saharan Africa and other Asian regions had high GDP loss rates similar to South-East Asia only under SSP3, indicating higher sensitivity to future socioeconomic conditions. Similar results were estimated globally under SSP2 in the authors' subsequent study but with stratification of countries into five regions instead of at the individual country level; a higher proportion of costs occurred in Asia, Middle East and Africa (Takakura et al., 2018). By 2100 under RCP8.5, Orlov et al. (2020) estimated GDP losses of 6%, 3.6%, and 2.4% in South Asia, Africa, and South-East Asia, respectively (Orlov et al., 2020). In comparison, these authors observed less than 1% losses in Europe, North America, and Oceania.

3.3. *Averted costs under climate adaptation measures*

Morabito et al. (2020) and Orlov et al. (2019) estimated the change in retrospective costs by working in the shade instead of the sun (Morabito et al., 2020; Orlov et al., 2019). The two studies estimated that under the shade, costs decreased by factors of over 6 and 10, respectively. Morabito et al. (2020) also estimated that shifting work schedules 2 h earlier (from 8am-5pm to 6am-3pm) reduced costs by about 33% (Morabito et al., 2020). Orlov et al. (2019) observed that direct costs from agriculture can be reduced by nearly 66% by working overtime to produce the same quantity of goods and services compared to working normal hours without heat stress (Orlov et al., 2019).

Three studies estimated the effect of climate adaptation measures on projected future costs. Costa and Floater (2015) evaluated five adaptation measures in reducing the projected annual cost of $777 million in Antwerp from 2081 to 2099 in indoor industrial sectors. These measures were: air conditioning access, solar blinds, increased indoor ventilation, adapting working hours to avoid work from 11am to 5pm, and increased insulation through glazing. The averted costs in millions were $713, $549, $517, $173, and -$127, respectively, with the negative $127 million figure representing an additional expense (Costa and Floater, 2020). Air conditioning was potentially the most effective adaptation, and only a small proportion of costs were averted with modified work hours. In another study, Takakura et al. (2018) estimated the global effect of shifting outdoor work to start and end 3 h earlier to reduce occupational heat exposure. With this measure, projected GDP losses reduced from 2.8% (1.7%–3.8%) to 1.6% (1.0%–2.4%) under RCP8.5 and from 0.44% (0.41%–0.92%) to 0.14% (0.12–0.47%) under RCP2.6, with the ranges reflecting costs from different projection models (Takakura et al., 2018). Shifting hours earlier was generally more effective in countries that were not OECD90 countries (i.e. lower-income countries) (Takakura et al., 2018). Orlov et al. (2020) estimated GDP losses when assuming mechanization for outdoor industries (agriculture and construction), with increased mechanization occurring with economic growth (Orlov et al., 2020). The estimated losses without mechanization compared to their mechanization counterparts were similar in 2050 and in 2100 were $<$0.1% greater under RCP2.6 (total loss of 0.5%) and ≈0.4% under RCP8.5 (total loss of 1.8% loss instead of 1.4% loss). The 2100 costs without mechanization were also estimated using ISO guidelines instead of the Hothaps exposure-response function, giving larger GDP losses of 0.9% and 2.4%.

3.4. *Costs per industry*

Takakura et al. (2017), Xiang et al. (2018), and Costa and Floater (2015) investigated direct costs from heat. Xiang et al. (2018) identified that the cost per claim in South Australia from 2000 to 2014 was considerably greater in the mining sector compared to other industries ($74,963 per claim; the next highest cost was from transport and storage at $14,997 per claim) (Xiang et al., 2018). The authors observed more than thrice the overall costs from OHI claims in the mining (and community services) sectors compared to other sectors. Costa and Floater (2015) projected higher proportions of losses in the construction and manufacturing sectors in Antwerp, Bilbao, and London, from 2081 to 2100, relative to the fractions of their baseline sectors' GVA, though the authors did not provide exact cost figures (Costa and Floater, 2020).

Takakura et al. (2017) projected greater costs in outdoor sectors (the construction followed by the primary industry sectors) (Takakura et al., 2017). These sectors had assumed greater work intensities than the indoor sectors (manufacturing and services) and thus more lost worktime. The indoor sectors were only projected to have decreased labor productivity under SSP3, where low economic-growth limited access to air conditioning. Similar results were estimated under SSP2 in the authors' subsequent study using the same industrial sectors (Takakura et al., 2018). This study projected GDP costs per industry by grouping countries into five regions. The OECD90 region was associated with lower and higher proportions of projected costs in the primary industry sector and construction sector, respectively. The inverse was true for the LAM (Latina America and the Caribbean), REF (Eastern Europe and former Soviet Union), and particularly MAF (Middle East and Africa) regions. Projected costs in the indoor sectors had a greater increase in the REF and MAF regions than other regions due to less access to air conditioning, but these figures were surpluses for the OECD90 region (because of overcompensation from increased air conditioning access).

Xia et al. (2018) analyzed both direct and indirect costs. For an industrial sector, direct costs from heatwave-induced productivity loss within that sector, and indirect costs resulted from decreased worktime in other sectors through industrial interdependencies (Orlov et al., 2019; Xia et al., 2018). In Nanjing, they estimated 63.1% of the costs occurred in the manufacturing sector, 14.3% in services, 10.7% in construction, 7.6% in agriculture, 3.3% in energy supply, and 0.9% in mining (Xia et al., 2018). The estimated worktime losses of 4.2–4.5% for outdoor sectors (agriculture, mining and construction) and 0.67–0.7% for indoor sectors alone were not sufficient to explain the costs per sector. Most costs were indirect, resulting from industrial interdependencies with other economic sectors, especially for the manufacturing and energy supply sectors where 88% and 90% of costs, respectively, were indirect. Though the study did not provide the sizes of the sectors' GVP, it did state the manufacturing and service sectors had the largest GVP, which may have partially explained their large cost figures. Agriculture and mining had greater proportions of direct costs; these were sectors with higher work intensities, more exposure to external heat, more occupational health and safety regulations, and relatively fewer industrial interdependencies. Orlov et al. (2019) estimated higher costs from decreased work efficiency in the agricultural sector compared to the construction sector (Orlov et al., 2019). Indirect costs compromised 30–32% of the estimated costs for agriculture. No indirect costs were assumed to occur for construction; the costs for this sector would have increased if this was assumed.

3.5. *Worker and workplace characteristics*

Four studies investigated the association between costs and different worker and workplace characteristics. These included gender (n 4), age (n 4) and business size (n 2).

3.5.1. *Gender*

According to a self-administered questionnaire survey in Australia, heat-induced productivity loss was more costly among males than females (Kruskal-Wallis test: 5.45, P-value 0.0245), despite the two genders having similar numbers (48% of workers were female) and productivity loss levels (30% for both genders) (Zander et al., 2015). The authors stated this could be partially explained by higher median income. However, a similar relative (RR) for injury claims and insurance payouts between males (1.15, 95% CI: 1.1–1.23) and females (1.14, 95% CI: 1.01–1.29) was observed in Guangzhou with a daily WBGT at or above 25 °C (Ma et al., 2019). Despite a similar rate of injury claims within the two genders, females were more influenced by higher heat conditions. Females had a greater increase in insurance payouts when WBGT was 28 °C and 30 °C compared to 24 °C (at 30 °C, RR 1.33, 95% CI: 1.05–1.68); males had smaller, non-statistically significant, increases. However, over three times as many claims and costs from insurance payouts were observed in male workers. Though numbers were not provided, this likely reflects a large male-to-female worker ratio. Xiang et al. (2018) observed a considerably higher number of claims and cost per OHI claim among males compared to females (353 vs 85, and \$10,888 vs \$3489, respectively), though this was demonstrated using descriptive analysis only (Xiang et al., 2018). A self-reported questionnaire survey in Malaysia estimated a non-statistically significant increase in median cost for females compared to males (median costs of \$72.4 and \$51.6, respectively, Kruskal-Wallis test: 1.34, P-value 0.247), with a gender of 1:1 (Zander and Mathew, 2019).

3.5.2. Age

Ma et al. (2019) identified an increased RR for injury claims and insurance payouts in workers aged under 35 years (1.15, 95% CI: 1.04–124), and 35–44 years (1.16, 95% CI: 1.06–1.28), and a non-statistically significant increase in workers above 44 (RR 1.15, 95% CI: 0.99 to 1.32) (Ma et al., 2019). A descriptive analysis by Xiang et al. (2018) showed the number of claims and cost per OHI claim was highest in the 25 to 44 age group relative to other age groups (0–24, 45–64 and 65+), though this was not statistically assessed (Xiang et al., 2018). Zander et al. (2015 and 2019) found no significant correlation between age and associated cost (Zander et al., 2015; Zander and Mathew, 2019).

3.5.3. Business size

Only two studies identified an association between potential costs and business size. Ma et al. (2019) identified increased RRs for injury claims for small- (RR 1.17, 95% CI: 1.08–1.27) and medium-sized businesses (RR 1.16, 95% CI: 1.04–1.29), but not for large businesses (RR 1.06, 95% CI: 0.91–1.28) (Ma et al., 2019). Xiang et al. (2018), on descriptive analysis, identified that although more OHI claims were from employees in larger businesses, employees from medium-sized businesses had greater costs per claim and overall costs (Xiang et al., 2018). Employees from small-sized businesses had lower costs compared to medium- and larger-sized businesses with both fewer claims and lower costs per claim.

4. Discussion

This review summarized estimated costs from occupational heat stress. These costs were large, potentially exceeding \$300 billion annually, globally, in previous years (DARA, 2012), with high costs also experienced in individual countries, including nearly \$4 billion in Nanjing, China during a heatwave. Considerably greater future costs were projected, with global annual costs increasing by an approximate factor of eight between 2010 and 2030 (DARA, 2012) (Kjellstrom et al., 2019), and costs in Germany increasing by a factor of nearly four from 2004 to 2071–2100 (SRES A1B scenario) (Hübler et al., 2008). Four studies investigated the relationship between temperatures and costs; all observed increasing costs with increasing temperatures, and three observed curvilinear (Costa and Floater, 2020; Takakura et al., 2018; Xiang et al., 2018) instead of linear (Takakura et al., 2017) relationships.

Previous studies have modelled decreased economic output and growth rates as functions of high ambient temperatures, and hypothesized that heat-induced labor output loss is a contributing factor to this function (Dell et al., 2014; Heal and Park, 2016), with one study observing similar decreases in labor output and economic income following high temperatures (Hsiang, 2010). This review identified cost figures to support the function between heat and costs and the similarity between decreased labor productivity and economic burden. However, this review also identified additional expenses following OIs (Ma et al., 2019; Martínez-Solanas et al., 2018; Xiang et al., 2018). Economies incur direct expenses through their healthcare systems and workers' compensation. Employees suffer financially through out-of-pocket payments and lost incomes (Mitra et al., 2017). This can result in reduced consumer spending and hence indirect economic loss. Both heat-related productivity loss and sick leave from OIs decrease labor output; this decreases economic and employer income. Employers may have additional expenses following OIs, such as hiring and training replacement staff (Martínez-Solanas et al., 2018) and potential lawsuits. Minimizing occupational heat stress can reduce financial burden for workers, employers, and the wider economy.

4.1. Projected economic costs that can be avoided

4.1.1. Climate adaptation

Adaptation measures can potentially greatly reduce future economic burden (Costa and Floater, 2020; Morabito et al., 2020; Orlov et al., 2020; Takakura et al., 2018). Costa and Floater (2015) assumed that no air conditioning was available at baseline, likely overestimating the averted cost. This assumption would be more reasonable in low- and middle-instead of high-income countries, where access to air conditioning, and also solar blinds and indoor ventilation, may be limited. However, these measures may be less effective in low- and middle-income countries because financing them is more difficult (Kjellstrom et al., 2016). This may favor measures with less ongoing expenses in these countries such as shifting work hours or working and resting in the shade. Of note, Takakura et al. (2018) observed that a work shift was more effective in low- and middle-than high-income regions (Takakura et al., 2018). Employers globally should adopt adaptation measures to reduce occupational heat stress, both for their workers' safety and to minimize workplace costs. These can include the aforementioned measures and heat management policies, such as training programs, appropriate clothing, adequate water access, and use of mechanical equipment to reduce work intensity (Day et al., 2019; Nunfam et al., 2020). A study in Texas reported that after implementing a heat stress awareness program covering training, improved access to cooling measures and decreased work-rest ratios during high temperatures, the number of OHIs in outdoor workers and associated compensation costs decreased (McCarthy et al., 2019) although total expenses and costs per worker were not reported. Where feasible, companies could substitute labor with capital, such as mechanization, in jobs associated with high levels of heat stress and shift employees into jobs with less heat stress. A gradual shift from agriculture to industrial and service industries has already been observed globally (Pope et al., 2009). Measures affecting workplaces can also be implemented at the government level. These include subsidizing workplace measures such as air conditioning, promoting heat stress awareness, and tax changes such as simultaneously increasing carbon prices and decreasing labor taxes (to decrease associated labor costs from occupational heat stress) (Day et al., 2019; Goulder and Schein, 2013).

4.1.2. Climate mitigation

Projected economic burden was notably more extreme under climate scenarios with higher greenhouse concentrations compared to scenarios with less warming (Hübler et al., 2008; Kovats et al., 2011; Orlov et al., 2020; Takakura et al., 2017, 2018). These results align with previous studies that projected lower labor productivity under projected scenarios with higher greenhouse concentrations (Kjellstrom et al., 2009c, 2016). Climate mitigation is imperative and should minimize most future costs. The IPCC stated that the global mitigation costs of limiting global warming to no more than 2 °C by 2100 is 4.8% of global GDP (Intergovernmental Panel on Climate Change, 2015). Approximately 40% of this cost could be avoided by offsetting the costs from occupational heat stress (Orlov et al., 2020) and more if global warming is limited to less than 1.5 °C (Takakura et al., 2017, 2018). The estimated reductions in costs from climate mitigation were more apparent in later projection time periods, when further global warming is likely to occur (Intergovernmental Panel on Climate Change, 2015). Within the next two decades, similar costs were observed between different climate scenarios (Kjellstrom et al., 2019; Kovats et al., 2011), but over twice the costs were observed by the end of the century under scenarios with higher greenhouse concentrations (Kovats et al., 2011; Orlov et al., 2020; Takakura et al., 2017, 2018). For example, Kovats et al. (2011) projected a potential difference of up to approximately $660 million between scenarios SRES A1B and ENSEMBLES E1 in Europe in 2100 alone. This figure would be greatly increased if the RCP8.5 scenario was used, which assumes no climate mitigation, or if evaluating global costs (DARA, 2012). However, under scenarios with lower greenhouse concentrations, estimated costs in 2070–2100 were similar to those in 2050 (Kovats et al., 2011; Orlov et al., 2020). Costs projected to occur by 2030 are significantly higher than those estimated in 2010 (DARA, 2012; Kjellstrom et al., 2019), indicating that a future increase in costs compared to now likely cannot be avoided, only minimized.

4.2. Costs per industry

Estimated costs were higher in the agriculture (Orlov et al., 2019), construction (Costa and Floater, 2020; Takakura et al., 2017), manufacturing (Costa and Floater, 2020; Xia et al., 2018) and mining sectors (Takakura et al., 2017; Xiang et al., 2018). These industries have been associated with increased morbidity from occupational heat stress due to increased work intensities and higher levels of heat exposure from environmental heat, machinery and/or use of personal protective equipment (Calkins et al., 2019; Kim and Lee, 2019; Moohialdin et al., 2019; Pogačar et al., 2018; Varghese et al., 2018, 2020). The increased cost per claim observed in Xiang et al. (2018) may reflect the greater severity of occupational injuries that occur in the mining sector (Nunfam et al., 2019), which could be exacerbated by heat. This could also hold true for the construction and manufacturing sectors. Workplace guidelines for minimizing occupational heat stress are particularly important for employers in these high-risk industries. This particularly applies for manufacturing businesses, as Xia et al. (2018) observed a large portion of indirect costs occurring in the manufacturing sector (Xia et al., 2018), and indirect costs can be difficult to track. Shifting labor from high-risk sectors to low-risk sectors such as the service sector should reduce future costs from lost worktime and may happen without government intervention (Costa and Floater, 2020; Kovats et al., 2011).

4.3. Regional differences

Based on labor productivity loss, low- and middle-income countries were estimated to have greater GDP percentage losses compared to high-income countries (DARA, 2012; Kjellstrom et al., 2019; Orlov et al., 2020; Roson and Sartori, 2016; Takakura et al., 2017). Low- and middle-income countries are usually more prone to the reduced labor productivity and OIs secondary to heat (Kjellstrom et al., 2009a, 2009b). Dell et al. (2008) observed that in low-income but not high-income countries, a 1 °C increase in monthly mean temperatures was associated with a decrease in economic growth rate by 1.087% (Dell et al., 2008) – this would have at least partially reflected decreased labor productivity. Low- and middle-income countries generally have warmer climates, less protection against occupational heat stress such as air conditioning, and a higher proportion of labor in industrial sectors more prone to industrial heat stress such as outdoor sectors (Kjellstrom et al., 2016, Kjellstrom et al., 2016; Stern, 2006). As observed in Kovats et al. (2014) and Costa and Floater (2015), even in high-income countries, warmer climates, and differences in labor structure can predispose the labor force to greater occupational heat sensitivity (Costa and Floater, 2020; Kovats et al., 2011). Due to decreased wealth, low- and middle-income countries are less likely to adapt to climate change than high-income countries (Intergovernmental Panel on Climate Change, 2015; Kjellstrom et al., 2016; Stern, 2006). This can increase costs from decreased labor productivity and widen the gap in income per capita between low- and high-income countries. High-income countries may also be indirectly affected through global economic effects such as decreased trade.

4.4. Worker and workplace characteristics

4.4.1. Gender

Studies investigating differences in genders' vulnerabilities to temperature increases usually showed small, statistically insignificant differences, and that females were more likely to report heat intolerance than males (Karjalainen, 2012; Pogačar et al., 2017), supporting the increased sensitivity in females observed by Ma et al. (2019). However, this review identified only one study finding a (non-statistically) increase in costs following occupational heat stress among females compared to males (Zander and Mathew, 2019), and three studies observing increased costs among males than females (Ma et al., 2019; Xiang et al., 2018; Zander et al., 2015). This could partially be explained through higher income rates among males (Zander et al., 2015) and male-to-female worker ratios (Ma et al., 2019). Males may be more likely to undertake work with greater physical demand and higher heat stress exposure (Cheung et al., 2016), both increasing their risk of heat-attributable OIs (Adam-Poupart et al., 2015; McInnes et al., 2017) and their severities (leading to large claim payouts). The large gender discrepancy in injury claims observed by Ma et al. (2019) and Xiang et al. (2018) may be partially explained by a higher under-reporting rate among females (Holdcroft, 2007), biasing and exaggerating the increased costs associated with males compared to females. Hence whilst greater costs were observed with males, emphasis should be placed on both genders when considering workplace strategies to minimize heat stress.

4.4.2. Age

Two studies estimated higher relative costs from occupational heat stress in younger workers (aged 25–44 years) due to OIs (Ma et al., 2019; Xiang et al., 2018). This could be because younger workers may be more likely to undertake more physically demanding work associated with a greater risk of OIs (Camino López et al., 2008), including heat-attributable OIs (Bonafede et al., 2016). This could outweigh the increased vulnerability to heat that older adults have compared to younger adults (Basu, 2009; Kenny et al., 2016; Lundgren et al., 2013). Zander et al. (2015 and 2019) observed no difference in costs between age groups due to labor productivity (Zander et al., 2015; Zander and Mathew, 2019). Costs from productivity loss are influenced by income rates. An Australian study identified approximately similar mean income rates across 10-year age groups in workers aged 25 to 64 (Tapper and Fenna, 2019). This could explain the similar costs between different age groups; the respondents in Zander et al. (2015) were centered around 40 years of age and from Australia, and the respondents in Zander and Mathew (2019) had relatively similar ages (most were aged from 20 to 40). Due to the small number of studies investigating age, these findings should only be interpreted as preliminary results.

4.4.3. Business size

Ma et al. (2019) and Xiang et al. (2018) identified greater associations between injury claims from heat-attributable OIs among employees from medium-sized (and also small-sized in Ma et al. (2019)) businesses compared to larger businesses (Ma et al., 2019; Xiang et al., 2018). Large companies have been associated with a lower risk of OIs from all causes (Lundgren et al., 2013; Malchaire, 1999). These companies may have improved facilities and greater enforcement of employee protection measures and education, thus they may be better prepared for managing occupational heat stress.

4.5. Further research

The majority of the literature focused on economic burden from decreased labor productivity based on corresponding recommended work-to-rest ratios or work efficiency. Costs estimated with ISO and NIOSH guidelines were approximately 1.4–2 times larger than those estimated with the Hothaps function (Morabito et al., 2020; Orlov et al., 2019, 2020). The aforementioned guidelines were designed to increase work-rest ratios in order to minimize heat-induced OIs; thus they estimate greater productivity losses than the Hothaps function, which was based on observed productivity without considering work-rest ratios or the minimization of OIs (Brode et al., 2018; Jacklitsch et al., 2016; Orlov et al., 2020). To compare costs estimated from the two methods and to comprehensively calculate economic expenses, future studies should combine results from estimated decreased work efficiency with those from heat-induced OIs and associated healthcare costs and sick leave. Only a few identified studies investigated costs related to healthcare (Ma et al., 2019; Martínez-Solanas et al., 2018; Xiang et al., 2018) and sick leave (Martínez-Solanas et al., 2018; Zander et al., 2015). Other causes that should be explored further include costs from employees resigning from high heat stress jobs, which to the authors best knowledge has yet to be investigated, and expenses from pain and suffering. Martínez-Solanas et al. (2018) estimated that in Spain, the expenses from pain and suffering exceeded the combined costs from productivity loss and healthcare (Martínez-Solanas et al., 2018). Further research is also warranted in low- and middle-income countries, which were limited to either global studies or two studies investigating retrospective costs in a middle-income country (Das, 2015; Zander and Mathew, 2019).

The costs and benefits of only a few climate adaptation measures were investigated and only in relation to labor productivity (Costa and Floater, 2020; Morabito et al., 2020; Orlov et al., 2019, 2020; Takakura et al., 2018). More measures should be analyzed, including heat management policies and measures at the government level, and should consider other costs such as healthcare costs. Measures can be tailored to specific countries, climate zones and/or industries so that the most effective measures are identified for given work cohorts. Measures were only investigated individually instead of concurrently. Whilst it is easier to determine their impact when investigated separately, implementing and analyzing multiple measures simultaneously may provide more accurate information on the predicted reductions in expenses and identifying which measures are more effective.

Most studies investigated costs in relation to WBGT. WBGT is a useful estimator for the temperature perceived by people and is used by international guidelines to recommend work-rest ratios (International Organizatio, 2017; Jacklitsch et al., 2016; Kjellstrom et al., 2018; Lemke and Kjellstrom, 2012). It considers multiple weather variables to estimate heat stress more comprehensively than air temperature alone (Lemke and Kjellstrom, 2012). The perceived temperature used by Hübler et al. (2008) has similar components to the WBGT (Hübler et al., 2008; Jendritzky et al., 2000; Lemke and Kjellstrom, 2012) and thus should perform similarly. Despite all this, the WBGT is a relatively simple estimator (Budd, 2008; Oliveira et al., 2018) that may not adequately reflect the full range of work situations (D'Ambrosio Alfano et al., 2014). Hence other heat metrics, such as apparent temperature (Steadman, 1984) and the more detailed predicted heat strain (Oliveira et al., 2018), may need to be further explored.

Limited information was identified on the associations of costs with workers' age, gender, business size and associated occupational sectors. These could be explored in future research to obtain more accurate and specific cost estimates. One study from US observed that excluding individual- and workplace-level variables overestimated the decrease in heat-related productivity among fruit pickers (Quiller et al., 2017), though the results were not statistically significant both with and without these variables. Furthermore, these factors may be subject to interaction effects, for example associated costs from different age distributions would vary across different industries. This could provide useful information for developing workplace guidelines and better targeting vulnerable subgroups. Only one study evaluated indirect costs across multiple industrial sectors, observing that they were larger than direct costs (Xia et al., 2018); including and providing estimates from both costs would better illustrate the magnitude of economic expenses.

4.6. Limitations

Whilst multiple databases were searched, the possibility of missing studies cannot be excluded. Studies included in this review were limited to those in English. Countries with high rates of heat stress are often non-English speaking, hence relevant studies may have been missed. This study only considered occupational heat-related costs. Other occupational costs can result from high temperatures without being directly related to workplace heat stress, such as costs from air conditioning and high-temperature employment subsidies (Zhao et al., 2016).

Finally, it should be stressed that all cost figures are estimates and should not to be taken to represent actual figures. Heat stress and its associated costs are influenced by multiple factors at an individual level that would realistically be impossible to calculate precisely (Glass et al., 2015; Stern, 2006). Many costs from labor productivity loss were based on assumed work-to-rest ratios, subjective responses, and/or acclimatization that may not apply to every worker. Healthcare cost estimates exclude costs from unreported OIs; this can potentially exclude many OIs (Missikpode et al., 2019). Projected costs are difficult to predict, because there is notable uncertainty in how climate, labor, and socio-economic characteristics will change over time (Intergovernmental Panel on Climate Change, 2015; Kjellstrom et al., 2009c).

5. Conclusions

Estimated economic burden from occupational heat stress is substantial. Significant expenses have already occurred which are projected to increase greatly with global warming. Fortunately, most projected costs can be averted with climate change adaptation and mitigation. Further research exploring the relationship between occupational heat stress and costs, in particular expenses from decreased work efficiency and healthcare, and costs stratified by demographics factors is warranted. The development of climate adaptation and mitigation strategies, including workplace heat management policies, are imperative to minimize future heat-attributable economic burden.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

Abiuso FL, Serra de La Figuera D, 2008. Análisis de los costes de la siniestralidad laboral en Cataluna. Universitat Pompeu Fabra; [cited 9 November 2020]. Available from: https://treball.gencat.cat/web/.content/09_-_seguretat_i_salut_laboral/publicacions/imatges/analisis_costes.pdf.

Adam-Poupart, A., Smargiassi, A., Busque, M.A., Duguay, P., Fournier, M., Zayed, J., et al., 2015. Effect of summer outdoor temperatures on work-related injuries in Quebec (Canada). Occup. Environ. Med. 72 (5), 338–345. https://doi.org/10.1136/oemed-2014-102428.

Bahadori, K., Doyle-Waters, M.M., Marra, C., Lynd, L., Alasaly, K., Swiston, J., et al., 2009. Economic burden of asthma: a systematic review. BMC Pulm. Med. 9 (1), 24. https://doi.org/10.1186/1471-2466-9-24.

Basu, R., 2009. High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. Environ. Health 8, 40. https://doi.org/10.1186/1476-069X-8-40.

Binazzi, A., Levi, M., Bonafede, M., Bugani, M., Messeri, A., Morabito, M., et al., 2019. Evaluation of the impact of heat stress on the occurrence of occupational injuries: meta-analysis of observational studies. Am. J. Ind. Med. 62 (3), 233–243. https://doi.org/10.1002/ajim.22946.

Bonafede, M., Marinaccio, A., Asta, F., Schifano, P., Michelozzi, P., Vecchi, S., 2016. The association between extreme weather conditions and work-related injuries and diseases. A systematic review of epidemiological studies. Ann. Ist. Super Sanita 52 (3), 357–367. https://doi.org/10.4415/ann_16_03_07.

Brode, P., Fiala, D., Lemke, B., Kjellstrom, T., 2018. Estimated work ability in warm outdoor environments depends on the chosen heat stress assessment metric. Int. J. Biometeorol. 62 (3), 331–345. https://doi.org/10.1007/s00484-017-1346-9.

Budd, G.M., 2008. Wet-bulb globe temperature (WBGT)–its history and its limitations. J. Sci. Med. Sport 11 (1), 20–32. https://doi.org/10.1016/j.jsams.2007.07.003.

Bux, K., 2006. Climate at the Workplace. State of the Art in Scientific Knowledge - Needs Analysis for Further Research. Dortmund, Germany.

Calkins, M.M., Bonauto, D., Hajat, A., Lieblich, M., Seixas, N., Sheppard, L., et al., 2019. A case-crossover study of heat exposure and injury risk among outdoor construction workers in Washington State. Scand. J. Work. Environ. Health 45 (6), 588–599. https://doi.org/10.5271/sjweh.3814.

Camino López, M.A., Ritzel, D.O., Fontaneda, I., González Alcantara, O.J., 2008. Construction industry accidents in Spain. J. Saf. Res. 39 (5), 497–507. https://doi.org/10.1016/j.jsr.2008.07.006.

Cheung, S.S., Lee, J.K.W., Oksa, J., 2016. Thermal stress, human performance, and physical employment standards. Appl. Physiol. Nutr. Metabol. 41 (6), S148–S164. https://doi.org/10.1139/apnm-2015-0518.

Chi, C.F., Chang, T.C., Ting, H.I., 2005. Accident patterns and prevention measures for fatal occupational falls in the construction industry. Appl. Ergon. 36 (4), 391–400. https://doi.org/10.1016/j.apergo.2004.09.011.

Costa, H., Floater, G., 2020. RAMSES project report D5.2: economic costs of heat and flooding in cities: cost and economic data for the European Clearinghouse databases. http://www.ramses-cities.eu/fileadmin/uploads/Deliverables_Uploaded/RAMSES_D5.2.pdf.

D'Ambrosio Alfano, F.R., Malchaire, J., Palella, B.I., Riccio, G., 2014. WBGT index revisited after 60 Years of use. Ann. Occup. Hyg. 58 (8), 955–970. https://doi.org/10.1093/annhyg/meu050.

Das, S., 2015. Temperature increase, labor supply and cost of adaptation in developing economies: evidence on urban workers in informal sectors. Clim Chang Econ 6 (2), 1–24. https://doi.org/10.1142/S2010007815500074.

Day, E., Fankhauser, S., Kingsmill, N., Costa, H., Mavrogianni, A., 2019. Upholding labour productivity under climate change: an assessment of adaptation options. Clim. Pol. 19 (3), 367–385. https://doi.org/10.1080/14693062.2018.1517640.

Dell, M., Jones, B.F., Olken, B.A., 2008. Climate change and economic growth: evidence from the last half century. Am. Econ. J. Macroecon. 4, 66–95. https://doi.org/10.3386/w14132.

Dell, M., Jones, B.F., Olken, B.A., 2014. What do we learn from the weather? The new climate–economy literature. J. Econ. Lit. 52 (3), 740–798. https://doi.org/10.1257/jel.52.3.740.

Dunne, J.P., Stouffer, R.J., John, J.G., 2013. Reductions in labour capacity from heat stress under climate warming. Nat. Clim. Change 3 (6), 563–566. https://doi.org/10.1038/nclimate1827.

Flouris, A.D., Dinas, P.C., Ioannou, L.G., Nybo, L., Havenith, G., Kenny, G.P., et al., 2018. Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis. Lancet Planet Health 2 (12), e521–e531. https://doi.org/10.1016/s2542-5196(18)30237-7.

Glass, K., Tait, P., Hanna, E., Dear, K., 2015. Estimating risks of heat strain by age and sex: a population-level simulation model. Int. J. Environ. Res. Publ. Health 12 (5), 5241–5255. https://doi.org/10.3390/ijerph120505241.

Goulder, L., Schein, A., 2013. Carbon taxes vs. cap and trade: a critical review. Clim Chang Econ 4 (3), 1–28. https://doi.org/10.3386/w19338.

Hanna, E.G., Kjellstrom, T., Bennett, C., Dear, K., 2011. Climate change and rising heat: population health implications for working people in Australia. Asia Pac. J. Publ. Health 23 (2 Suppl. l), 14s–26. https://doi.org/10.1177/1010539510391457.

Heal, G., Park, J., 2016. Reflections—temperature stress and the direct impact of climate change: a review of an emerging literature. Rev. Environ. Econ. Pol. 10 (2), 347–362. https://doi.org/10.1093/reep/rew007.

Holdcroft, A., 2007. Gender bias in research: how does it affect evidence based medicine? J. R. Soc. Med. 100 (1), 2–3. https://doi.org/10.1177/014107680710000102.

Hsiang, S.M., 2010. Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America. Proc. Natl. Acad. Sci. Unit. States Am. 107 (35), 15367–15372. https://doi.org/10.1073/pnas.1009510107.

Hsiang, S., Kopp, R., Jina, A., Delgado, M., Rising, J., Mohan, S., Muir-Wood, R., Rasmussen, D.J., Michael, Mastrandrea, Wilson, P., Larsen, K., Trevor, Houser, 2014. American Climate Prospectus: Economic Risks in the United States. New York, United Status. Rhodium Group 2nd edition cited 9 November 2020. https://rhg.com/wp-content/uploads/2014/10/AmericanClimateProspectus_v1.2.pdf.

Hübler, M., Klepper, G., Peterson, S., 2008. Costs of climate change. Ecol. Econ. 68 (1–2), 381–393. https://doi.org/10.1016/j.ecolecon.2008.04.010.

Kovats, S, Lloyd, SJ, Hunt, A, Watkiss, P, 2011. The impacts and economic costs on health in Europe and the costs and benefits of adaptation. Results of the EC RTD ClimateCost project. Stockholm Environment Institute, Sweden cited 26 April 2020. Available from: http://www.climatecost.cc/images/Policy_Brief_5_Climatecost_Health_Summary_Results_vs_5_draft_final_web.pdf.

Jendritzky, G, Staiger, H, Bucher, K, Graetz, A.G.L., 2000. The perceived temperature: the method of the Deutscher Wetterdienst for the assessment of cold stress and heat load for the human body. Deutscher Wetterdienst, Germany [cited 10 December 2019]. Available from: http://www.utci.org/isb/documents/perceived_temperature.pdf.

DARA, 2012. Climate vulnerability monitor 2012: a guide to the cold calculus of a hot planet. DARA Internacional 2nd edition, Madrid, Spain [cited 9 November 2020]. Available from: https://daraint.org/wp-content/uploads/2012/10/CVM2-Low.pdf.

Intergovernmental Panel on Climate Change, 2015. Climate change 2014: synthesis report. Contribution of working groups I, II and II to the fifth assessment report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: Intergovernmental Panel on Climate Change; [cited 3 April 2020]. Available from: https://www.ipcc.ch/assessment-report/ar5/.

International Organization for Standardization, 2017. Ergonomics of the Thermal Environment— Assessment of Heat Stress Using the WBGT (Wet Bulb Globe Temperature) Index. Switzerland, Geneva.

Jacklitsch, B., Williams, W.J., Musolin, K., Coca, A., Kim, J.-H., Turner, N., et al., 2016. Criteria for a recommended standard occupational exposure to heat and hot environments. In: Department of Health and Human Services, Editor. NIOSH Publication No 86-113. Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Atlanta, GA.

Intergovernmental Panel on Climate Change, 2007a. Emissions scenarios. a special report of working group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York [cited 9 November 2020]. Available from: https://www.ipcc.ch/site/assets/uploads/2018/03/emissions_scenarios-1.pdf.

Intergovernmental Panel on Climate Change, 2007b. Synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change, Geneva, Switzerland [cited 4 October 2019]. Available from: https://www.ipcc.ch/assessment-report/ar4/.

Karjalainen, S., 2012. Thermal comfort and gender: a literature review. Indoor Air 22 (2), 96–109. https://doi.org/10.1111/j.1600-0668.2011.00747.x.

Kenny, G.P., Groeller, H., McGinn, R., Flouris, A.D., 2016. Age, human performance, and physical employment standards. Appl. Physiol. Nutr. Metabol. 41 (6), S92–S107. https://doi.org/10.1139/apnm-2015-0483.

Kim, D., Lee, J., 2019. Spatial changes in work capacity for occupations vulnerable to heat stress: potential regional impacts from global climate change. Saf Health Work 11 (1), 1–9. https://doi.org/10.1016/j.shaw.2019.10.004.

Kjellstrom, T., 2016. Impact of climate conditions on occupational health and related economic losses: a new feature of global and urban health in the context of climate change. Asia Pac. J. Publ. Health. https://doi.org/10.1177/1010539514568711.

Kjellstrom, T., Gabrysch, S., Lemke, B., Dear, K., 2009a. The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: an invitation to carry out field studies. Glob. Health Action 2. https://doi.org/10.3402/gha.v2i0.2082.

Kjellstrom, T., Holmer, I., Lemke, B., 2009b. Workplace heat stress, health and productivity – an increasing challenge for low and middle-income countries during climate change. Glob. Health Action 2 (1), 2047. https://doi.org/10.3402/gha.v2i0.2047.

Kjellstrom, T., Kovats, R.S., Lloyd, S.J., Holt, T., Tol, R.S.J., 2009c. The direct impact of climate change on regional labor productivity. Arch. Environ. Occup. Health 64 (4), 217–227. https://doi.org/10.1080/19338240903352776.

Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., Hyatt, O., 2016. Heat, human performance, and occupational health: a key issue for the Assessment of global climate change impacts. Annu. Rev. Publ. Health 37 (1), 97–112. https://doi.org/10.1146/annurev-publhealth-032315-021740.

Kjellstrom, T., Freyberg, C., Lemke, B., Otto, M., Briggs, D., 2018. Estimating population heat exposure and impacts on working people in conjunction with climate change. Int. J. Biometeorol. 62 (3), 291–306. https://doi.org/10.1007/s00484-017-1407-0.

Kjellstrom, T., Maître, N., Saget, C., Otto, M., Karimova, T., 2019. Working on a Warmer Planet: the Impact of Heat Stress on Labour Productivity and Decent Work. International Labour Organization, Geneva, Switzerland. https://www.ilo.org/wcmsp5/groups/public/—dgreports/—dcomm/—publ/documents/publication/wcms_711919.pdf.

Kjellstrom T, Otto M, Lemke B, Hyatt O, Briggs D, Freyberg C, et al, 2016. Climate change and labor: impacts of heat in the workplace. New York, United States: United Nations Development Programme; [cited 26 April 2020]. Available from: https://www.undp.org/content/undp/en/home/librarypage/climate-and-disaster-resilience-/tackling-challenges-of-climate-change-and-workplace-heat-for-dev.html.

Lemke, B., Kjellstrom, T., 2012. Calculating workplace WBGT from meteorological data: a tool for climate change assessment. Ind. Health 50 (4), 267–278. https://doi.org/10.2486/indhealth.ms1352.

Levi, M., Kjellstrom, T., Baldasseroni, A., 2018. Impact of climate change on occupational health and productivity: a systematic literature review focusing on workplace heat. Med. Lav. 109 (3), 163–179. https://doi.org/10.23749/mdl.v109i3.6851.

Lundgren, K., Kuklane, K., Gao, C., Holmer, I., 2013. Effects of heat stress on working populations when facing climate change. Ind. Health 51 (1), 3–15. https://doi.org/10.2486/indhealth.2012-0089.

Ma, R., Zhong, S., Morabito, M., Hajat, S., Xu, Z., He, Y., et al., 2019. Estimation of work-related injury and economic burden attributable to heat stress in Guangzhou, China. Sci. Total Environ. 666, 147–154. https://doi.org/10.1016/j.scitotenv.2019.02.201.

Mahidin, M.U., 2018. Key statistics of labour force in malaysia. January. Department of Statistics, Malaysia [cited 16 April 2020]. https://www.dosm.gov.my/v1/index.

php?r column/cthemeByCat&cat 124&bul_id aUVrUWh2ZnZubkl2RUxEQU15N3ZWdz09&menu_id U3VPMldoYUxzVzFaYmNkWXZteGduZz09.

Malchaire, J., 1999. Strategy for evaluation and prevention of risk due to work in thermal environments. Ann. Occup. Hyg. 43 (5), 367–376. https://doi.org/10.1093/annhyg/43.5.367.

Martínez-Solanas, È., López-Ruiz, M., Wellenius, G.A., Gasparrini, A., Sunyer, J., Benavides, F.G., et al., 2018. Evaluation of the impact of ambient temperatures on occupational injuries in Spain. Environ. Health Perspect. 126 (6) https://doi.org/10.1289/ehp2590.

McCarthy, R.B., Shofer, F.S., Green-McKenzie, J., 2019. Outcomes of a heat stress awareness program on heat-related Illness in municipal outdoor workers. J. Occup. Environ. Med. 61 (9), 724–728. https://doi.org/10.1097/JOM.0000000000001639.

McInnes, J.A., Akram, M., MacFarlane, E.M., Keegel, T., Sim, M.R., Smith, P., 2017. Association between high ambient temperature and acute work-related injury: a case-crossover analysis using workers' compensation claims data. Scand. J. Work. Environ. Health 43 (1), 86–94. https://doi.org/10.5271/sjweh.3602.

Milton, D.K., Glencross, P.M., Walters, M.D., 2000. Risk of sick leave associated with outdoor air supply rate, humidification, and occupant complaints. Indoor Air 10 (4), 212–221. https://doi.org/10.1034/j.1600-0668.2000.010004212.x.

Missikpode, C., Peek-Asa, C., Wright, B., Ramirez, M., 2019. Characteristics of agricultural and occupational injuries by workers' compensation and other payer sources. Am. J. Ind. Med. 62 (11), 969–977. https://doi.org/10.1002/ajim.23040.

Mitra, S., Palmer, M., Kim, H., Mont, D., Groce, N., 2017. Extra costs of living with a disability: a review and agenda for research. Disabil Health J 10 (4), 475–484. https://doi.org/10.1016/j.dhjo.2017.04.007.

Moohialdin, A.S.M., Lamari, F., Miska, M., Trigunarsyah, B., 2019. Construction worker productivity in hot and humid weather conditions: a review of measurement methods at task, crew and project levels. Eng. Construct. Architect. Manag. https://doi.org/10.1108/ECAM-05-2018-0191.

Morabito, M., Messeri, A., Crisci, A., Bao, J., Ma, R., Orlandini, S., et al., 2020. Heat-related productivity loss: benefits derived by working in the shade or work-time shifting. Int. J. Prod. Perform. Manag. https://doi.org/10.1108/ijppm-10-2019-0500 ahead-of-print(ahead-of-print).

Murray, B., 2007. Hydration and physical performance. J. Am. Coll. Nutr. 26 (Suppl. 5) https://doi.org/10.1080/07315724.2007.10719656, 542S-8S.

Nunfam, V.F., Van Etten, E.J., Oosthuizen, J., Adusei-Asante, K., Frimpong, K., 2019. Climate change and occupational heat stress risks and adaptation strategies of mining workers: perspectives of supervisors and other stakeholders in Ghana. Environ. Res. 169, 147–155. https://doi.org/10.1016/j.envres.2018.11.004.

Nunfam, V.F., Adusei-Asante, K., Frimpong, K., Van Etten, E.J., Oosthuizen, J., 2020. Barriers to occupational heat stress risk adaptation of mining workers in Ghana. Int. J. Biometeorol. 64 (7), 1085–1101. https://doi.org/10.1007/s00484-020-01882-4.

Oliveira, A.V.M., Gaspar, A.R., Raimundo, A.M., Quintela, D.A., 2018. Assessment of thermal environments: working conditions in the Portuguese glass industry. Ind. Health 56 (1), 62–77. https://doi.org/10.2486/indhealth.2017-0048.

Orlov, A., Sillmann, J., Aaheim, A., Aunan, K., de Bruin, K., 2019. Economic losses of heat-induced reductions in outdoor worker productivity: a case study of Europe. Econ. Disas. Clim. Change 3 (3), 191–211. https://doi.org/10.1007/s41885-019-00044-0.

Orlov, A., Sillmann, J., Aunan, K., Kjellstrom, T., Aaheim, A., 2020. Economic costs of heat-induced reductions in worker productivity due to global warming. Global Environ. Change 63. https://doi.org/10.1016/j.gloenvcha.2020.102087.

Otte Im Kampe, E., Kovats, S., Hajat, S., 2016. Impact of high ambient temperature on unintentional injuries in high-income countries: a narrative systematic literature review. BMJ Open 6 (2), e010399. https://doi.org/10.1136/bmjopen-2015-010399.

O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., et al., 2013. A new scenario framework for climate change research: the concept of shared socioeconomic pathways. Climatic Change 122 (3), 387–400. https://doi.org/10.1007/s10584-013-0905-2.

Parsons, K., 2014. Human Thermal Environments, third ed. Taylor & Francis, London.

Pogačar, T., Črepinšek, Z., Kajfež Bogataj, L., Nybo, L., 2017. Comprehension of climatic and occupational heat stress amongst agricultural advisers and workers in Slovenia. Acta Agric. Slov. 109 (3), 545–554. https://doi.org/10.14720/aas.2017.109.3.06.

Pogačar, T., Casanueva, A., Kozjek, K., Ciuha, U., Mekjavić, I.B., Kajfež Bogataj, L., et al., 2018. The effect of hot days on occupational heat stress in the manufacturing industry: implications for workers' well-being and productivity. Int. J. Biometeorol. 62 (7), 1251–1264. https://doi.org/10.1007/s00484-018-1530-6.

Pope, C.A., Ezzati, M., Dockery, D.W., 2009. Fine-particulate air pollution and life expectancy in the United States. N. Engl. J. Med. 360 (4), 376–386. https://doi.org/10.1056/nejmsa0805646.

Quiller, G., Krenz, J., Ebi, K., Hess, J.J., Fenske, R.A., Sampson, P.D., et al., 2017. Heat exposure and productivity in orchards: implications for climate change research. Arch. Environ. Occup. Health 72 (6), 313–316. https://doi.org/10.1080/19338244.2017.1288077.

Reuters, T., Google Finance, 2020. Morningstar for currency and coinbase for cryptocurrency [cited 14 September 2019]. https://www.google.com/intl/en/googlefinance/disclaimer/#!#disclaimers.

Roson, R., Sartori, M., 2016. Estimation of climate change damage functions for 140 regions in the GTAP 9 Database. J. Glob. Econ. Anal. 1 (2), 78–115. https://doi.org/10.21642/jgea.010202af.

Sahu, S., Sett, M., Kjellstrom, T., 2013. Heat exposure, cardiovascular stress and work productivity in rice harvesters in India: implications for a climate change future. Ind. Health 51 (4), 424–431. https://doi.org/10.2486/indhealth.2013-0006.

Spector, J.T., Masuda, Y.J., Wolff, N.H., Calkins, M., Seixas, N., 2019. Heat exposure and occupational injuries: review of the literature and Implications. Curr Environ Health Rep. https://doi.org/10.1007/s40572-019-00250-8.

Steadman, R.G., 1984. A universal scale of apparent temperature. J. Clim. Appl. Meteorol. 23 (12), 1674–1687. https://doi.org/10.1175/1520-0450 (1984) 023<1674:AUSOAT>2.0.CO;2.

Stern, N., 2006. Stern Review on the Economic Effects of Climate Change. Government of the United Kingdom, United Kingdom.

Takakura, J.Y., Fujimori, S., Takahashi, K., Hijioka, Y., Hasegawa, T., Honda, Y., et al., 2017. Cost of preventing workplace heat-related illness through worker breaks and the benefit of climate-change mitigation. Environ. Res. Lett. 12 (6), 064010 https://doi.org/10.1088/1748-9326/aa72cc.

Takakura, J.Y., Fujimori, S., Takahashi, K., Hasegawa, T., Honda, Y., Hanasaki, N., et al., 2018. Limited role of working time shift in offsetting the increasing occupational-health cost of heat exposure. Earth's Future. 6 (11), 1588–1602. https://doi.org/10.1029/2018ef000883.

Tapper, A., Fenna, A., 2019. The relationship between income, wealth and age in Australia. Aust. Econ. Rev. https://doi.org/10.1111/1467-8462.12326.

van der Linden, P., Mitchell, J.F.B., 2009. Ensembles: climate change and its impacts: summary of research and results from the Ensembles Project. European Commission, United Kingdom [cited 26 April 2020]. http://ensembles-eu.metoffice.com/docs/Ensembles_final_report_Nov09.pdf.

Van Vuuren, D.P., Carter, T.R., 2014. Climate and socio-economic scenarios for climate change research and assessment: reconciling the new with the old. Climatic Change 122 (3), 415–429. https://doi.org/10.1007/s10584-013-0974-2.

Vanos, J., Vecellio, D.J., Kjellstrom, T., 2019. Workplace heat exposure, health protection, and economic impacts: a case study in Canada. Am. J. Ind. Med. https://doi.org/10.1002/ajim.22966.

Varghese, B.M., Hansen, A., Bi, P., Pisaniello, D., 2018. Are workers at risk of occupational injuries due to heat exposure? A comprehensive literature review. Saf. Sci. 110, 380–392. https://doi.org/10.1016/j.ssci.2018.04.027.

Varghese, B.M., Barnett, A.G., Hansen, A.L., Bi, P., Nairn, J., Rowett, S., et al., 2019. Characterising the impact of heatwaves on work-related injuries and illnesses in three Australian cities using a standard heatwave definition- Excess Heat Factor (EHF). J. Expo. Sci. Environ. Epidemiol. https://doi.org/10.1038/s41370-019-0138-1.

Varghese, B.M., Hansen, A.L., Williams, S., Bi, P., Hanson-Easey, S., Barnett, A.G., et al., 2020. Determinants of heat-related injuries in Australian workplaces: perceptions of health and safety professionals. Sci. Total Environ. 718, 137138. https://doi.org/10.1016/j.scitotenv.2020.137138.

Wee, B.V., Banister, D., 2016. How to write a literature review paper? Transport Rev. 36 (2), 278–288. https://doi.org/10.1080/01441647.2015.1065456.

Wondmagegn, B.Y., Xiang, J., Williams, S., Pisaniello, D., Bi, P., 2019. What do we know about the healthcare costs of extreme heat exposure? A comprehensive literature review. Sci. Total Environ. 657, 608–618. https://doi.org/10.1016/j.scitotenv.2018.11.479.

Wyndham, C.H., 1969. Adaptation to heat and cold. Environ. Res. 2, 442–469. https://doi.org/10.1016/0013-9351(69)90015-2, 0013–9351 (Print).

Xia, Y., Li, Y., Guan, D., Tinoco, D.M., Xia, J., Yan, Z., et al., 2018. Assessment of the economic impacts of heat waves: a case study of Nanjing, China. J. Clean. Prod. 171, 811–819. https://doi.org/10.1016/j.jclepro.2017.10.069.

Xiang, J., Bi, P., Pisaniello, D., Hansen, A., 2014a. Health impacts of workplace heat exposure: an epidemiological review. Ind. Health 52 (2), 91–101. https://doi.org/10.2486/indhealth.2012-0145.

Xiang, J., Bi, P., Pisaniello, D., Hansen, A., 2014b. The impact of heatwaves on workers' health and safety in Adelaide, South Australia. Environ. Res. 133, 90–95. https://doi.org/10.1016/j.envres.2014.04.042.

Xiang, J., Bi, P., Pisaniello, D., Hansen, A., Sullivan, T., 2014c. Association between high temperature and work-related injuries in Adelaide, South Australia. Occup. Environ. Med. 71 (4), 246–252. https://doi.org/10.1136/oemed-2013-101584, 2001–2010.

Xiang, J., Hansen, A., Pisaniello, D., Bi, P., 2015. Extreme heat and occupational heat illnesses in South Australia, 2001-2010. Occup. Environ. Med. 72 (8), 580–586. https://doi.org/10.1136/oemed-2014-102706.

Xiang, J., Hansen, A., Pisaniello, D., Dear, K., Bi, P., 2018. Correlates of occupational heat-induced illness costs: case study of South Australia 2000 to 2014. J. Occup. Environ. Med. 60 (9), e463–e469. https://doi.org/10.1097/JOM.0000000000001395.

Zander, K.K., Mathew, S., 2019. Estimating economic losses from perceived heat stress in urban Malaysia. Ecol. Econ. 159, 84–90. https://doi.org/10.1016/j.ecolecon.2019.01.023.

Zander, K.K., Botzen, W.J.W., Oppermann, E., Kjellstrom, T., Garnett, S.T., 2015. Heat stress causes substantial labour productivity loss in Australia. Nat. Clim. Change 5 (7), 647–651. https://doi.org/10.1038/nclimate2623.

Zhao, Y., Sultan, B., Vautard, R., Braconnot, P., Wang, H.J., Ducharne, A., 2016. Potential escalation of heat-related working costs with climate and socioeconomic changes in China. Proc. Natl. Acad. Sci. Unit. States Am. 113 (17), 4640–4645. https://doi.org/10.1073/pnas.1521828113.

2.4 Updates to the literature

The initial literature search was repeated to cover publications from 18 October 2020 to 31 August 2022. Four new publications were identified, all published in 2021. A brief overview of the retrospective and projected estimated cost findings are included in Tables 2.1 and 2.2, respectively. Two were based in USA, one was based in Brazil, and one was based globally across 163 countries. $\mathrm{T}_{\mathrm{average}}$ and $\mathrm{T}_{\mathrm{max}}$ were heat metrics each used by two separate studies; two of these studies also used WBGT. Three studies estimated retrospective costs and all four estimated future costs. All these studies estimate costs secondary to heat-induced labor productivity loss instead of to OIIs.

Table 2.1: Overview of newly included studies estimating retrospective economics costs from occupational heat stress

Study	Location	Time period	Heat and cost metrics	Statistical analysis	Main cost estimates
Oliveria et al. 2021	Brazil	2015	*Heat* : $\mathrm{T}_{\mathrm{average}}$ (°C) *Cost* : Decreased worker hourly wages	Monthly panel analysis with predictors for temperature, rain, worker, firm, month and year. Limited to workers aged 25–55 not working in agriculture, public administration and military.	In 2015, annual loss of 0.34% in wages compared to the yearly average from 1980–2009, equivalent to $21.75 per worker or $1.26 billion.
Parsons et al. 2021	Global: 163 countries	2001–2020	*Heat* : WBGT and $\mathrm{T}_{\mathrm{average}}$ (°C) *Cost* : GDP from lost hourly worktime	Exposure-response function to estimate lost hourly worktime based on WBGT. Cost estimated from estimated loss multiplied by workers earnings.	$670 billion. If work moved from hottest three to coldest three hours of days, this estimate would reduce by 30%.
Zhang and Shindel 2021	USA	1980–2016	*Heat* : $\mathrm{T}_{\mathrm{max}}$ (°C) *Cost* : Wage value of lost annual lost labor hours	Estimate number of hours lost using an exposure-response function with daily maximum temperature, county-level annual employment, annual average weekly ages.	$14 billion per year from 1980–2016, ranging from 2.3 to 18.7 per year. From 2006–2016, annual cost of 0.07% of 2016 GDP, with an increase of $1.7 billion (11%) compared to 1980–1990.

All studies were ecological studies except for Oliveria et al. 2021 which used a retrospective cohort design. Acronyms; GDP: gross domestic product, Hothaps: High Occupational Temperatures Health and Productivity Suppression, $\mathrm{T}_{average}$: average air temperature, T_{max}: maximum air temperature, WBGT: wet bulb global temperature

Table 2.2: Overview of newly included studies estimating projected future economics costs from occupational heat stress

Study	Location	Time period	Heat and cost metrics	Projection scenarios	Statistical analysis	Main cost estimates
Neidell et al. 2021	USA	2020–2099	*Heat* : T_{max} (°C) *Cost* : Wage value of lost annual labor hours	*Climate* : RCP4.5 and RCP8.5	Estimate number of hours lost using an exposure-response function with daily maximum temperature, county-level annual employment, annual average weekly ages.	Under RCP4.5, \$7.8, \$15.8, \$25.8 and \$36.7 billion in 2030, 2050, 2070 and 2090, respectively. These costs under RCP85 were \$8.7, \$21.0, \$45.1 and \$80.0 billion, respectively.
Oliveria et al. 2021	Brazil	NA	*Heat* : T_{average} (°C) *Cost* : Decreased real worker hourly wages	*Climate* : 2°C increase in daily T_{average} compared to 2015	Monthly panel analysis with predictors for temperature, rain, worker, firm, month and year. Limited to workers aged 25–55 not working in agriculture, public administration and military.	0.87% decrease in worker wages, equivalent to 0.12% of 2015GDP and \$2.17 billion. Larger effect in North (1.2%) compared to Center-South Brazil (0.8%), where the North is warmer and relatively less developed.
Parsons et al. 2021	Global: 163 countries	NA	*Heat* : WBGT and T_{average} (°C) *Cost* : GDP from lost hourly worktime	*Climate* : 1% CO_2 simulations representing 1, 2, 3 and 4°C increase in daily T_{average} compared to 2001–2020	Exposure-response function to estimate lost hourly worktime based on WBGT. Cost estimated from estimated loss multiplied by workers earnings.	\$1.07, \$1.62 and \$3.29 trillion with a 1, 2 and 4°C increase in T_{average}, respectively. If work moved from hottest three to coldest three hours of days, cost reduce by 30% - (2% for every 1°C increase in T_{average}).
Zhang and Shindel 2021	USA	2050s and 2100	*Heat* : T_{max} (°C) *Cost* : Wage value of lost annual lost labor hours	*Climate* : RCP4.5 and RCP8.5 *Soceioeconomic* : SSP1	Estimate number of hours lost using an exposure-response function with daily maximum temperature, county-level annual employment and annual average weekly ages.	RCP4.5: \$25.2 (4.2–33.6) and \$29.8 (5.0–39.7) billion in 2050s and 2100s, respectively. RCP8.5: \$30.2 (5.0–40.3) and \$50.6 (8.4–67.5) billion in 2050s and 2100s, respectively
Zhang and Shindel 2021	USA	2050s and 2100	*Heat* : WBGT (°C) *Cost* : GDP from decreased work efficiency	*Climate* : RCP4.5 and RCP8.5 *Soceioeconomic* : SSP1	Hothaps exposure-response function to estimate worker efficiency loss based on WBGT. Loss measured as the number of full-time jobs lost is multiplied by GDP earned by worker.	RCP4.5: \$31.7 (5.3–42.3) and \$40.7 (6.8–54.3) billion in 2050s and 2100s, respectively. RCP8.5: \$43.4 (7.2–57) and \$118.6 (19.8–158.1) billion in 2050s and 2100s, respectively

All studies were ecological studies except for Oliveria et al. 2021 which used a retrospective cohort design. Zhang and Shindel used two highly different statistical analyses to estimate projected costs; the summaries from these two methods have been described in separate rows. Acronyms; GDP: gross domestic product, Hothaps: High Occupational Temperatures Health and Productivity Suppression, NA: not applicable, RCP: representative concentration pathway, SSP: Shared Socioeconomic Pathway, $T_{average}$: average air temperature, T_{max}: mean air temperature, WBGT: wet bulb global temperature.

2.4.1 Costs from heat-induced labor productivity loss

Zhang et al. 2021 estimated annual total costs in the USA to be $14 billion from 1980 to 2016, ranging from 2.3 to 18.7 billion per year (48). This increased to $25.2 (4.2-33.6) and $30.2 (5.0-40.3) billion in the 2050s under RCP4.5 and RCP8.5, respectively, and to $29.8 (5.0-39.7) and $50.6 (8.4-67.5) billion in the 2090s under RCP4.5 and RCP8.5, respectively. These estimates were based on T_{max} and an exposure-response function derived from USA-representative survey data, referred to as the GZN (Graff Zivin and Neidell) approach (49). This study also produced estimates using the Hothaps exposure-response function (50); these estimates ranged from 25% to 134% larger, with larger cost estimates having relatively larger increases. Neidell et al. 2021 used the GZN approach to estimate costs under RCP4.5 of $7.8, $15.8, $25.8 ,and $36.7 billion in 2030, 2050, 2070, and 2090, respectively (51). These costs under RCP85 were $8.7, $21.0, $45.1, and $80.0 billion, respectively.

For Brazilian workers aged 25 to 55 years excluding those in agriculture, public administration and military industrial sectors, there was an estimated annual loss of 0.34% of workers' wages compared to the yearly average from 1980 to 2009, equivalent to $1.26 billion or $21.75 per worker (52). With a 2°C increase in global $T_{average}$ compared to 2015, wages deceased by 0.87%, equivalent to 2.17 billion (0.12% of GDP). This affected the North more than Center-South Brazil, as the North is warmer and relatively less developed (52).

Parsons et al. 2021 used a similar exposure-response function to the Hothaps function globally (53). They estimated a global annual cost of $607 billion secondary to lost hourly work-time from 2001 to 2020. This increased to $1,069, $1,626, and $3,286 billion worldwide following a 1, 2, and 4° increase in global $T_{average}$. This study also investigated the climate adaptation measure of shifting work from the three hottest hours of the day to the three coldest hours. This reduced costs by 30% - (2% * every 1°C increase in T_{average}).

2.4.2 Discussion

These studies provide more up-to-date estimates for current and projected heat-attributable costs globally (53) and in the USA (48,51) compared to previous global estimates (47), whilst also adding country-economic results for Brazil (52). The findings add to the growing evidence to suggest that occupational heat stress is associated with extensive economic burden that is likely to worsen in the future. Likewise, climate adaptation and mitigation can greatly reduce costs. Shifting work hours could potentially reduce annual costs globally by up to 30% (53). In the USA, reducing greenhouse gas emissions to a RCP4.5 setting can potentially reduce costs by 42% (48) or 59% (51) in the 2090s in USA compared to no climate mitigation (RCP8.5).

Zhang et al. and Neidell et al. used the GZN approach to estimate heat-attributable costs, which is more specific to the USA than the Hothaps exposure-response function and hence potentially more accurate for estimating relevant costs in the USA. Zhang et al. observed a large difference in costs between the two methodologies (despite both methods providing large estimates), suggesting that the Hothaps function may potentially overestimate costs in the USA and other high-income countries (47). However, the Hothaps function is easier to apply and can be implemented globally, whereas the GZN method was specific to the USA, which largely explains why the Hothaps function is more commonly used. Further research into the methodology for analyzing the degree of labor productivity secondary to high temperatures would be beneficial for more precise estimates of associated economic costs.

2.5 Chapter synopsis

This chapter explored existing literature on retrospective and projected cost estimates secondary to work-related heat stress. The estimated financial burden is substantial. Global annual heat-attributable cost estimates are approaching \$1 trillion and are likely to exceed this within the century without climate adaptation or mitigation strategies. Most of the literature explored costs secondary to labor productivity loss, with limited research exploring costs attributable to OIIs and associated demographic factors. This literature review contributed to the research aims and methodological concepts of this thesis' subsequent studies to better address these research gaps in Australia.

3

Methodology and study design

3.1 Preface

This chapter outlines the cities for study, the compensation claims and meteorological datasets, and the statistical analysis for Chapters 4 and 5. Because those two chapters include their own-standalone methodological descriptions, this chapter focuses on further methodological details not included in those two chapters whilst omitting other methodological aspects to reduce unnecessary repetition between chapters.

Because the literature review on occupational heat stress predominantly identified studies investigating costs from labor productivity loss, the studies described in Chapters 4 and 5 focused on investigating costs secondary to OIIs. The primary aim in both studies was to investigate heat-attributable OIIs and their associated economic burden within Australia. Analysis was performed using Australian workers' compensation claims data to examine the relationship between apparent temperature or heatwaves and both OIIs and their associated costs.

This thesis was completed as part of a national Australian projection funded by the Australian Research Council (ARC Discovery Projects Scheme 2019 Grant DP190102869). This project was led by the University of Adelaide (UofA) and involved researchers from Charles Darwin University and Monash University.

3.2 Cities for study

The study was conducted in seven of the eight Australian capital cities: Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth, and Sydney (Figure 3.1). The other capital city, Canberra, was excluded. Workers in Canberra, compared to the other major cities, are less likely to be working in industries considered more vulnerable to heat stress (agriculture, construction, manufacturing, and mining), an issue attenuated by its smaller population size compared to most of the other cities for study (23,35,54,55). The seven cities for study collectively represent four different Köppen climate zones: Mediterranean hot summer, humid subtropical, tropical savanna climate with dry-winter characteristics, and marine west coast zones (Table 3.1) (56). For each city, meteorological data were sourced from re-analysis or gridded data at grid centroids correlating to the center of the city's central business district (CBD). Coordinates for the center were obtained using Google Maps (57). OIIs and associated costs occurring within the metropolitan areas for each city were included for analysis, where the metropolitan areas were defined using the Greater Capital City Statistical Area (GCCSA) (58,59). In all these cities except for Hobart and (prior to 2015) Brisbane, most of the workforce was located within the metropolitan areas (55). Adelaide, Brisbane, Melbourne, Perth, and Sydney are the five largest cities in terms of workforce size in Australia, with Darwin and Hobart having smaller workforces compared to the other cities (Table 3.2) (55).

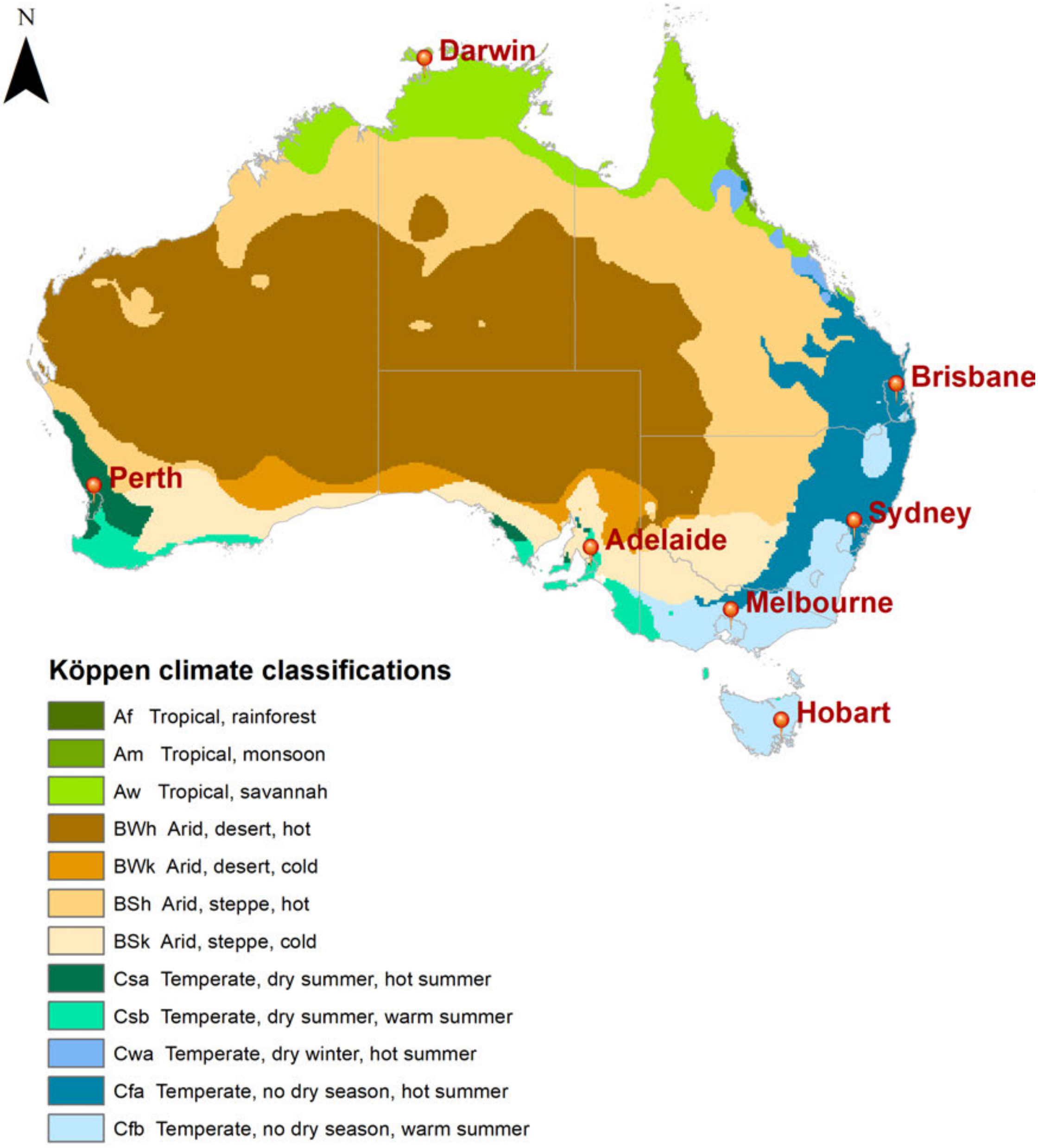

Figure 3.1: Australian capital cities

Table 3.1: Climate zones and coordinates from which meteorological data were sourced

City	Köppen climate zone	BoM climate zone	Latitude	Longitude
Adelaide	Mediterranean hot summer	Warm summer, cold winter	-34.93	138.62
Brisbane	Humid subtropical	Warm humid summer	-27.47	153.02
Darwin	Aw	Hot humid summer	-12.46	130.84
Hobart	Marine west coast	Mild/warm summer, cold winter	-42.85	147.30
Melbourne	Marine west coast	Warm summer, cold winter	-37.80	144.95
Perth	Mediterranean hot summer	Warm summer, cold winter	-32.00	115.90
Sydney	Humid subtropical	Warm summer, cold winter	-33.95	151.20

Aw: Tropical savanna climate and dry-winter characteristics, BoM: Bureau of Meteorology.

Table 3.2: Australian capital cities included for analysis, their states/territories, compensation scheme regulators and workforce sizes

City	State/territory	Compensation authority	2006	2011	2016
Adelaide	South Australia	SafeWork SA	586,105	624,497	629,148
Brisbane	Queensland	Workplace Health and Safety	1,007,005	1,107,675	1,184,438
Darwin	Northern Territory	NT WorkSafe	61,746	73,490	86,088
Hobart	Tasmania	WorkSafe Tasmania	96,560	103,707	104,065
Melbourne	Victoria	WorkSafe Victoria	1,891,600	2,140,657	2,420,644
Perth	Western Australia	WorkSafe WA	820,243	975,009	1,016,513
Sydney	New South Wales	SafeWork NSW	2,141,632	2,307,908	2,542,241

The seven cities for study and their states/territories, compensation scheme authorities, and labor force sizes in August 2006, 2011 and 2016.

3.3 Compensation claims data

Employers are legally required to pay for their workers' compensation insurance covering OIIs in Australia (60). There are eleven Australian workers' compensation schemes, collectively representing approximately 90% of the Australian workforce (61). These include eight primary schemes, each representing a different state and territory, and three Commonwealth Government (national, not state or local) schemes for government employees (Commonwealth Comcare), defence force personnel (Commonwealth DVA), and seafarers (Commonwealth Seacare) (62,63). Safe Work Australia (SWA) complies the compensation claims data (64). Claims data from July 2005 to June 2019 were extracted from SWA pertaining to the seven compensation schemes representing seven Australian capital cities: Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth, and Sydney (Table 3.2). This dataset included, at the time of data request, data for as many financial years (July to June in Australia) as possible, as July 2005 is when the most recent version of the SWA national dataset, the National Data Set for Compensation-Based Statistics third edition, was introduced (64). These data have information describing characteristics of the employee, employer, occupation, OII, and associated payments per claim. The funding for the schemes is provided by a single, public insurer in Adelaide, Brisbane, and Melbourne, private insurers in Darwin, Hobart, and Perth, and both public and private insurers in Sydney (65). These schemes, in turn, are funded by employer premiums. Premiums are based on the employers' jurisdiction, size, industry, and individual claims experience, factoring in projected and previous estimates for compensation payouts, and were approximately equal to 1.3% of employers' averaged payrolls in the 2018 financial year (63,66,67).

The compensation policies and payout rates operate under a "no-fault" principle where covered workers only need to prove that their OIIs were work-related in order to receive compensation (63). The policies vary between cities and can change over time but are generally similar (63). These differences are comprehensively described in online SWA annual publications (63,65). Relevant summary tables of the financial payouts and employer excess on 30th September 2018 are included in Chapter 3 Supplementary Material: Appendices 1 and 2, respectively (65). The changes in compensation policies over time are usually small increases or decreases in the eligibility for or the quantity of specific types of compensation payments (63). The full list of the changes over time per state are included in Chapter 3 Supplementary Material: Appendix 3 (63); the relatively larger changes during the study period are briefly summarized in Table 3.3 (63,68 74). Employer excess refers to payments to be paid by the employer, if any. Excess is absent in Hobart and Perth, restricted to any part-day lost on the day of OII for Darwin, and equivalent to one to two weeks of weekly compensation benefits in Adelaide, Brisbane, Melbourne, and Sydney, although the excess can be waived or reimbursed in Adelaide, Melbourne, and Sydney under specific conditions (65,68). Self-insured and self-employed workers are not considered in the compensation schemes; summary statistics for these groups are included in Chapter 3 Supplementary Material: Appendix 4.

Table 3.3: Brief summaries of major changes in legislation of workers' compensation claims affecting payouts

City	Date	Descriptions
Adelaide	1 Jul 2015	Weekly payments capped at two years of entitlements unless seriously injured; greater focus on rehabilitation and return to work after OIIs; streamlined dispute resolution process
Darwin	1 Jul 2015	Compensation for weekly earnings after 26 weeks reduced; five-year cap on payments for less serious injuries; increase in death benefits; duration of compensation for workers older than 67 years increased from 26 to 104 weeks; no compensation for strokes or heart attacks if work is not the cause; easier for firefighters to claim compensation for specific cancers
Darwin	1 Oct 2015	Payments provided for family counselling, medical and rehabilitation when claims are deferred, legal advice at mediation, legal and financial advice regarding negotiated settlements, and settlements of disputed claims; defence for mental injury claim based on reasonable management (previously administrative) action; exclude claims for OIIs during journeys to and from work
Hobart	1 Jul 2010	Medical expenses provided up to 12 months after weekly benefits end; increased payments for permanent impairment or death; changes to step-down payments; weekly payments extended if whole person impairment (WPI) exceeds 15%; access to common law payments available when WPI is at least 20% (previously 30%); employer covers payments until claim is reported
Melbourne	5 Apr 2010	Almost doubling of lump sum death benefits; increases in payments for workers with permanent impairment
Perth	1 Dec 2011	Removal of all age-based restrictions on compensation payments; improved access for common law payments should employers not have insurance
Sydney	19 Jun - 1 Oct 2012	Changes to weekly benefits and permanent impairment lump sums; medical expenses cease 12 months after weekly benefits end; OIIs occurring from journeys to and from employment harder to claim; heart attacks, strokes and nervous shock payments no longer claimable
Sydney	1 Sep 2015	Increased compensation payments; reduced premiums for employers with strong safety and return to work records; improved compensation service and regulation

Ethics approval was obtained from the UofA Human Research Ethics Committee to access and analyze de-identified SWA data (Approval numbers: H-2019-141 and H-2016-085). An Information Sharing Deed was established between the UofA and SWA to legally define a framework for disclosure and exchange of the data. Only members of the research team had access to the data.

3.3.1 Payout constituents

Claim payouts can comprise multiple different payments as detailed in Table 3.3 (64), although payouts in their entirety are the focus of this thesis. Collectively, they represent direct costs regarding income replacement, mortality, legal aspects, healthcare including over-the-counter payments, and administration.

The three main payment categories are compensation, goods and services, and non-compensation payments. Compensation payments include weekly benefits (income replacement) and lump sums. Lump sums can cover death benefits (payments to workers' families in the event of workers' death), income replacement, non-economic losses, and payments under common law arrangements (income replacement and non-economic losses obtained by workers suing their employers). Weekly benefits are equal to a percentage of the workers' pre-OII wages (75% to 100% based on their wage, city and duration of incapacity) (75); this is an economic measure of labor productivity loss. Non-economic losses include, but are not limited to, permanent injuries, pain and suffering, severe injury payments, and gratuitous care (64). Most goods and services costs include public and private healthcare costs from medical services, vocational rehabilitation services, allied health services, and hospital services (64). The other goods and services include over-the-counter payments that relate to treatment such as prescriptions, medical and surgical supplies, costs regarding medical aids and appliances, workplace/home/vehicle modifications, home assistance such as cleaners, repairing damaged clothing, and road accident rescue services. Non-compensation payouts are those not paid to, or on behalf of, the worker. These are mostly legal costs; other costs are predominantly administrative and include investigation expenses and medical reports for administration, non-ambulance transport, accommodation, and interpreter services. Common law payments are not covered in Darwin (65).

Table 3.4: Payment categories of compensation claim payouts

Categories	Payments	Descriptions
Compensation	Weekly benefits	Income replacement paid weekly
	Death benefit lump sum	Payment to worker's family if the worker died
	Total statutory lump sum	Income replacement and non-economic loss
	Common law lump sum	Income replacement and non-economic loss under common law arrangements
Goods and services	Medical services	Costs from registered medical practitioners
	Vocational rehabilitation services	Vocational rehabilitation not provided by medical practitioners
	Allied health services	Healthcare not provided by medical practitioners or vocational rehabilitation
	Hospital services	Costs from hospital visits that do not belong in another category
	Other	Costs for other goods and services paid
Non-compensation	Legal	Legal costs not paid to, or on behalf of, worker
	Other	Non-legal costs not paid to, or on behalf of, worker

3.4 Meteorological data

Retrospective hourly climate data were obtained from the Australian Bureau of Meteorology (BoM) Atmospheric high-resolution Regional Reanalysis (76). This dataset was selected because of (1) its high quality data derived using a variety of sources such as climate stations and satellites, (2) it has reasonable resolution for city-level analysis (each grid is 12km*12km), and (3) the data extends over a long-time period (January 1990 to February 2019) (76 78). The long-time period enables calculation of a heatwave threshold using an approximately 30-year reference period for long-term climate variability and climate change analysis (79). In comparison, daily humidity, wind speed, and solar radiation data are regularly missing or not recorded in station data (80 82). Such data were needed for calculating both indoor and outdoor apparent temperature metrics; indoor metrics require air temperature and humidity, and outdoor metrics also require solar radiation and wind speed (41,83).

Future daily meteorological gridded data were obtained from Climate Change in Australia (84) using eight general circulation models (GCMs) described online (85). These data were selected for projections because of their high resolution

(5km*5km grids) for city-level analysis that could approximately be aligned with the BARRA data (7*7 5km grids and 3*3 12km for climate areas expanding 35*35km and 36*36km, respectively), they include daily mean humidity data, and they are high quality and derived for multiple sources (84). To the best of the author's knowledge, no projected climate datasets were identified as having both suitable resolution for Australian city-level analysis (most global datasets have grids with approximately 50km*50km resolution) and daily maximum or minimum humidity data (86,87). Hence Chapter 4, which has a larger focus on assessing the relationships between apparent temperature and both OIIs and costs compared to Chapter 5, only includes retrospective analysis. Data under Representative Concentration Pathways [RCP]4.5 and RCP8.5 were used to represent a low/moderate and high greenhouse gas emissions scenario, respectively. Data for RCP2.6 and RCP6.0, although available, was not used as there were less GCMs available for these data, reducing the reliability of the projections. Data were projected to 2016-2045 (centered on 2030) and 2036-2065 (centered on 2050). Current Australian city-level projections for population data by the Australian Bureau of Statistics (ABS) did not extend beyond 2066 (88).

3.5 Overview of analytical methodology

Modeling OII-associated costs as a continuous outcome directly against temperature/heatwaves is important to accurately establish the relationship between costs and temperature/heatwaves. Estimating costs by only modeling the number of OIIs and assigning set cost values to each OII such as the mean and median assumes that (1) each OII has the same cost, (2) OIIs and their costs have identical relationships with temperature/heatwaves and (3) the number of OIIs and costs are distributed equally (31). These are large and almost certainly incorrect assumptions. Daily claim payouts for OIIs depend not only on the number of OIIs but also OII characteristics such as severity and duration, the workers' income pre-OII, and potential legal and administrative costs (64). These factors influence the costs per

OII, may affect their relationship with temperature/heatwaves, and contribute to a larger amount of variance and uncertainty when modeling costs. To capture these factors' effects, for this thesis' studies, costs were modeled directly against temperature/heatwaves over time, similar to previous studies modeling healthcare costs against temperature (89 94). OIIs and their costs were modeled based on the date of OII onset instead of the date of claim submission in order to model the effect of heat on OIIs.

To capture the non-linear effects of temperature and excess heat, which can be both immediate and delayed, distributed lag non-linear models (DLNMs) were used (95). DLNMs were constrained to reduce collinearity and the number of parameters, particularly when analyzing longer lag periods (95,96). To model these effects against OIIs and their costs, time series models were used. This is the most common study design for analyzing OIIs against temperature/heatwaves (13) and enables analysis of daily outcomes whilst controlling for seasonal and temporal confounders (96,97). A time-stratified case-crossover design, a viable alternative to time series models that controls for the number of workers by design, was considered for this study (39,98). However, it was not used because initial testing with the case-crossover design showed unsatisfactory control of autocorrelation in the residuals compared to time series models. This finding can be explained by case-crossover design's more strict control for seasonality and long-term trends (by forcing sudden changes in risk between adjacent time periods) relative to using the more flexible spline (99,100). Instead, to control for the number of workers, the monthly labor force size were included as a logarithmic offset in the models using ABS data (55). Although monthly labor force data may not capture short-term fluctuations in workforces occurring over a few days, this can be alleviated by including variables to adjust for holidays (31,101) and other influential days as determined by model residuals and Akaike information criterion (AIC) (39,40,102).

To estimate the national (non-linear) effects of temperature/heatwaves, the individual model results were pooled using (multivariate) meta-analysis (103,104). Given that the seven cities represent approximately 97% of the metropolitan workforce (55), the pooled results reasonably represent the Australian national metropolitan workforce. Furthermore, this enables the creation of best linear unbiased predictors (BLUP) that can improve the individual models' accuracy and precision by letting them utilize information from the other cities (103–105).

OIIs are frequently modeled with distributions designed for count data (usually Poisson, quasi-Poisson, negative binomial, or logistic regression) (13,96,106). Hence Poisson regression was used to model OIIs, or quasi-Poisson when the data were over-dispersed (106).

Daily cost data from insurance claims data are usually difficult to model. This non-count data are generally semicontinuous — a combination of continuous, (highly) right-skewed data with a point mass at zero (i.e. days without any costs), which invalidates many continuous distributions such as Gamma and Inverse Gaussian (107–110). The most popular solution, adding a constant value such as one to the outcome variable, introduces bias and is ill-advised (111,112). Hence the SWA cost data were modeled with the Tweedie distribution, specifically the compound Poisson-Gamma distribution. The use of this distribution is similar to a two-part model with both a Poisson and Gamma distribution, where the Poisson component fits the daily number of OIIs and the Gamma component fits the costs on days where OIIs occurred (which, when combined, model the daily costs) (107,110). The Tweedie distribution is a reparameterisation of the two-part Poisson-Gamma model to fit within a single distributional framework instead of consisting of two models, each with a separate outcome, combined (107,108,113). Because the Tweedie distribution has a singular framework, it is simpler in terms of the number of parameters, the selection of parameters and clinical interpretation (107,114), and is thus less likely to have unnecessary adjustment and overadjustment bias (115). Although two-part models have been associated with slightly improved accuracy (113,116), having two sets of model estimates adds additional complexity when using DLNMs (increased likelihood of collinearity with the exposure variable's parameters) and pooling the model estimates with meta-analysis. The latter requires the count (Poisson) and cost per day (Gamma) models to be meta-analyzed separately, and it is not clear whether these two meta-analytic outputs can be clinically combined into a singular output representing estimated costs across all the cities. Tobit, quasi-Poisson, and negative binomial models were also considered. Tobit models involve censoring or truncating the data with zero values. This was not considered ideal in this situation, because this would lose information regarding the real zero values (117,118).

Although quasi-Poisson and negative binomial distribution can model costs (92 94,118,119), the Tweedie distribution can better account for a range of different skews. For each Tweedie model, this required selecting the Tweedie index parameter, also known as the power or shape parameter, with the largest log-likelihood value from 1.001 to 1.999 using series expansion (120). The variance function of the Tweedie distribution is $V(Y) = \phi\mu^\rho$, where ϕ is the dispersion parameter (to account for dispersion), μ is the mean and ρ is the index parameter. The variance function is identical to that of the Gamma distribution if ρ is 2, the quasi-Poisson distribution if ρ is 1 and the Poisson distribution if both ϕ and ρ are 1 (120,121).

OIIs were modeled using generalized linear models (GLMs), similar to most other studies modeling OIIs (13,29). Costs were analyzed using generalized additive models (GAMs) fitted with restricted maximum likelihood. GAMs enable increased flexibility with modeling seasonal trend to potentially better capture more complex long-term trends and have improved precision, computational efficiency, and stability when estimating the Tweedie index parameter (this estimation can be unstable with GLMs) (122 125).

4

Anomalous temperatures increase occupational injuries, illnesses and their associated cost burden in Australia

4.1 Statement of Authorship

This subchapter includes signed forms detailing the contribution of all authors involved in this study pertaining to Chapter 4 and the Chapter 4 Supplementary Material.

Statement of Authorship

Title of Paper	Anomalous temperatures increase occupational injuries, illnesses and their associated cost burden in Australia
Publication Status	☐ Published ☐ Accepted for Publication ☐ Submitted for Publication ☒ Unpublished and Unsubmitted work written in manuscript style
Publication Details	Currently not applicable

Principal Author

Name of Principal Author (Candidate)	Matthew Anthony Borg		
Contribution to the Paper	Conceptualisation; Methodology design; Programming; Formal analysis; Visualisation; Writing drafting manuscript; Data curation; Reviewing and editing the manuscript;		
Overall percentage (%)	85%		
Certification	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	4/11/2022

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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4.2 Abstract

Background: Anomalous ambient temperatures elevate the risk of occupational injuries and illnesses (OIIs). However, the associated economic burden is under-explored internationally. This burden is likely substantial. Understanding the temperature-attributable variations in costs can help mitigate these costs.

Objectives: To establish a national cost profile of heat- and cold-attributable OIIs and their associated costs in Australia.

Methods: Workers' compensation claims from seven Australian capital cities were merged with re-analysis climate and workers' demographic data from July 2005 to June 2018. Time series analysis with distributed lag non-linear models were used to estimate OIIs and associated costs attributable to daily maximum wet bulb globe temperature (WBGT). Workers and WBGT were classified as indoors or outdoors, which were modelled separately. OIIs and costs were modelled using Poisson and Tweedie distributions, respectively. Individual models were pooled with multivariate meta-analysis to produce national and city-level estimates.

Results: 2,321,602 OIIs comprising AU$43 billion in total payouts were included for analysis. The heat-attributable and cold-preventable fractions of OIIs were 1.66% (95% eCI: 1.38-1.94) and 0.66% (95% eCI: 0.45-0.89%), respectively. These represented 38,540 heat-attributable OIIs and 15,409 cold-preventable OIIs. 1.53% (95% eCI: 0.77-2.27%) and 1.33% (95% eCI: 0.66-1.97%) of costs were heat- and cold-attributable, respectively, with increased costs per OII during cold despite less OIIs. The associated financial burdens were AU$651 and AU$574 million, respectively, collectively representing AU$94 million annually.

Discussion: Environmental heat and cold temperatures in workers poses a substantial morbidity and cost burden in Australia. The relationship between anomalous temperatures and costs does not necessarily follow that of OII occurrence, which is likely more influenced by heat compared to cold relative to their associated costs. Although heat adaptation is likely more important for preventing OIIs than cold adaptation, addressing both is important to reduce OII-associated costs.

Keywords: Attributable risk; Compensation claims; Environmental economics; Occupational injuries; Wet bulb globe temperature; Worker safety.

Abbreviations: ABS: Australian Bureau of Statistics, AF: attributable fraction, AN: attributable number, ANZSCO: Australian and New Zealand Standard Classification of Occupations, BLUP: best linear unbiased prediction, DLNM: Distributed lag non-linear model, GAM: Generalized additive model, GCCSA: Greater Capital City Statistical Area, OII: Occupational injury or illness, SWA: Safe Work Australia.

4.3 Introduction

Heat, and to a lesser extent cold, have been associated with an increased risk of occupational injuries and illnesses (OIIs) (28,31,39,40,126,127). Causes include working in high and low temperatures, inappropriate clothing for the weather, workplace radiant heat exposure, metabolic heat production from physical work, and reduced access to thermoregulatory safety interventions such as air conditioning (13,28,127). Heat and cold can damage multiple physiological systems and impair physical and mental performance (3,128), predisposing to both directly temperature-attributable OIIs such as heat stroke and chilblains, and general occupational injuries like falls (13,28,129). Extreme temperatures are one of the most threatening health impacts of climate change (3,4). More heat-attributable OIIs are expected due to increasing intensity and duration of extreme heat (3,4).

The temperature-attributable economic burden from OIIs is underexplored (47). This includes healthcare costs, compensation costs such as income maintenance, legal expenses, and indirect costs from labor productivity loss (31,32,47). Costs are also incurred by employees, such as personal expenses and potential healthcare costs, and by employers through hiring replacement staff, legal costs and decreased labor productivity (47). These costs can be substantial: a study from Spain estimated an annual cost of 370 million from temperature-attributable occupational injuries (31).

A recent literature review identified three studies that investigated costs from heat-attributable OIIs (47). One study was descriptive and limited to directly heat-related OIIs (130), another estimated costs by modelling temperature against occupational injuries and using set cost figures alongside the temperature-OII relationships instead of modelling costs directly (31), and the third investigated costs in one city beyond heat stress but not cold stress thresholds (89). The exposure-cost relationship and its distribution across both hot and cold temperatures have yet to be explored. Compensation claims and healthcare costs data are generally highly right-skewed and semi-continuous unlike count-based injury data, with many cases associated with low or no costs but a few associated with high costs (107,108). The effect of temperature on costs is multifactorial, depending not only on the number of OIIs but also on their severity and duration. These affect healthcare costs and policies regarding compensation, legal and other administrative payments (47). Understanding the temperature-attributable variations in costs can help workplaces and public health agencies implement financially viable temperature-attributable OII prevention and management plans. Median costs from directly heat-related illnesses were halved after implementing a heat stress awareness program in Texas (46). Many of these costs are avoidable. This is particularly important in the context of climate change.

This study aimed to establish a national profile of heat- and cold-attributable OIIs and their associated costs in Australia. Given the lack of previous studies evaluating the relationship between temperature and associated costs, a secondary aim was to evaluate this relationship and associated factors, comparing results between OIIs and their costs, to enable better tailoring of interventions to the national Australian workforce.

4.4 Material and methods

4.4.1 Data

Workers' compensation claims data

Employers must pay for workers' compensation insurance, which financially covers Australian workers for OIIs (60). Each Australian state and territory has its own compensation scheme. Claims data are collected by Safe Work Australia (SWA). The authors extracted data for all claims submitted from 1st July 2005 to 30th June 2019 from seven compensation schemes, each one representing a different Australian state or territory and by extension their capital city: Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth and Sydney, for a study period representing OIIs from 1 July 2005 to 30 June 2018. This period ends one year earlier to that of claim submission, as claims were commonly submitted in the financial year following that of the OII, with an Australian financial year occurring from 1st July to 30th June. These claims represent over 97% of Australia's workforce in capital cities across the study period (55). The other capital city, Canberra, was excluded due to its relatively small population size and high proportion of office workers (131), which are generally less exposed to temperature extremes. Compensation policies and payout rates vary between states and change over time, although they remain generally similar including in their obligation to provide worker financial support. A comprehensive description of these differences is available online in annual publications by SWA (65). The most notable difference is that the employer excess period, the period when employers pay an excess before the compensation insurer provides financial compensation, varies from 0 to 14 days across jurisdictions (65,72). Workplace postcodes and hence metropolitan status were not available for claims submitted in Tasmania prior to July 2007; these claims were excluded, and by extension, OIIs occurring from July 2005 to June 2006 in Hobart were excluded from analysis. (The number of OIIs occurring from July 2006 to June 2007 in Hobart was similar to that of other years; thus these OIIs were retained for analysis). Payouts for a single claim can continue across multiple years.

OIIs were subdivided into those from outdoor workers (defined as those undertaking main duties outside for at least part of their working hours) or indoors (no outdoor work). Workers' occupations, as defined by the Australian and New Zealand Standard Classification of Occupations (ANZSCO) (132), were linked with their corresponding occupations from the Canadian National Occupation System (NOC) as part of a cross-walk (133,134). NOC occupations marked as having main duties with outdoor work by the 'L3 location' were treated as outdoor work, including occupations with multiple locations, and those without 'L3 location' marked were classified as indoor workers. Cross-matching was done for 6-digit

ANZSCO occupations (the lowest level classification) and then aggregated to 4-digit unit groups to match the SWA data. If an ANZSCO occupation was associated with both outdoor and indoor NOC occupations, the more common classification was chosen, with indoors being selected in the event of a tie. The linking of occupations from the ANZSCO and NOC were cross-checked against two previous versions using older ANZSCO and NOC versions (39,134) that have been used previously by other Australian studies examining the relationship between temperature and OIIs (29,39,40,135,136). Both the ANZSCO and NOC derive from the International Standard Classification of Occupations (137), and the original cross-walk was validated with a strong correlation between the two systems for outdoor work (134). The categorization of occupations as indoors or outdoors is included in Appendix Table C.1. Indoor/outdoor status for workers with partially but not completely missing occupational data (one to three ANZSCO digits reported, 0.3% of claims) was estimated based on the more common classification of the possible occupations. Sensitivity analyses were performed with estimated indoor/outdoor status based on workplace industry (industrial sectors of “agriculture, forestry and fishing”, “construction”, “electricity, gas and water” and “mining” were classified outdoors, all other industries were indoors) instead of occupation (54,138). This method is more common for analyzing heat-attributable occupational health impacts (39,47), but is more likely to misclassify indoor/outdoor status (39).

Claims were limited to non-duplicates, those submitted on the day or after the date of OII, OIIs occurring within the study period, OIIs occurring in metropolitan areas, and pertaining to workers aged 15 to 75 years with occupational data (in the labor force and not completely missing). These restrictions are similar to those of previous studies investigating OIIs using SWA data (29,39,72,139,140). Metropolitan status was based on whether the location of OII, based on Australian postcode, was located within a Greater Capital City Statistical Area (GCCSA) (59). Injuries and illnesses were assessed collectively, with the two categories analyzed separately in supplementary analyses. These were defined by Type of

Occurrence Classification System codes A-G and H-R, respectively, for the nature of injury or disease (141). 0.02% of claims were associated with an overall negative claim cost (i.e. a financial gain, which can be due to workers or a third party reimbursing already-paid compensations); their payments were adjusted to $0 so that they did not impact cost estimates but were still included in OII estimates. The costs were adjusted for inflation and standardized to the last quarter in the financial year of 2018 from the ABS (ending June 2019) (142). The consumer price index categories for compensation/administrative costs, health services, and other goods and services were "insurance and financial services", "health services" and "general", respectively. This study focuses on total costs, with additional analyses for the three SWA categories of payments: (1) compensation (paid to workers or their families), (2) goods and services (predominantly health services but also out-of-pocket expenses such as medical supplies and workplace/home/vehicle modifications), and (3) non-compensation (not paid to or on behalf of the worker) (64). Cost per OII (total costs divided by the number of OIIs) on days where at least one OII were reported was also analyzed. A supplementary analysis for costs was performed for claims submitted no later than June 2014 with costs restricted to up to five financial years after the financial year of claim submission. This removed claims that may had artificially decreased costs due to occurring later in the study period at the expense of artificially decreasing the size of the cost data.

Meteorological data

Hourly climate data were obtained from the Australian Bureau of Meteorology (BoM) Atmospheric high-resolution Regional Reanalysis from 1st June 2005 to 30th June 2018 (76,143). This starts one month earlier than the claims data to provide non-missing lagged climate values across the entire study period. A 3*3 grid of 12km cells was extracted at grid centroids correlating to the centre of the central business districts for Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth and Sydney. The variables extracted were air temperature, specific humidity, air pressure, wind speed, solar radiation (including its diffuse and direct components) and fraction of the sky covered by cloud. There were no missing data.

To account for both temperature and humidity, daily maximum wet bulb globe temperature (WBGT) was chosen as the primary exposure variable. It is commonly used for assessing workplace heat stress and heat-related occupational economic costs (47), has been used previously for assessing the impact of both cold and heat effects on occupational injuries (89,144), can be measured on-site and is used in international workplace guidelines (145). It can represent both indoor and outdoor heat exposure, the first representing the effects of air temperature and humidity, and the second also incorporating wind speed and solar radiation (41). These were estimated empirically with Bernard's and Liljegren's equations, respectively, which have previously been shown to estimate indoor and outdoor WBGT, respectively, with high accuracy (41,146,147). Sensitivity analyses were performed using daily average WBGT, other apparent temperature metrics (Steadman's apparent temperature (83), heat index (148) and humidex (149), air temperature (with and without specific humidity) and relative humidity. The calculations of maximum and average temperatures and all derived meteorological variables, including stratification by indoors and outdoors if applicable, are detailed in the Supplementary Equations.

Population count data

Population employed worker counts were derived from the Australian Bureau of Statistics (ABS) labor force detailed survey data (55), available monthly, with counts stratified by city (GCCSA). As this dataset does not contain detailed occupational data, indoor and outdoor worker counts were estimated by extracting worker counts from the ABS Census TableBuilder Basic data and deriving the proportion of indoor/outdoor workers in the labor force using the ANZSCO-NOC cross-walk (131). The ABS Census is a 5-yearly survey conducted for all Australian households with stratification for employees at August 2006, 2011 and 2016. To extend the indoor/outdoor worker proportions across the study period, the population counts were (1) stratified by workplace GCCSA (standardized to the 2016 metrics), (2) logit-transformed and then interpolated using cubic splines and extrapolated linearly for each month, and (3) back-transformed to the normal population scale. For the 2006 Census, workplace location was reported by Statistical Local Area and then converted to GCCSA (150). This was also used to estimate the 1-monthly worker count for Darwin relative to the rest of Northern Territory, as ABS worker 1-monthly counts are reported only for Northern Territory collectively. Industry-stratified worker's population data, available every 3 months, was used for the sensitivity analysis stratifying indoor/outdoor workers by industry instead of occupation (55).

4.4.2 Statistical analysis

Stage 1

Statistical analysis was conducted in two stages. The first involved assessing the relationships between daily maximum WBGT and either OIIs or their associated costs over the study period. Costs were considered to occur on the date that the OII occurred, instead of the date of claim submission or payout, to represent the temporal relationship between heat and OIIs. Each city, stratified into outdoor and indoor workers, was modelled separately (14 models in total) using time series distributed lag non-linear models (DLNMs) (151). Estimates for outdoor workers were modelled using outdoor WBGT, and indoor workers using indoor WBGT. OIIs and costs were fitted using a Poisson and Tweedie distribution, respectively, with a log-link function. The Tweedie distribution is a reparameterization of the compound Poisson-Gamma distribution to fit within a single distributional framework and is commonly used for analyzing insurance claims (107,108). This choice was justified given the highly right-skewed data, the presence of days with zero costs (which invalidates many continuous distributions including Gamma), and its relative simplicity compared to two-part models in terms of both the number of parameters and clinical interpretation (107). For each Tweedie model, the index parameter took the value from 1.001 to 1.999 that had the largest log-likelihood value as selected using series expansion (120); this provided the models more flexibility to better account for dispersion and the number of days with zero costs. OIIs were modelled using generalized linear models. Costs were analyzed using generalized additive models (GAMs) fitted with restricted maximum likelihood to potentially better represent more complex and non-linear long-term trends and to more precisely estimate the index parameter (122 124).

The model equation was:

$$log[E(Y_t)] = cb(T_t) + ns(t) + DOW_t + Month_t + PH_t + School_t + D1_t + S_t + Sat : (PH_t + School_t + D1_t) + Sun : (PH_t + School_t + D1_t) + offset(log(n)) + \alpha$$

Where $E(Y_t)$ is the expected number of daily OIIs or costs on day t. $cb(T)$ is the cross-basis natural cubic spline function for daily maximum WBGT with one internal knot at the 50th percentile. $ns(t)$ is a natural cubic spline with 4 fixed degrees of freedom (df) per year across a 13-year study period (12-year for Hobart), representing long-term trend and seasonality. DOW is the day of the week. *Month* is the month of the year. *PH* is a binary marker indicating whether the day was a public holiday or not. *School* designates each of the four school holidays periods, with no school holidays as the reference period (152). The number of hours worked in Australia is known to vary seasonally with school holidays (153). *D1* is a binary marker indicating whether it is the first day of the month (excluding New Year's Day). This variable was included because there were more OIIs on the first day of the month relative to the other days; this was likely because OIIs with an unknown day but known month and year of occurrence were reported as occurring on the first day. S is a factor variable designating specific days or time periods that were highly influential on model fit with categories being (1) the Christmas break (23rd to 30th Dec), (2) New Year's Eve, (3) New Year's Day, (4) 2nd to 4th January and (5) specific days for Adelaide (the week of 24th to 30th

Monday June 2008, which had considerably less OIIs than expected), Brisbane (the city-specific public holidays of the Royal Queensland Show and 2014 G20 Leaders' Summit), Melbourne (the day before Melbourne Cup) and Sydney (Australia Day, which includes a public celebration at the Sydney Opera House). Interaction terms denoted by "*:*" were included with Saturday/Sunday and *PH*, *School* and *D1*. *offset(log(n))* is the logarithmic number of workers included as an offset. Finally, α is a modelled intercept. Every Sunday is a public holiday in Adelaide (154). Thus for Adelaide, *PH* was always zero on a Sunday and *Sun:PHt* was not included, as this information would instead be conveyed through the DOW category for Sunday. The lag dimension was modelled using a natural cubic spline with one central knot and a maximum lag of 20 days to include the delayed effects of cold (155) and represent three weeks including day zero. Sensitivity analyses were performed for model variations in the exposure-response and lag-response relationships and seasonality trends, including a (GAM) penalized seasonality trend with a high number of df per year (12) (102). Potential dispersion for OII models was assessed by inspecting the dispersion parameters (the sum of the squared Pearson residuals divided by the residual df (121)).

Stage 2

The individual indoor and outdoor city exposure-response relationships were pooled with random-effects multivariate meta-analysis to derive a national (the seven cities combined) overall exposure-response relationship and fit best linear unbiased predictors (BLUPs) to each model to improve precision (104). Residual heterogeneity was analyzed using the multivariate extension of the Cochran Q test and the I^2 statistic (104,156). Analyses were centered on the daily maximum WBGT for (1) easier interpretation of results compared to usual working conditions, with an approximately equal time of exposure to temperatures above and below the mean (2) to keep centering consistent across different models for both OIIs and costs. Overall cumulative exposure-response relationships and cumulative lag-response relationships were derived nationally. Exposure-response relationship curves at the city-level (pooled indoor and outdoor) and national indoor/outdoor level (pooled by city) were generated using secondary multivariate meta-analyses to derive BLUPs using a random-effects metapredictor for city and indoor/outdoor status, respectively (104).

Attributable fractions (AF) and numbers (AN) of OIIs and costs were estimated for each model fitted with their BLUPs. For this study, heat and cold represent WBGT values above and below the mean, respectively. WBGT values between the mean value and the 2.5th/97.5th values were defined as moderate cold/heat, and values beyond this range were defined as extreme heat/cold. AF is defined as $1 - e^{\sum_{l=l_0}^{L} \beta_{x,l}}$, which includes the sum of all logarithmic relative risks $\beta\ x, l$ from WBGT on a given day to 20 future days (155,157). AN is equal to AF multiplied by the costs or number of OIIs on the given day. ANs were pooled across strata to produce national, city- and indoor-/outdoor-level estimates. OIIs and costs per worker were calculated by dividing the AN by the averaged monthly workforce size across the study period. Empirical 95% confidence intervals were estimated using 5000 Monte Carlo simulations assuming a multivariate normal distribution (157).

Stratified analyses were performed with data restricted by sex, age, indoor and outdoor industries, occupation and the nature of OII to explore their impact on the national AFs. Some nature categories had low counts and were combined together. For these analyses, seven models were used for each city using indoor WBGT as the exposure metric without stratification by indoor/outdoor status; this improved the individual models' sample size to compensate for the analyses' decreased sample sizes. All statistical analysis was performed using R version 4.2.1 (158). The *HeatStress* package was used to calculate WBGT (159), the *dlnm*, *mcgv* and *mixmeta* packages were used to model DLNMs, GAMs and multivariate meta-regression models, respectively (104,122,151), and attributable risk was calculated using the *FluMoDL* package (160) which is based on the original *attrdl* function

(157). *mcgv* utilizes the *tweedie* and *statmod* packages to fit Tweedie models and estimate the index parameter, respectively (125,161).

4.4.3 Ethics

Ethics approval to access and analyze SWA data were obtained from the University of Adelaide Human Research Ethics Committee (Numbers: H-2019-141 and H-2016-085).

4.5 Results

4.5.1 Descriptive statistics

Brisbane and particularly Darwin had higher WBGT values than the other cities, while Hobart had lower values (Tables 4.1 and 4.2). Throughout the study period, on average 14% of workers were classified as outdoor workers. There were 4,142,872 claims obtained from SWA (Appendix Table C.2). After restricting claims to workers aged 15 to 75 years in the cities under investigation during the study period, 2,321,602 (56%) claims were included for analysis. The more populous cities had more claims (Brisbane, Melbourne and Sydney), with fewer claims in Darwin and Hobart. The included claims comprised AU$43 billion total payouts (Table 4.3). 60% of financial payouts were compensation payments, 30% covered goods and services, and 10% were non-compensation costs. 58% of compensation payments were for income support, and 95% of the goods and services costs were for health services (all except the 'Other' category).

Table 4.1: Mean meteorological metrics and workers' populations in Adelaide, Brisbane, Darwin and Hobart during the study period

	Adelaide	Brisbane	Darwin	Hobart
Köppen climate	Csa	Cfa	Aw	Cfb
Max temperature (°C)	21.8 (14.4-29.3)	25.8 (21.5-30.1)	29.3 (27.6-30.9)	16.0 (10.4-21.6)
Relative humidity (%)	40.9 (21.0-60.7)	43.6 (29.4-57.9)	58.6 (43.1-74.1)	51.3 (36.0-66.6)
Wind speed (m/s)	4.7 (2.7-6.7)	4.1 (2.4-5.8)	4.8 (2.6-7.0)	4.0 (1.5-6.5)
Solar radiation (W/m^2)	645 (384-906)	714 (474-947)	391 (29-754)	561 (296-826)
Indoor WBGT (°C)	16.0 (11.5-20.4)	20.1 (16.5-23.8)	24.9 (22.5-27.4)	12.2 (8.1-16.3)
Outdoor WBGT (°C)	21.1 (15.3-26.9)	24.6 (20.8-28.4)	28.6 (25.5-31.6)	15.5 (11.0-20.0)
Indoor workers (000s)	543 (526-561)	974 (914-1034)	64 (57-70)	90 (87-93)
Outdoor workers (000s)	77 (72-81)	144 (132-156)	12 (10-14)	15 (14-15)

The temperature metrics were recorded at the time of daily maximum temperature and were collectively used to calculate both indoors and outdoors wet bulb globe temperature (WBGT). The ranges represent ±1 standard deviation. Aw: Tropical savanna climate with dry-winter characteristics, Cfa: Humid subtropical, Cfb: Marine west coast, Csa: Mediterranean hot summer.

Table 4.2: Mean meteorological metrics and workers' populations in Melbourne, Perth and Sydney during the study period

	Melbourne	Perth	Sydney
Köppen climate	Cfb	Csa	Cfa
Max temperature (°C)	20.9 (14.1-27.7)	24.5 (17.9-31.2)	23.3 (17.8-28.7)
Relative humidity (%)	42.8 (27.3-58.3)	40.0 (23.0-57.0)	43.4 (27.7-59.1)
Wind speed (m/s)	5.0 (3.0-7.0)	4.6 (2.6-6.6)	5.0 (3.3-6.7)
Solar radiation (W/m^2)	541 (270-813)	700 (431-970)	609 (330-889)
Indoor WBGT (°C)	15.6 (11.1-20.0)	18.3 (14.2-22.4)	17.8 (13.6-22.0)
Outdoor WBGT (°C)	19.7 (14.6-24.9)	25.8 (20.5-31.2)	21.7 (17.5-26.0)
Indoor workers (000s)	1928 (1767-2088)	828 (761-895)	2120 (1982-2258)
Outdoor workers (000s)	252 (221-283)	139 (126-153)	252 (223-280)

The temperature metrics were recorded at the time of daily maximum temperature and were collectively used to calculate both indoors and outdoors wet bulb globe temperature (WBGT). The ranges represent ±1 standard deviation. Cfa: Humid subtropical, Cfb: Marine west coast, Csa: Mediterranean hot summer.

Generally, the number of OIIs gradually decreased across successive financial years (July to June). Associated costs gradually increased up to the 2010 financial year and then decreased (Appendix Table C.3). There were almost three times as many OIIs and associated costs for indoor compared to outdoor workers. Payments predominately occurred in the same or subsequent financial year as the date of claim submission. 64% of claimants were male, and most claimants (79%) were 20 to 54 years old. There were approximately 3.5 times more injuries reported than illnesses (diseases/conditions).

Table 4.3: National costs and their components across all claims included for analysis

Payment category	Component	Total 000s (%)	Mean	Median	IQR
Total		42,846,949 (100.00)	18.460	1.618	0.415 - 8.906
Compensation		25,578,529 (59.70)	11.021	0.323	0.000 - 3.025
	Weekly benefits (income support)	14,895,874 (34.77)	6.418	0.263	0.000 - 2.475
	Death benefit lump sum	582,165 (1.36)	0.251	0.000	0.000 - 0.000
	Total statutory lump sum*	4,007,474 (9.35)	1.726	0.000	0.000 - 0.000
	Common law lump sum	6,095,100 (14.23)	2.626	0.000	0.000 - 0.000
Goods & services		12,868,506 (30.03)	5.544	0.716	0.206 - 3.816
	Medical services	6,375,303 (14.88)	2.747	0.427	0.139 - 1.781
	Hospital services	2,118,294 (4.94)	0.912	0.000	0.000 - 0.000
	Allied health services	1,873,174 (4.37)	0.807	0.000	0.000 - 0.636
	Vocational rehabilitation services	1,908,116 (4.45)	0.822	0.000	0.000 - 0.000
	Other	600,075 (1.40)	0.259	0.000	0.000 - 0.029
Non-compensation		4,408,540 (10.29)	1.899	0.000	0.000 - 0.247
	Legal	1,962,043 (4.58)	0.845	0.000	0.000 - 0.000
	Other	2,446,877 (5.71)	1.054	0.000	0.000 - 0.202

Descriptive summaries of all claim payments for analysis presented to the nearest thousand Australian dollars (000s). A median of 0 indicates that most claims were not associated with this category of payment. *Total statutory lump sums are settlements of weekly benefits and non-economic payments. Non-economic payments included, but are not limited to, payments for permanent injuries, pain and suffering, severe injury payments and gratuitous care. IQR: interquartile range.

4.5.2 Overall cumulative relationships

The relative risk (RR) of OIIs gradually increased with higher WBGT (Figure 4.1). Cold had a small "protective effect" against developing OIIs, though statistical significance decreased at extremely cold temperatures. Costs increased during both cold and heat, forming a U-shaped association. At cold temperatures, although there were fewer OIIs, the cost per OII increased. There was no significant association between hot temperatures and the cost of OIIs. Compared to OIIs, heat induced a larger proportional increase in costs albeit with a larger confidence interval. Approximately similar relationships were observed with costs stratified into compensation and non-compensation costs, although goods and services costs had smaller heat estimates and no significant relationship with cold. Exposure-response relationships at the indoor/outdoor and city levels were similar to the national estimates for both OIIs and costs (Figures 4.2 and 4.3), and likewise for the individual models (Figures C.1 and C.2).

Across the 20-day lag period, heat exposure immediately increased the risk of OIIs and the associated costs (Figures 4.4 and 4.5). The risk for OIIs gradually dissipated after about ten days and slightly increased afterwards, whereas the risk for costs increased throughout the lag period. The risk of OIIs and costs immediately increased after cold exposure for about a week (five days for costs), slightly increased until about 15 days, and was negligible afterwards.

The OII models' dispersion parameters indicated only a little over-dispersion ranging from 1.015 to 1.507 (Appendix Table C.4). Heterogeneity was not detected in the total cost multivariate meta-regression (Cochran Q-statistic=22.639, df=26, P-value=0.653). Although the OII models had statistically significant heterogeneity (Cochran Q-statistic=42.041, df=26, P-value=0.024), it was not substantial (I^2=38.2%).

4.5.3 Attributable fractions

1.66% (95% eCI: 1.38-1.94%) of all OIIs were heat-attributable (Figure 4.6, with estimates listed in Appendix Table C.5). Cold temperatures reduced the attributable proportion of OIIs by 0.66% (95% eCI: 0.45-0.89%). Heat-AFs were higher for indoor workers, and workers in Sydney, Melbourne and Perth. Cold-preventable fractions (PFs, equivalent to negative AFs (162)) were higher among workers from Adelaide and Darwin, and similar between indoor and outdoor workers. Across all cities, the extreme heat and cold estimates ranged from 0.14-0.31% and -0.01 to -0.14%, respectively.

1.53% (95% eCI: 0.77-2.27%) and 1.33% (95% eCI: 0.66-1.97%) of costs were heat- and cold-attributable, respectively. Indoor workers had larger heat and cold estimates. Heat-AFs were largest in Darwin (2.70%, 95% eCI: 0.01-5.23), followed

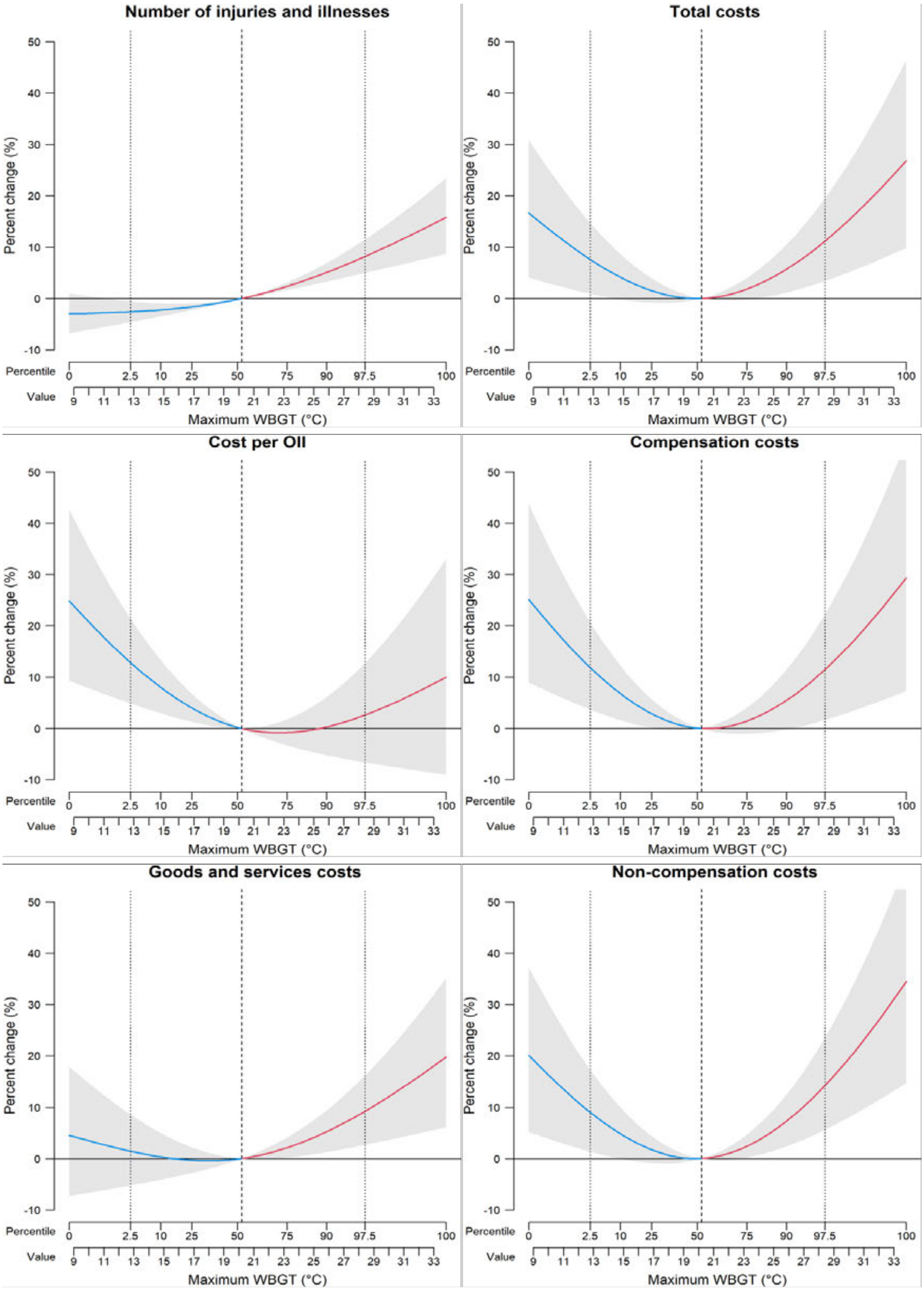

Figure 4.1: Overall cumulative exposure-response curves pooled nationally with 95% confidence intervals for change in the daily number of occupational injuries and illnesses (OIIs), total costs, cost per OII, and costs for compensation, goods and services, and non-compensation. The three dashed lines represents, from left to right, the 2.5th percentile, mean and 97.5th percentile of daily maximum WBGT. Cold- and heat-attributable effects are compared against the mean and are displayed in blue and red, respectively.

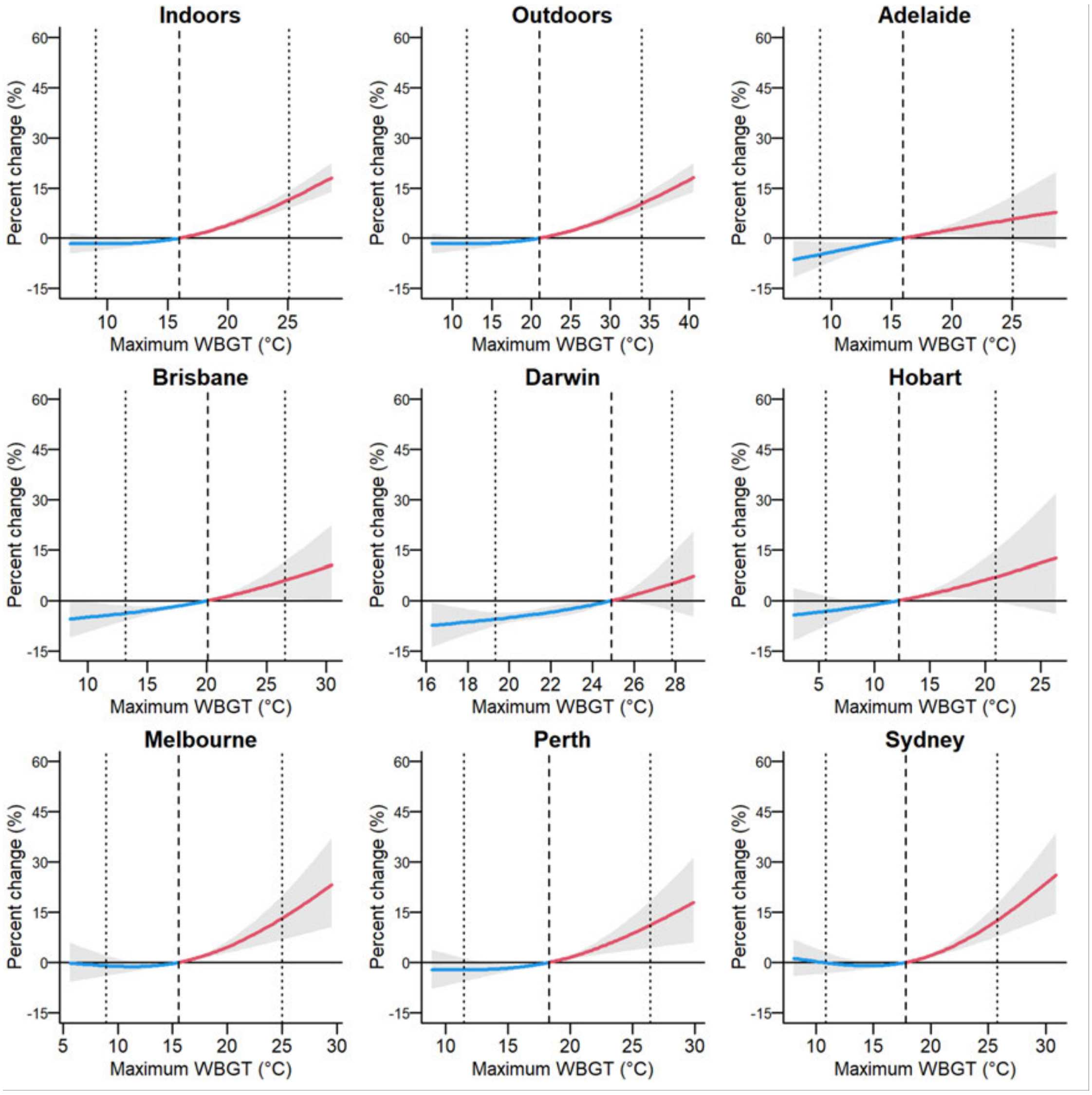

Figure 4.2: Overall cumulative exposure-response curves for each city and national indoor/outdoor status for the number of occupational injuries and illnesses in Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth and Sydney. The curves, shown with 95% confidence intervals, represent percentage change from mean daily maximum wet bulb globe temperature (WBGT). The dashed lines represent the 2.5th percentile, mean and 97.5th percentiles of WBGT.

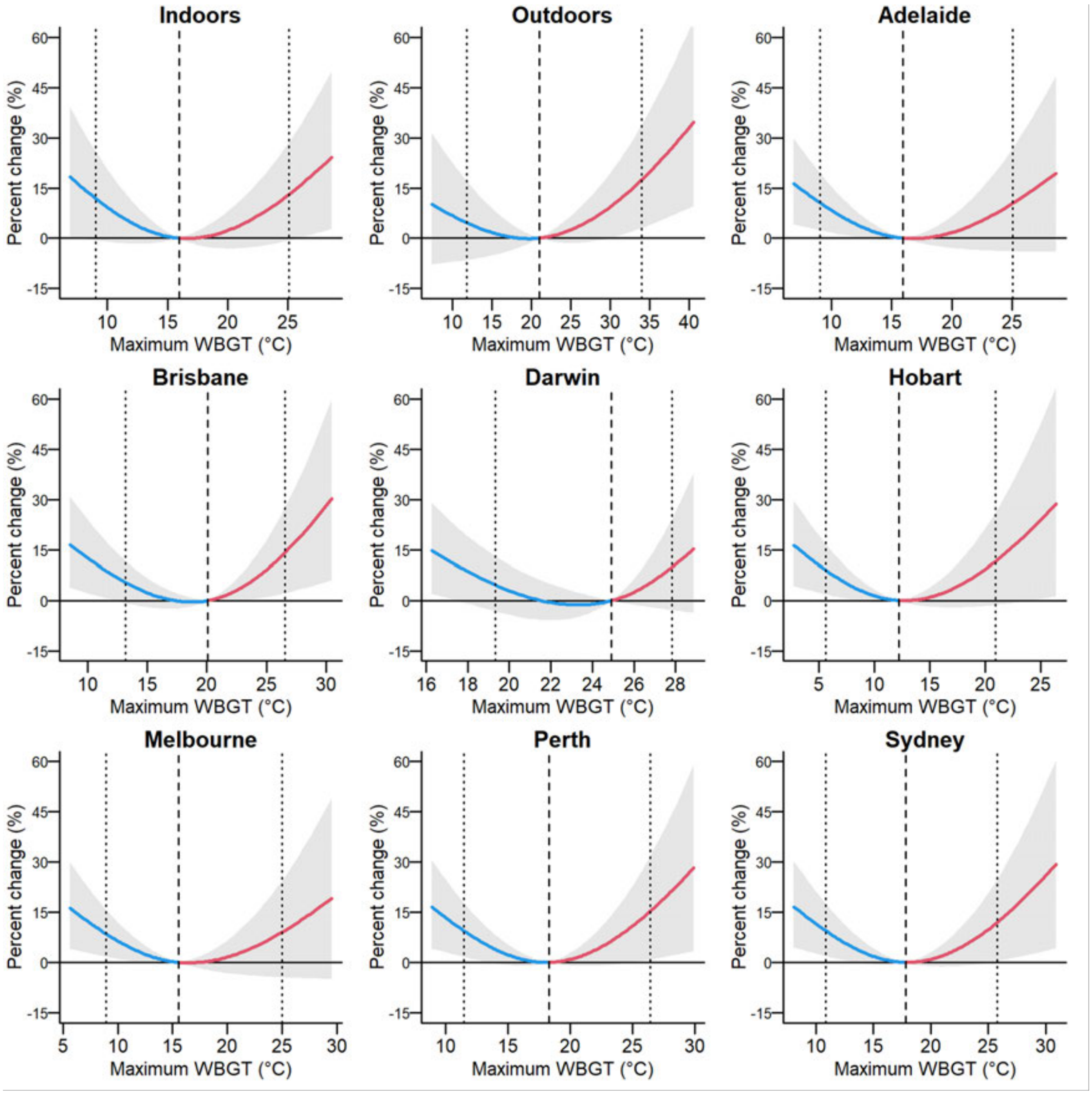

Figure 4.3: Overall cumulative exposure-response curves for occupational injury- and illness-associated costs in indoor workers, outdoor workers and workers in Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth and Sydney. The curves, shown with 95% confidence intervals, represent percentage change from mean daily maximum wet bulb globe temperature (WBGT). The dashed lines represent the 2.5th percentile, mean and 97.5th percentiles of WBGT.

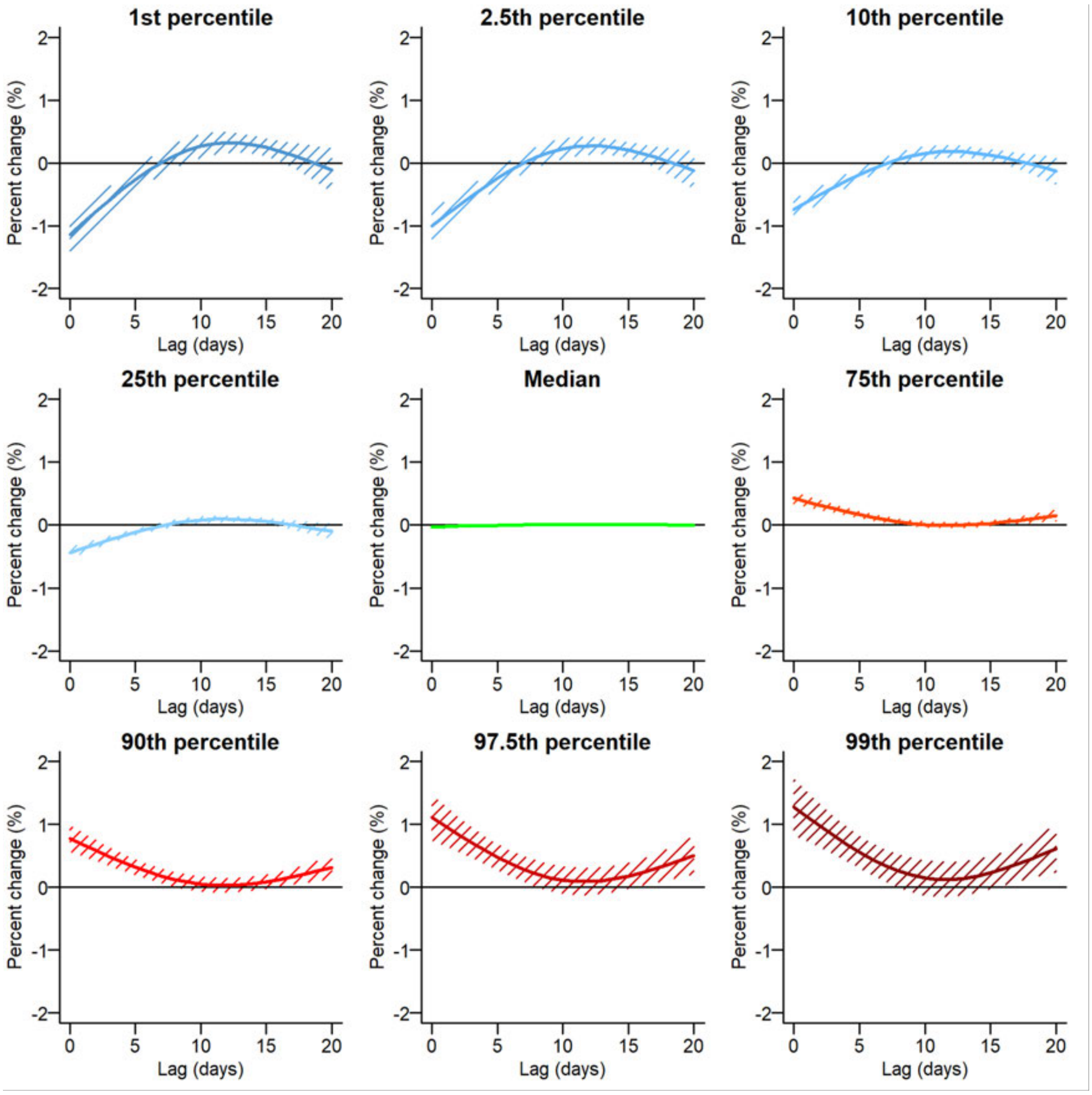

Figure 4.4: Percentage change in daily national heat- and cold-attributable occupational injuries and illnesses with 95% confidence intervals. The lag period extends to 20 days. The overall cumulative lag-response relationships are plotted at exposure percentiles of (from left to right, then top to bottom) the 1st, 2.5th, 10th, 25th, 50th, 75th, 90th, 97.5th and 99th percentiles of daily maximum WBGT.

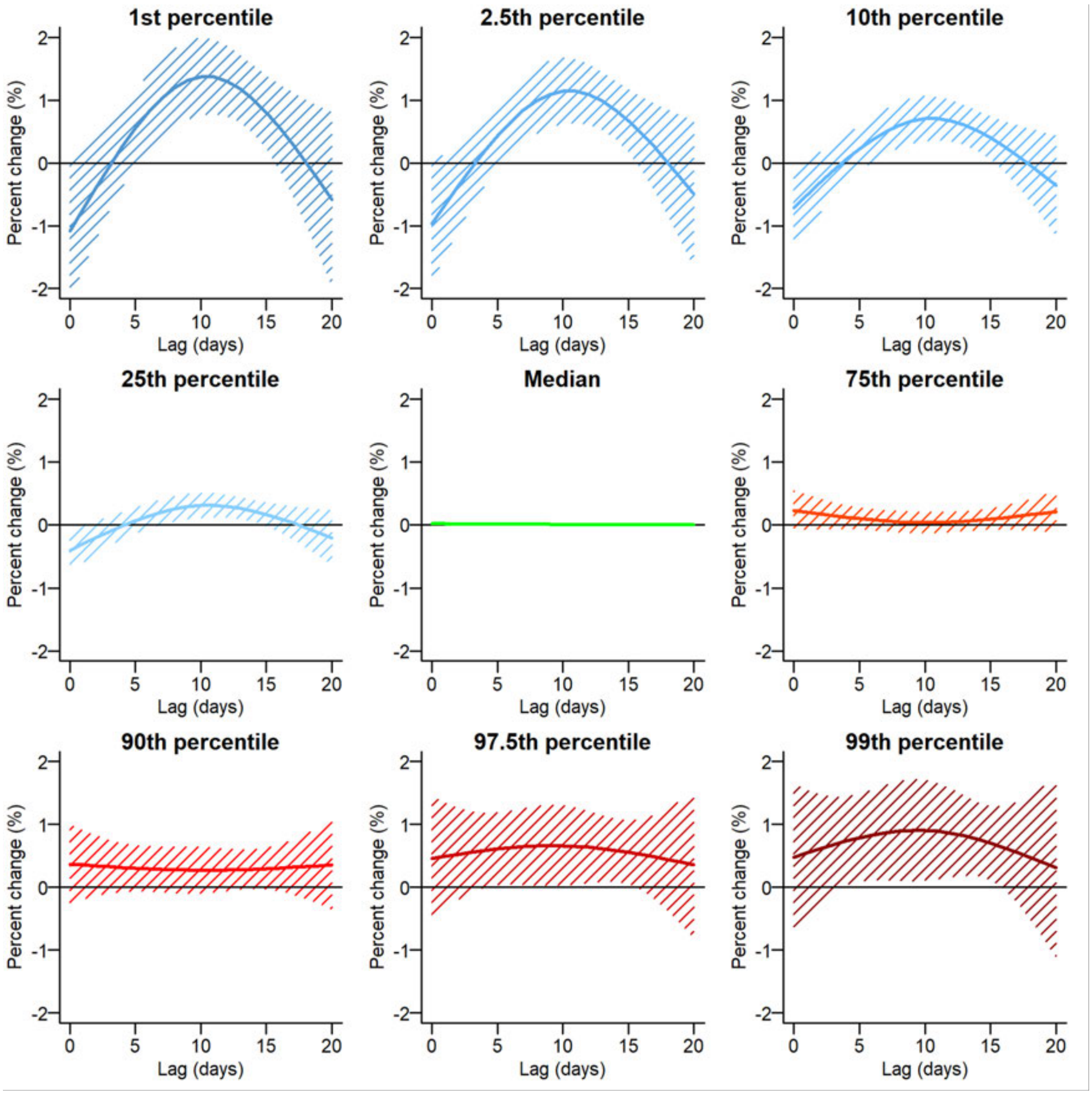

Figure 4.5: Percentage change in daily national heat- and cold-attributable occupational injury- and illness-associated costs with 95% confidence intervals. The lag period extends to 20 days. The overall cumulative lag-response relationships are plotted at exposure percentiles of (from left to right, then top to bottom) the 1st, 2.5th, 10th, 25th, 50th, 75th, 90th, 97.5th and 99th percentiles of daily maximum WBGT.

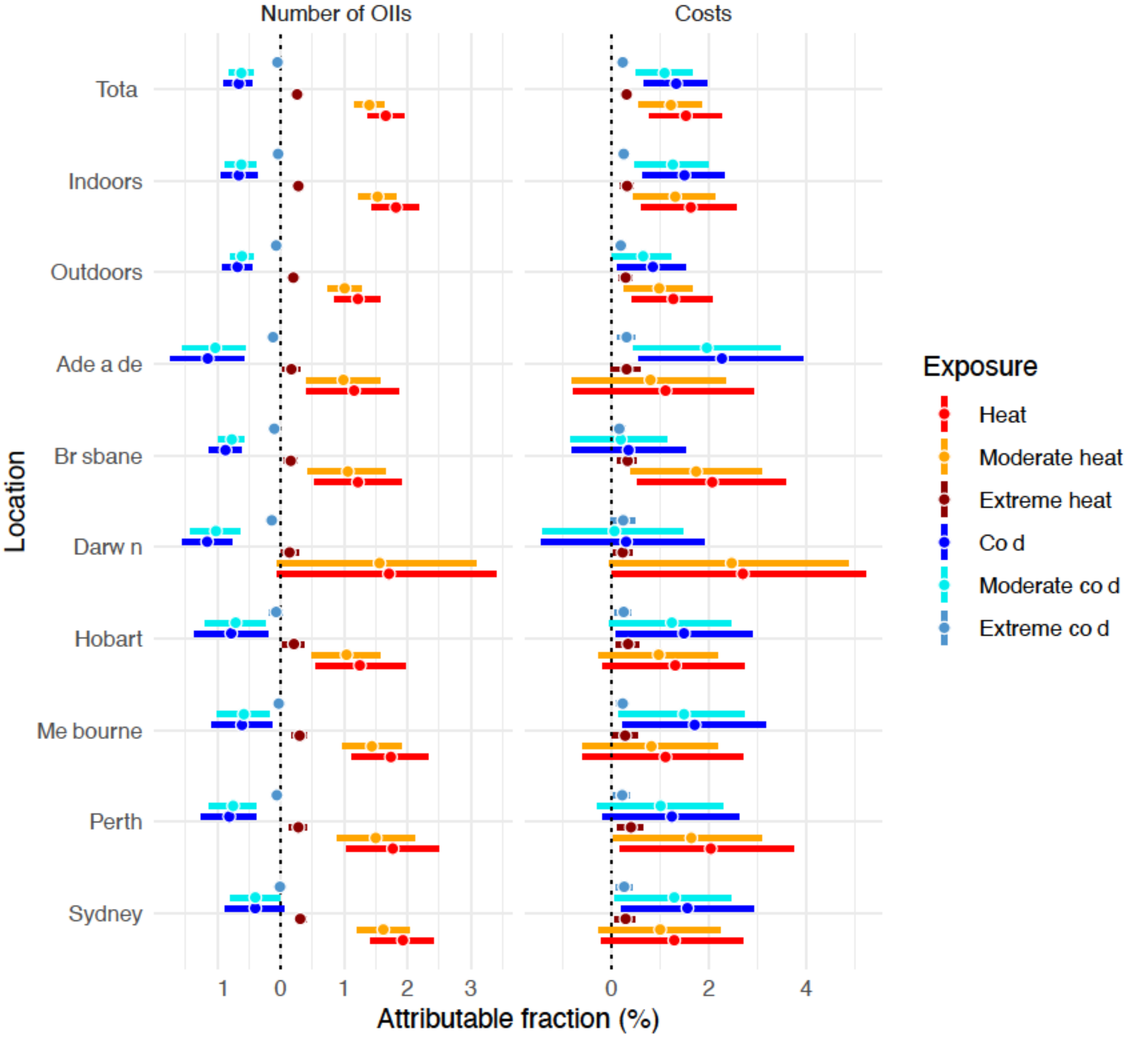

Figure 4.6: Attributable fractions for heat- and cold-attributable occupational injuries and illnesses (OIIs) and associated costs. The proportion of the number of OIIs and associated costs attributable to heat and cold, with 95% empirical confidence intervals. Negative attributable fractions represent preventable fractions.

by Brisbane (2.07, 95% eCI: 0.52-3.57%) and Perth (2.04%, 95% eCI 0.17-3.74%). Cold-AFs were larger in Adelaide (2.27%, 95% eCI: 0.55-3.94%) and smaller in Brisbane (0.35%, 95% eCI: -0.80-1.51%) and Darwin (0.30, 95% eCI: -1.44-1.90%). Extreme heat- and cold-AFs were significant in all cities, ranging from 0.23-0.40% and 0.16-0.31%, respectively.

Similar conclusions were derived with different model choices (Appendix Tables C.6 and C.7). Models with air temperature instead of apparent temperature, with and without adjustment for humidity, had lower heat-AFs for both OIIs and costs, with heat-AFs for costs generally being significant only at extreme levels.

4.5.4 Attributable numbers

There were 38,540 (95% eCI: 32,048-44,948) heat-attributable and 15,409 (95% eCI: 10,438-20,636) cold-preventable OIIs (Table 4.4). This is equivalent to 5.2 (95% eCI: 4.3-6.0) and 2.1 (95% eCI: 1.4-2.8) OIIs per 1,000 workers, respectively, and 2965 and 1185 OIIs per year, respectively. The associated heat- and old-attributable costs were AU$651 (95% eCI: 333-954) million and AU$574 (95% eCI: 284-850) million, or AU$87.5 (95% eCI: 44.8-128.3) and AU$77.1 (95% eCI: 38.2-114.3) per worker, respectively. These represent AU$50 million and AU$44 million annually, respectively, or relative to Australia's GDP of AU$1.95 trillion in June 2019 (163), 0.0026% and 0.0023% of annual GDP, respectively. Although many of the OIIs and costs occurred among indoor workers and in Sydney, outdoor workers had more OIIs and costs per worker. Heat-attributable OIIs per worker were highest in Sydney, Perth and Hobart, heat-attributable costs were highest in Brisbane and Darwin (though weakly significant in Darwin), and cold-attributable costs were highest in Adelaide, Sydney, and Hobart.

Table 4.4: Heat- and cold-attributable occupational injuries and illnesses and associated costs

Location	Exposure	Number of OIIs	OIIs per 1000 workers	Total costs (000s)	Cost per worker
Total	Heat	38,540 (32,048 to 44,948)	5.2 (4.3 to 6.0)	655,143 (330,168 to 972,603)	88.1 (44.4 to 130.8)
	Cold	-15,409 (-20,636 to -10,438)	-2.1 (-2.8 to -1.4)	567,784 (283,148 to 846,096)	76.3 (38.1 to 113.8)
Indoors	Heat	31,197 (24,949 to 37,243)	4.8 (3.8 to 5.7)	506,539 (191,307 to 801,863)	77.4 (29.2 to 122.5)
	Cold	-11,308 (-16,239 to -6,384)	-1.7 (-2.5 to -1.0)	468,727 (195,987 to 722,918)	71.6 (29.9 to 110.4)
Outdoors	Heat	7,343 (5,193 to 9,385)	8.2 (5.8 to 10.5)	148,605 (49,678 to 241,322)	166.9 (55.8 to 271.0)
	Cold	-4,101 (-5,476 to -2,783)	-4.6 (-6.1 to -3.1)	99,057 (15,218 to 177,922)	111.2 (17.1 to 199.8)
Adelaide	Heat	2,833 (1,018 to 4,551)	4.6 (1.6 to 7.3)	37,759 (-27,046 to 99,016)	60.9 (-43.6 to 159.6)
	Cold	-2,800 (-4,211 to -1,430)	-4.5 (-6.8 to -2.3)	77,308 (18,683 to 134,128)	124.6 (30.1 to 216.2)
Brisbane	Heat	4,878 (2,111 to 7,628)	4.4 (1.9 to 6.8)	188,253 (47,260 to 324,704)	168.3 (42.3 to 290.4)
	Cold	-3,449 (-4,476 to -2,514)	-3.1 (-4.0 to -2.2)	31,854 (-72,558 to 137,725)	28.5 (-64.9 to 123.2)
Darwin	Heat	275 (-8 to 546)	3.6 (-0.1 to 7.2)	11,037 (49 to 21,395)	146.0 (0.6 to 283.1)
	Cold	-186 (-248 to -124)	-2.5 (-3.3 to -1.6)	1,223 (-5,886 to 7,775)	16.2 (-77.9 to 102.9)
Hobart	Heat	566 (252 to 884)	5.4 (2.4 to 8.4)	9,299 (-1,262 to 19,439)	88.6 (-12.0 to 185.3)
	Cold	-354 (-615 to -97)	-3.4 (-5.9 to -0.9)	10,585 (640 to 20,579)	100.9 (6.1 to 196.2)
Melbourne	Heat	6,876 (4,461 to 9,143)	3.2 (2.0 to 4.2)	79,420 (-41,925 to 194,329)	36.4 (-19.2 to 89.2)
	Cold	-2,390 (-4,246 to -526)	-1.1 (-1.9 to -0.2)	123,040 (17,583 to 226,756)	56.5 (8.1 to 104.0)
Perth	Heat	5,660 (3,346 to 7,970)	5.9 (3.5 to 8.2)	124,272 (10,177 to 227,861)	128.5 (10.5 to 235.6)
	Cold	-2,569 (-4,002 to -1,223)	-2.7 (-4.1 to -1.3)	75,268 (-11,628 to 159,697)	77.8 (-12.0 to 165.1)
Sydney	Heat	17,452 (12,924 to 21,819)	7.4 (5.4 to 9.2)	205,103 (-31,286 to 428,368)	86.5 (-13.2 to 180.6)
	Cold	-3,661 (-7,925 to 459)	-1.5 (-3.3 to 0.2)	248,506 (32,961 to 465,343)	104.8 (13.9 to 196.2)

The number of occupational injuries and illnesses (OIIs) and associated costs attributable to heat and cold stress, with 95% empirical confidence intervals. OIIs and costs per worker were calculated using the mean number of workers across the study period as listed in Table 4.1.

4.5.5 Associated factors

Male workers had a slightly larger heat-AF and cold-PF for OIIs compared to females (Table 4.5). For costs, males had a higher cold-AF (1.76: 95% eCI: 0.84-2.65%) but females had a slightly higher heat-AF (1.32, 95% eCI: 0.43-2.16%) (Table 4.6). Older workers (50-75 years) had fewer heat-attributable but more cold-attributable OIIs compared to younger (15-29 years) and middle-aged (30-49 years) workers. For costs, middle-aged workers had larger heat-AFs and older workers had higher cold-AFs.

Outdoor industries had a slightly higher heat-AF and no significant cold-PF for OIIs compared to indoor industries. For costs, outdoor industries had a higher but insignificant cold-AF (3.08%, 95% eCI: -0.34-5.90%) and an unremarkable heat-AF (-0.14%, 95% eCI: -1.89-1.32%). Occupations with higher heat-AFs for OIIs included machinery operators and drivers (MODs), technicians and trades workers, and managers. Significant heat-AFs for costs were only identified for MODs at extreme heat. Cold-AFs for costs were high for MODs (4.69%, 95% eCI: 2.53-6.59%) and sales workers (4.89%, 95% eCI: 2.56-7.06%), and strongly negative (preventative) for managers (-7.73%, 95% eCI: -19.79 to -0.52%).

The number of occupational illnesses had larger heat-AFs compared to injuries. For costs, illnesses had larger heat- and cold-AFs compared to injuries generally. However, the only significant heat-AFs were for musculoskeletal and connective tissue diseases and injuries other than fractures, musculoskeletal, wounds, lacerations, amputations and internal organ damage, and extreme heat-AFs for illnesses (0.35%, 95% eCI: 0.02-0.60%).

Table 4.5: Attributable fractions by worker and OII characteristics for number of OIIs

	Number of OIIs	
	Heat	Cold
All workers	1.77 (1.43 to 2.12)	-0.62 (-0.91 to -0.35)
Male	2.00 (1.48 to 2.52)	-0.81 (-1.11 to -0.53)
Female	1.34 (1.07 to 1.61)	-0.32 (-1.13 to 0.42)
Aged 15 to 29 years	2.24 (1.85 to 2.65)	-1.69 (-2.48 to -0.93)
Aged 30 to 49 years	1.91 (1.34 to 2.44)	-1.10 (-1.55 to -0.66)
Aged 50 to 75 years	1.14 (0.72 to 1.54)	1.03 (0.52 to 1.54)
Industrial sector		
Indoor industries	1.72 (1.41 to 2.02)	-0.65 (-1.06 to -0.26)
Outdoor industries	2.11 (1.25 to 2.91)	-0.28 (-0.96 to 0.35)
Occupation		
Office & administrativion	1.48 (0.54 to 2.39)	-0.56 (-1.64 to 0.45)
Community & personal service	1.05 (0.43 to 1.69)	-1.03 (-1.63 to -0.47)
Laborers	1.75 (1.26 to 2.25)	-0.82 (-1.28 to -0.40)
Machinery operators & drivers	2.73 (2.01 to 3.41)	-0.98 (-1.56 to -0.40)
Managers	1.97 (0.14 to 3.52)	0.22 (-1.51 to 1.79)
Professionals	0.65 (-0.35 to 1.58)	0.46 (-0.23 to 1.11)
Sales workers	1.47 (0.36 to 2.49)	0.84 (0.05 to 1.61)
Technicians & trade workers	2.27 (1.67 to 2.82)	-1.29 (-1.96 to -0.64)
OII nature		
All injuries	1.64 (1.27 to 2.00)	-0.70 (-1.23 to -0.20)
Fractures	1.31 (0.68 to 1.94)	1.96 (1.19 to 2.71)
Traumatic joint, ligament, muscle & tendon injuries	1.01 (0.48 to 1.53)	-0.73 (-1.34 to -0.16)
Wounds, lacerations, amputations & internal organ damage	2.16 (1.82 to 2.50)	-1.11 (-1.57 to -0.66)
All other injuries	3.68 (2.50 to 4.77)	-1.90 (-3.80 to -0.22)
All illnesses (diseases/conditions)	2.19 (1.74 to 2.64)	-0.34 (-1.15 to 0.48)
Mental disorders	2.76 (1.26 to 4.11)	-0.31 (-1.50 to 0.78)
Musculoskeletal & connective tissue diseases	2.14 (0.87 to 3.37)	-1.11 (-2.72 to 0.34)
All other illnesses	0.96 (-0.90 to 2.53)	0.82 (-1.64 to 2.92)

Attributable fractions (%) of the number of occupational injuries and illnesses (OIIs) attributable to heat and cold stress from daily indoor wet bulb globe temperature stratified by demographic, occupational and OII characteristics, with 95% empirical confidence intervals.

Table 4.6: Attributable fractions by worker and OII characteristics for costs

	Total costs		
	Heat	Extreme heat	Cold
All workers	1.08 (0.52 to 1.65)	0.23 (0.14 to 0.32)	1.41 (0.67 to 2.08)
Male	0.97 (0.21 to 1.67)	0.23 (0.12 to 0.33)	1.76 (0.84 to 2.65)
Female	1.32 (0.43 to 2.16)	0.26 (0.11 to 0.38)	0.95 (-0.29 to 2.18)
Aged 15 to 29 years	0.32 (-3.55 to 3.25)	0.11 (-0.70 to 0.56)	2.41 (-0.47 to 4.68)
Aged 30 to 49 years	1.96 (1.13 to 2.74)	0.34 (0.22 to 0.45)	0.55 (-0.50 to 1.57)
Aged 50 to 75 years	0.10 (-0.86 to 1.02)	0.12 (-0.04 to 0.25)	2.51 (1.41 to 3.57)
Industrial sector			
Indoor industries	1.27 (0.66 to 1.89)	0.26 (0.16 to 0.34)	1.18 (0.41 to 1.93)
Outdoor industries	-0.14 (-1.89 to 1.32)	0.08 (-0.26 to 0.34)	3.08 (-0.34 to 5.90)
Occupation			
Office & administrativion	1.92 (-0.17 to 3.72)	0.33 (-0.10 to 0.64)	-0.10 (-7.80 to 5.16)
Community & personal service	-0.52 (-2.15 to 0.93)	-0.09 (-0.34 to 0.12)	-0.14 (-3.97 to 3.03)
Laborers	0.64 (-0.54 to 1.70)	0.15 (-0.02 to 0.30)	1.22 (-0.22 to 2.50)
Machinery operators & drivers	2.10 (-1.13 to 4.58)	0.49 (-0.11 to 0.85)	4.69 (2.53 to 6.59)
Managers	-1.14 (-13.03 to 5.63)	-0.48 (-3.60 to 0.53)	-7.73 (-19.79 to -0.52)
Professionals	0.59 (-2.21 to 2.91)	0.26 (-0.15 to 0.56)	4.22 (-1.74 to 8.48)
Sales workers	-1.32 (-5.45 to 1.91)	-0.03 (-0.71 to 0.42)	4.89 (2.56 to 7.06)
Technicians & trade workers	0.60 (-1.09 to 2.11)	0.08 (-0.29 to 0.37)	0.36 (-3.06 to 3.25)
OII nature			
All injuries	0.69 (-1.94 to 2.94)	0.16 (-0.22 to 0.43)	1.22 (-0.79 to 3.04)
Fractures	-1.79 (-3.78 to -0.06)	-0.19 (-0.65 to 0.14)	3.35 (-2.82 to 7.74)
Traumatic joint, ligament, muscle & tendon injuries	1.01 (-1.48 to 3.04)	0.20 (-0.15 to 0.46)	1.08 (-1.28 to 3.15)
Wounds, lacerations, amputations & internal organ damage	1.13 (-1.11 to 3.07)	0.09 (-0.17 to 0.31)	-3.00 (-9.52 to 1.79)
All other injuries	1.25 (-8.05 to 7.06)	0.14 (-2.10 to 0.90)	-0.58 (-13.05 to 6.69)
All illnesses (diseases/conditions)	1.61 (-1.08 to 3.96)	0.35 (0.02 to 0.60)	1.97 (-1.65 to 4.99)
Mental disorders	2.24 (-1.66 to 5.42)	0.51 (0.05 to 0.83)	2.79 (-3.88 to 7.57)
Musculoskeletal & connective tissue diseases	1.68 (0.18 to 3.00)	0.30 (0.03 to 0.51)	0.25 (-1.95 to 2.26)
All other illnesses	0.44 (-6.74 to 5.24)	0.15 (-0.97 to 0.71)	1.70 (-6.57 to 7.14)

Attributable fractions (%) of occupational injury- and illness- (OIIs) associated costs attributable to heat and cold stress from daily indoor wet bulb globe temperature stratified by demographic, occupational and OII characteristics, with 95% empirical confidence intervals.

4.6 Discussion

This study is the first, worldwide, to report a national cost profile of both heat- and cold-attributable OIIs by modelling costs directly. It is also the first to estimate OIIs and their costs whilst incorporating both indoor and outdoor temperature and humidity (through WBGT) based on occupation to represent heat and cold effects more accurately. Across the seven Australian cities, covering approximately 66% of the Australian workforce during the 13-year study period (55), this study observed 38,540 OIIs and AU$655 million from heat, and a AU$568 million increase in costs during cold temperatures despite preventing 15,409 OIIs. This highlights the substantial health and financial burden from OIIs under anomalous temperatures. The financial burden is considerably greater when also considering labor productivity loss beyond compensation payouts (47); an Australian study estimated annual costs of US$655 per person to employers from subjective productivity loss (32).

The results align with a previous study in Guangzhou, China observing the RR for occupational injuries increases with WBGT and increased claim payouts beyond WBGT thresholds (89). Similarly, previous Australian studies using air temperature instead of WBGT observed increased RRs for OIIs during heat in Adelaide and Melbourne, and decreased RRs during cold in Brisbane, although this study found a protective instead of an adverse cold effect in Adelaide and a significant relationship with heat in both Brisbane and Perth (29,39,40). Two studies in Spain and Italy observed increased OIIs during both high and low air temperatures (31,126). These countries have colder climates than Australia, which may predispose workers to OIIs during their cold seasons.

Exposure-response relationships differed between costs and OIIs, despite using similar models, particularly during cold temperatures. Even if cold decreases the risk of OIIs, OIIs more likely to occur during cold may be more severe or longer-lasting, such as chronic pain (164). This would explain the increased cost per OII observed during cold temperatures. Such OIIs may incur increased health-care, compensation and associated legal and administrative fees. These factors are all likely involved given the significant exposure-response relationships with compensation, goods and services, and non-compensation costs. Public health and workplace interventions aimed at both preventing OIIs and managing OIIs that occur are recommended to reduce associated costs. Preventative measures should be more orientated towards minimizing heat stress. These include air conditioning, decreasing work during warmer hours, adequate access to hydration, hydration monitoring, appropriate clothing and minimizing workplace-generated heat (47,165). Interventions for managing OIIs should be aimed at both heat and cold stress. Examples include facilitating access to first aid and adaptation of work to suit unwell employees, such as reducing physical workloads and enabling work from home, reducing compensation costs from potential loss of work. Workplace and public health education on these topics can further address both groups of interventions. Because AFs for both OIIs and costs were significant across different ages, sex, industries and occupations, education should be aimed at the general working population.

Heat-AFs were higher for workers in Sydney, Melbourne and Perth for OII numbers, and Darwin, Brisbane and Perth for OII-related costs. This may be because Darwin, Brisbane and Perth had higher maximum air temperatures and WBGTs (Table 1), and a smaller proportion of Sydney and Melbourne households have air conditioning than in other capital cities (166) (assuming this correlates with smaller proportions in workplaces). Brisbane and Darwin have warmer and more tropical climates than the other cities (167), which may explain their smaller cold-AFs for costs. Conversely, Adelaide had higher cold-AFs for costs. Adelaide has a dry climate with cold winters which may predispose to more severe OIIs during cold, although Adelaide also has a high household proportion of heating (166,167). This study observed slighter larger heat-AFs for indoor compared to outdoor workers for the main analysis, aligning with the findings from a previous meta-analysis (28). Thermoregulatory workplace regulations may benefit both indoor and outdoor workers.

Males had higher heat-AFs for OIIs compared to females, but females had higher heat-AFs for costs heat-attributable OIIs among females, although less in proportion, incurred more costs. The converse was true for cold-AFs. This likely reflects their different occupational distributions, with males more likely to undertake physically demanding jobs associated with more heat-attributable OIIs (127), but the OIIs have shorter recovery periods and hence less costs. The occupations with the highest heat-AFs for OIIs in this study, machinery operators and drivers, technicians and trade workers, and managers, are more frequently undertaken by males (168). Cold-attributable OIIs, however, may be longer-lasting. Females are more likely to suffer from chronic illnesses (169), which are likely associated with payments over longer durations. Supporting this, heat- and cold-AFs were higher for the number of illnesses than injuries. Although there was only sufficient power to determine that illnesses generally were associated with increased costs in extreme and not moderate heat, they are associated with higher financial expenditure than injuries (44). Musculoskeletal and connective tissue diseases, which had a significant heat-AF for costs, are also more common in Australian females (170). These different occupational and illness patterns may explain the AF differences observed in workers by age and indoor/outdoor (the construction industry had more claims than all other outdoor industries combined). Sales workers and managers had considerably higher and lower cold-AFs with costs, respectively. Sales work involves high person-to-person contact, which may predispose workers to common infectious winter illnesses such as influenza. Managers likely have easier access to heating and additional clothing to prevent more severe diseases during cold, although they did not have significant cold-AFs for OIIs.

The main study limitation is that the claims data only include reported OIIs, hence the results only represent minimum OII and cost burdens that are likely underestimated. OIIs of mild severity are less likely to be reported (171), potentially biasing the data to overrepresent more severe OIIs. Claims data for workers not covered by state compensation schemes was not collected, in particular self-employed workers, and employees with separate private schemes that partially or completely cover payments instead (63). Claims can have future payments due beyond the study period. These payments would not be captured in the data, underestimating costs, especially for claims submitted later in the study period. To address this, a supplementary analysis was included with claims submitted before July 2014, only including payments occurring up to five financial years after the year of submission; this had a similar national AF to the main cost analysis (Appendix Table C.7). Furthermore, most payments occurred in the same or subsequent financial year as the claim lodgment. There were fewer claims in Hobart and Darwin due to their smaller populations, resulting in less precise estimates for these cities. This was partially mitigated by refitting models with multivariate meta-analysis derived BLUPs. Selection bias may exist because some claims were removed due to missing data, with higher proportions of claims removed to represent Darwin, Melbourne and Hobart. No OIIs before July 2006 were included from Hobart (Methods), underestimating the burden for the 2005 financial year. Similar to most ecological studies, non-meteorological temperature variation such as air conditioning and workplace-generated heat was not analyzed. However, stratification of indoor and outdoor workers would partially mitigate potential confounding from air conditioning, as indoor workers likely have more access to air conditioning. Minor biases existing in the climate dataset for low and high wind speed values, an issue shared with other global reanalysis datasets (172). This only affects outdoor apparent temperature in this study, and the impact is likely very low, especially compared to the bias from using the commonly used simplified WBGT (41,173,174). Finally, the results may be less applicable to countries with different climates, with studies in colder countries observing cold-attributable instead of cold-preventable OIIs (31,126). The relationship between temperatures and occupational costs should be further explored in areas with different (non-temperate) climates, particularly considering the limited research on the topic.

4.7 Conclusion

Environmental heat and cold temperatures in workers, both moderate and extreme, poses a substantial morbidity and cost burden in Australia. Preventing and managing OIIs attributable to anomalous temperatures can improve both health and financial outcomes. The relationship between suboptimal temperatures and costs does not necessarily follow that of OII occurrence, which is likely more influenced by heat compared to cold relative to their associated costs. Although heat adaptation is likely more important for preventing OIIs than cold adaptation, addressing both is important to reduce OII-associated costs.

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4.10 Data availability

Restrictions apply to the availability of the SWA data which were used under license for the current study. The data used can be requested from SWA at https://www.safeworkaustralia.gov.au/data-and-research/request-data and may be made available with the permission of SWA. SWA has made some of this data publicly available in the Australian workers' compensation statistics report, which provides detailed statistics about workers' compensation claims lodged in Australia from July 2000 to June 2020. This report can be accessed at https://www.safeworkaustralia.gov.au/doc/australian-workers-compensation-s tatistics-2019-20.

The climate data were sourced from the Australian Bureau of Meteorology Atmospheric high-resolution Regional Reanalysis: http://www.bom.gov.au/research/projects/reanalysis/. The license under which the data were used is available online: http://www.bom.gov.au/metadata/catalogue/view/ANZCW0503900566.shtml?template=full.

The workers' population data were derived from the Australian Bureau of Statistics (ABS) and has been included as supplementary material. The ABS labor force dataset (LM1) is publicly available online: https://www.abs.gov.au/statistics/labour/employment-and-unemployment/labour-force-australia-detailed/latest-release. The ABS Census TableBuilder Basic data used to derive indoor/outdoor population estimates are available online: https://tablebuilder.abs.gov.au/webapi/jsf/login.xhtml, and its conditions of use is listed online: https://www.abs.gov.au/statistics/microdata-tablebuilder/responsible-use-abs-microdata/conditions-use.

The public and school holidays data have been deposited in figshare (https://doi.org/10.25909/6311e7a0dcb3f (154) and https://doi.org/10.25909/6311e7b3bc760 (152), respectively).

5

Current and projected heatwave-attributable occupational injuries, illnesses, and associated economic burden in Australia: a national time-series analysis

5.1 Statement of Authorship

This subchapter includes signed forms detailing the contribution of all authors involved in this study pertaining to Chapter 5 and the Chapter 5 Supplementary Material.

Statement of Authorship

Title of Paper	Current and projected heatwave-attributable occupational injuries, illnesses, and associated economic burden in Australia: a national time-series analysis
Publication Status	☐ Published ☐ Accepted for Publication ☐ Submitted for Publication ☒ Unpublished and Unsubmitted work written in manuscript style
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Principal Author

Name of Principal Author (Candidate)	Matthew Anthony Borg		
Contribution to the Paper	Conceptualisation; Methodology design; Programming; Formal analysis; Visualisation; Writing drafting manuscript; Data curation; Reviewing and editing the manuscript;		
Overall percentage (%)	85%		
Certification	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	4/11/2022

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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5.2 Abstract

Background: The costs of climate change are substantial. These include costs from occupational illnesses and injuries (OIIs), which have been associated with increases during heatwaves. This study estimated retrospective and projected future heatwave-attributable OIIs and their costs in Australia.

Methods: Climate and workers' compensation claims data were extracted from seven Australian capital cities representing OIIs from July 2005 to June 2018. Heatwaves were defined using the Excess Heat Factor. OIIs and associated costs were estimated separately per city with time-series distributed lag non-linear models; estimates were pooled with multivariate meta-analysis. Results were projected to 2030 (2016-2045) and 2050 (2036-2065).

Findings: Of all OIIs, 0.13% (95%eCI: 0.11-0.16%) were attributable to heatwaves, equivalent to 120 (95%eCI:70-181) OIIs annually. These were associated with 0.25% of heatwave-attributable costs (95%eCI: 0.18-0.34%), equal to AU$4.3 (95%eCI: 1.4-7.4) million annually. Our estimates of heatwave-attributable OIIs by 2050, under Representative Concentration Pathway [RCP]4.5 and RCP8.5, were 0.17% (95%eCI: 0.10-0.27%) and 0.23% (95%eCI: 0.13-0.37%), respectively. Projected costs estimates for 2030 under RCP4.5 and RCP8.5 were 0.13% (95%eCI: -0.27-0.46%) and 0.04% (95%eCI: -0.66-0.60), respectively, with significant associations observed with extreme heatwaves in 2030 (0.04%, 95%eCI: 0.02-0.06%) and 0.04% (95%eCI: 0.01-0.07), respectively. Attributable fractions were approximately similar to baseline when assuming theoretical climate adaptation.

Interpretation: Heatwaves represent notable and preventable portions of preventable OIIs and economic burden. OIIs are likely to increase in the future, but climate adaptation can minimize this increase. Workplace and public health policies aimed at heat adaptation can reduce associated morbidity and costs.

Funding: Australian Research Council.

5.3 Introduction

Future global warming will slow economic growth and pressure human socioeconomic systems (175). Workers are particularly susceptible to increasing temperatures due to additional metabolic heat production from physical work, radiant workplace heat exposure, personal protective equipment, and potentially reduced access to heat safety interventions such as air conditioning (13,28,176). Heatwaves, when high temperatures occur over consecutive days, have been associated with increased occupational illnesses and injuries (OIIs) globally, including heat-related illnesses and general injuries such as falls (13,28,176). With global warming, heatwaves are expected to increase in frequency, duration and intensity (176).

Heat-attributable illnesses and injuries induce considerable healthcare financial burden (42,177). However, the economic impact of heatwave-attributable OIIs is unknown. Two studies estimated increasing work-related injury costs with higher temperatures in Spain (31) and Guangzhou, China (89), and one study observed that costs decreased from heat-related illnesses following a heat stress awareness program (46). More studies have evaluated the economic impact of heat-induced labor productivity loss (47,178), including during heatwaves (179,180). Incorporating costs from OIIs can result in more comprehensive occupational economic burden estimates.

To the authors' knowledge, currently only one study has currently estimated the projected impact of global warming on OIIs, limited to Adelaide (29). Understanding this risk can aid the development of heat-adaptation measures to reduce morbidity, mortality and associated costs. In Australia, heatwaves are responsible for substantial morbidity (181) and are the most common cause of climate-related mortality (13). To address these concerns and knowledge gaps in the literature, this study created a national retrospective and future cost profile of heatwave-attributable OIIs. This study also assessed the potential benefit of future heat adaptation.

5.4 Methods

5.4.1 Data

Workers' compensation claims data

Workers' compensation claims data submitted from 1st July 2005 to 30th June 2019 representing seven Australian capital cities: Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth, and Sydney were collected from Safe Work Australia (SWA). SWA compiles national workers' compensation data from workers' compensation authorities in each Australian state and territory. Under Australian law, employers must have insurance to cover their workers if they become sick/injured because of work (60). Claims for OIIs are regularly submitted in the Australian financial year (July to June) following that of the OII, and payouts per claim can continue across multiple years. In this study, data were limited to OIIs occurring within a Greater Capital City Statistical Area (GCCSA) of the seven cities (59)) during the warm season (October to November) from 1 July 2005 to 30 June 2018 claims (not June 2019, because claims were regularly submitted one financial year after OII occurrence). We used on-duplicate OII claims pertaining to workers aged 15 to 75 years, and those submitted on the day or after the day of OII occurrence as in previous studies (29,39,62,72,140). OIIs occurring from July 2005 to June 2006 in Hobart were excluded from analysis, because claims submitted in Tasmania prior to July 2007 had missing location status. OII counts in Hobart from July 2006 to June 2007 were similar to those of other years and thus retained for analysis. Compensation policies and payout rates change over time and vary between cities but are generally similar. These differences are comprehensively described in online SWA annual publications (65).

Injuries and illnesses (diseases and conditions) were defined by Type of Occurrence Classification System codes A-G and H-R, respectively (141), and assessed collectively. For the 0.02% of claims where there was an overall negative claim cost (a financial gain, which can result from reimbursement of already-paid compensations) payments were adjusted to $0 so that they did not impact cost estimates. Payments were adjusted for inflation and standardized to the end of the 2018 financial year (April to June 2019) (142). The consumer price index (CPI) categories for "compensation/administrative costs", "health services", and "other goods and services" were "insurance and financial services", "health services" and "general", respectively (142). Payouts comprise compensation (paid to workers or their families), goods and services (mostly health services), and non-compensation (not paid to workers or their families) payments (64). Costs per OII (total costs divided by the number of OIIs) on days where at least one OII were reported were analyzed. To remove claims that may have had artificially decreased payouts due to occurring later in the study period, a supplementary analysis was performed only using claims submitted no later than June 2014 with payments restricted to up to five financial years after the financial year of claim submission. Ethics approval to access and analyze SWA data were obtained from the University of Adelaide Human Research Ethics Committee (H-2019-141 and H-2016-085).

Meteorological data

Retrospective hourly climate data were obtained from the Australian Bureau of Meteorology (BoM) Atmospheric high-resolution Regional Reanalysis to match the study period (76). Results were projected to 2030 (2016-2045) and 2050 (2036-2065) using daily meteorological gridded data from Climate Change in Australia (84) under Representative Concentration Pathway [RCP]4.5 and RCP8.5 using eight general circulation models (GCMs) described online (85). From the retrospective and projected datasets, 3*3 12km and 7*7 5km grids, respectively, were extracted at grid centroids correlating to the center of the seven included cities' for study central business districts.

Heatwaves were defined using the BoM Excess Heat Factor (EHF). EHF defines Australian heatwaves nationally (182,183) and can measure severity across different climate zones (79,184 187), incorporating recent climate acclimatization up to 30 days (79). EHF is calculated using daily mean temperature (DMT) averaged over the current and previous two days ($\mathrm{DMT}_{\mathrm{3days}}$) (188). Using the EHF definition, heatwave days occurred when $\mathrm{DMT}_{\mathrm{3days}}$ exceeded the 95th percentile for DMT (DMT_{95}) across January 1990 to February 2019 at which EHF>0°K (°C^2). EHF assumes long-term adaptation to this 29-year period. Severe heatwaves occurred when EHF was at least equal to the 85th percentile of all positive EHF values. Extreme heatwaves were defined as at least twice this 85th percentile value (185). Sensitivity analyses were performed adding linear variables for relative and specific humidity, using a calculation of EHF using $\mathrm{DMT}_{\mathrm{3days}}$ representing the current and future two days, and EHF using the heat index (148) instead of air temperature. Detailed calculations of EHF, humidity and heat index are in Supplementary Material for Chapter 5: Supplementary Methods.

Workers' population data

Monthly population employed worker counts stratified by city (GCCSA) were derived from the Australian Bureau of Statistics (ABS) labor force detailed survey data (55). As data for Darwin were unavailable, estimates were obtained by multiplying counts counts for Northern Territory (NT) by the proportion of NT workers in Darwin obtained with 3-monthly data that were interpolated to monthly data using cubic splines (55). Projected increases in future workforce sizes relative to 2017 were calculated as the ratio between the projected city populations for 2017-2044 to estimate 2030, and 2036-2065 to estimate 2050 (88). Projections assumed a medium-population growth scenario based on ABS-projected fertility, migration and mortality rates. High, low and unchanged (from baseline) population scenarios were included as sensitivity analyses (88).

5.4.2 Statistical analysis

Daily OIIs and associated costs, on the date of OII occurrence, were modeled against EHF as a continuous metric (90,189) per city using time-series distributed lag non-linear models (DLNMs) with a ten-day lag period (151,190). OIIs and costs were fitted using generalized linear and additive models, respectively, with a quasipoisson and Tweedie distribution, respectively (121). The Tweedie distribution is a reparameterisation of a Poisson-Gamma model to fit within a single distributional framework (107,108). Cost models converged using restricted maximum likelihood (124) and included the Tweedie index parameter with the largest likelihood value from 1.001-1.999 selected by series expansion (120). The model equation is detailed in Supplementary Material for Chapter 5: Supplementary Methods. Modeling decisions regarding exposure-/lag-response relationships and long-term trends were determined using Akaike information criterion (AIC) considering both the OII and cost models.

Individual city exposure-response relationships were pooled using random-effects multivariate meta-analysis to evaluate national (the seven cities combined) relationships and derive best linear unbiased predictors (BLUPs) from each model (104). Residual heterogeneity was assessed using the multivariate-extended Cochran Q test and I^2 statistic (104,156).

Attributable fractions (AF) and numbers (AN), as defined by Gasparrini et al. (155,157), were estimated per BLUP for heatwave days including stratification into low-intensity, severe and extreme heatwaves. Empirical 95% confidence intervals (95%eCI) assuming a multivariate normal distribution were created using 5000 Monte Carlo simulations (88). AFs and ANs were projected to 2030 and 2050 per RCP as GCM-ensemble averages by extrapolating exposure-response relationships using the projected climate dataset (191,192). ANs were adjusted with the projected future workforce sizes per time period. Non-adaptation scenarios assumed an unchanged heatwave threshold (baseline DMT_{95}). Theoretical 100% long-term climate adaptation (henceforth adaptation) scenarios were created by recalculating EHF using the DMT_{95} in the projected 30-year period as the heatwave threshold. This uses a non-arbitrary statistic inherent to EHF calculation assuming that workers have adapted to the projected climate instead of an arbitrary set value of adaptation, for example 10% (191,193)

Analyses for national, baseline AFs were conducted with data stratified by age, sex, indoor/outdoor status based on both industry and occupation (as described in the Supplementary Material for Chapter 5: Supplementary Methods (39)), occupation, and injuries and illnesses separately. All analyses were performed using R version 4.2.1 (158). DLNMs, GAMs, Tweedie distributions, and multivariate meta-regression models were modeled with the *dlnm*, *mcgv*, *tweedie* and *mixmeta* packages, respectively (104,122,125,151). Attributable risk and Tweedie index parameters were calculated using the *FluMoDL* and *statmod* packages, respectively (120,160,161). The code for analysis is available upon reasonable request.

5.4.3 Funding

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5.5 Results

5.5.1 Descriptive statistics

The cities' averaged DMT across the study period ranged from 14-29°C (Table 5.1). Darwin had the highest value and lowest variance, reflective of its tropical climate. Across cities, there was an approximately similar spread of heatwave days, including severe and extreme heatwaves, across cities (Appendix Table D.1). Projected climate data generally had more heatwave days annually with lower 50th and 85th positive EHF values compared to baseline in non-adaptation scenarios, and similar or slightly less days in adaptation scenarios (Appendix Table 5.2). Darwin was an exception, with higher positive EHF values and considerably more heatwave days.

Table 5.1: Descriptive meteorological factors per city

City	Average DMT (SD)	DMT_{95}	EHF_{50p}	EHF_{85p}	Köppen climate
Adelaide	19.67 (5.10)	26.51	12.29	34.31	Mediterranean hot summer
Brisbane	24.05 (2.54)	27.28	1.93	7.23	Humid subtropical
Darwin	29.08 (0.77)	30.02	0.20	0.54	Aw
Hobart	14.07 (3.89)	18.79	6.30	17.35	Marine west coast
Melbourne	19.24 (4.63)	25.23	6.86	25.97	Marine west coast
Perth	22.08 (4.53)	27.97	5.02	20.72	Mediterranean hot summer
Sydney	22.08 (3.46)	26.24	4.01	11.01	Humid subtropical

Daily mean temperature (DMT), standard deviation (SD), 95th percentile of DMT (DMT_{95}), 50th (EHF_{50p}) and 85th percentiles (EHF_{85p}) of all positive EHF values, and Köppen climate zones per city. DMT is expressed in °C, and EHF is expressed in $°C^2$. Aw: Tropical savanna climate with dry-winter characteristics

Overall 1,208,004 claims were included for analysis. Details on excluded claims are in Appendix Table 5.3. Claim payouts totalled to AU$22 billion (Appendix Table 5.4). Approximately 60%, 30% and 11% of financial payouts covered compensation payments, goods and services (predominantly health services), and non-compensation costs, respectively. Details on national demographics and claim statistics are included in Appendix Table D.5. The number of OIIs gradually decreased across successive financial years, whereas associated costs gradually increased up to the 2009 financial year and then decreased. Most payouts occurred in the same or subsequent financial year as the date of claim submission. Injuries were 3.3 times more common than illnesses, but illnesses had on average a 1.6 higher cost per OII ratio.

5.5.2 Overall cumulative relationships

As EHF increased, OIIs gradually increased across all days with a similar pattern was observed with associated costs during heatwaves (Figure 5.1). Approximately identical relationships were observed with costs stratified into compensation and goods and services but with larger confidence intervals; a non-significant relationship was observed with non-compensation costs. City-level relationships were similar to the national relationships for OIIs (Figure 5.2), and also costs during heatwave but not non-heatwave days (Figure 5.3). During heatwaves, the risk of OIIs during heatwaves was elevated throughout the ten-day lag period, although slightly higher in the first few days (Appendix Figure D.1). For costs, a significant relationship was only observed five to ten days after exposure (Appendix Figure D.2).

Heterogeneity was not detected in the OII meta-analysis (Cochran Q-statistic= 12.06, df=12, P-value=0.44). Substantial heterogeneity was detected with the cost models (Cochran Q-statistic=39.11, df=12, P-value=0.0001, I^2=69.32%). Comparing city-level overall exposure-response relationships with and without BLUPs highlighted large statistical shrinkage (estimates pulled towards the national exposure-response relationship) in Adelaide, Darwin, and Hobart (Appendix Figure D.3).

5.5.3 Attributable risk

About 0.129% (95% eCI: 0.106-0.164%) of all OIIs were heatwave-attributable (Figure 5.4, estimates listed in Appendix Table D.6). Generally similar OII-AFs were observed across all cities although Perth and Darwin had relatively higher and lower AFs, respectively. 0.252% (95% eCI: 0.184-0.342%) of costs were heatwave-attributable (Figure 5.4, estimates listed in Appendix Table D.7). Cost-AFs for heatwaves generally were significant in all cities except Adelaide and Hobart, although these cities had significant AFs for extreme heatwaves (and severe heatwaves in Hobart). Cost-AF estimates were lowest in Darwin. The other four cities had

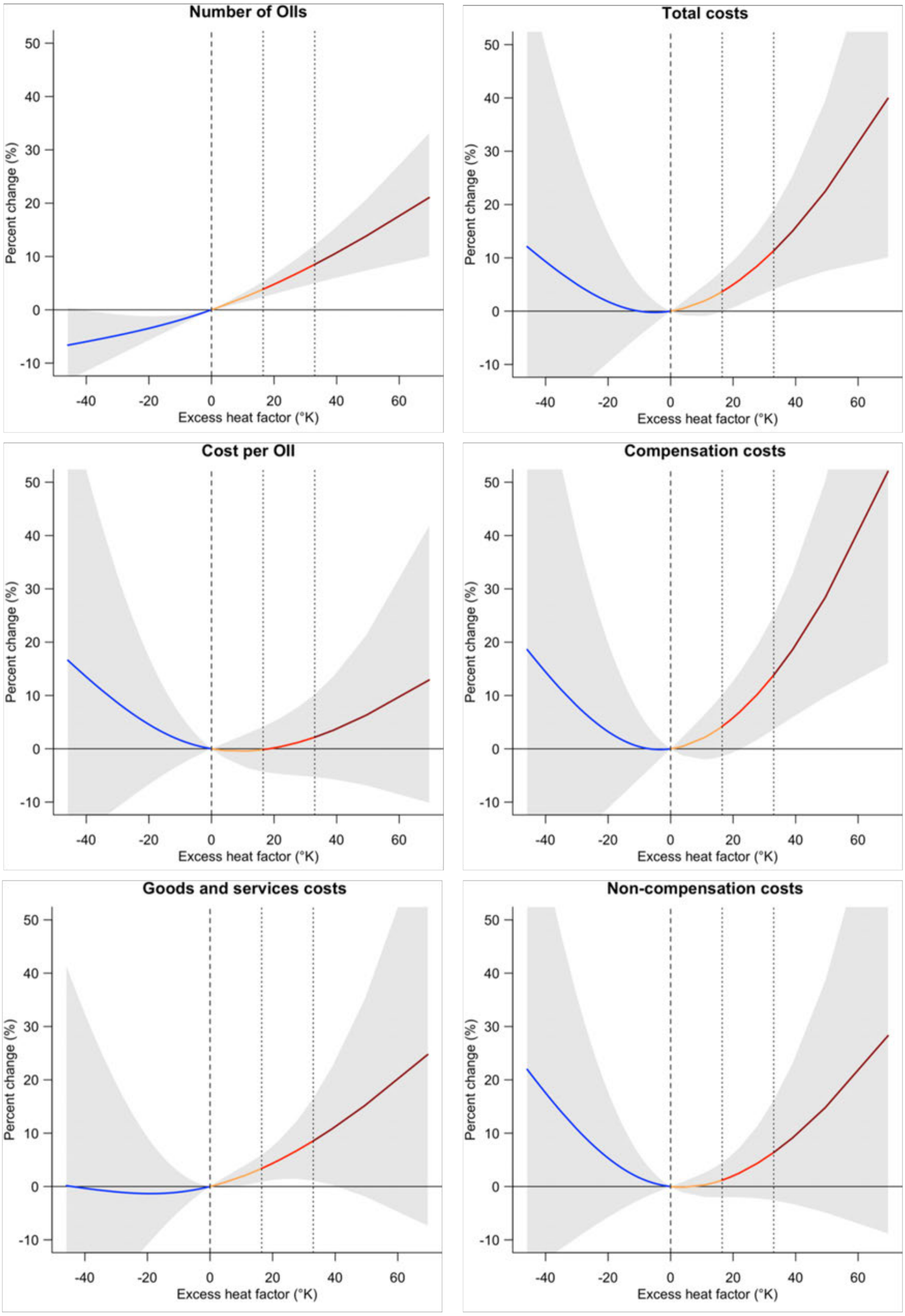

Figure 5.1: Overall cumulative exposure-response curves pooled nationally. The curves with 95% confidence intervals represent percentage change in the number of occupational injuries and illnesses (OIIs), total costs, costs per OII, compensation costs. The dashed lines from left to right represent the thresholds for heatwaves, severe heatwaves and extreme heatwaves.

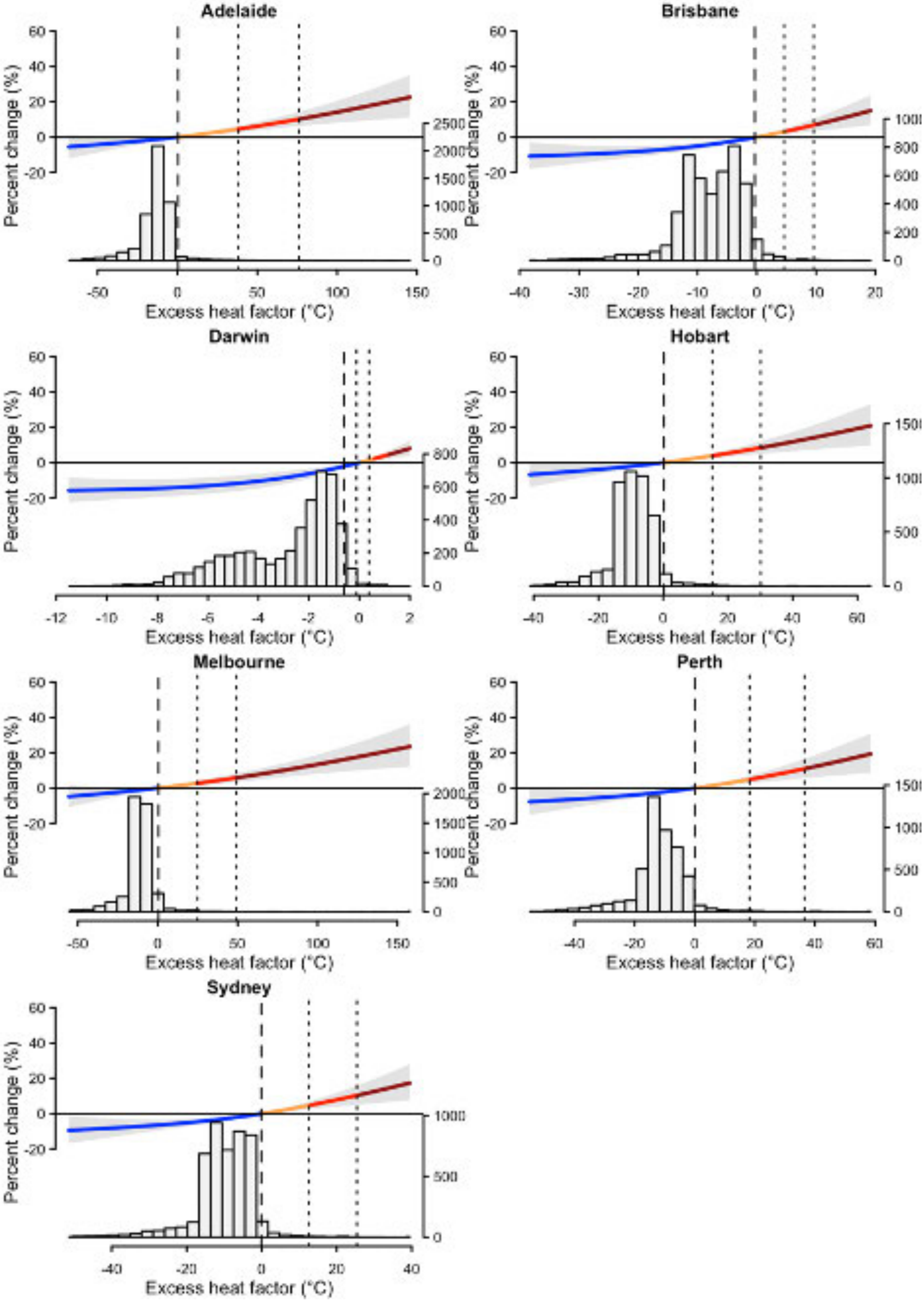

Figure 5.2: Overall cumulative exposure-response relationships for occupational injuries and illnesses in Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth and Sydney. The curves with 95% confidence intervals represent percentage change in the number of occupational injuries and illnesses against Excess Heat Factor. The dashed lines from left to right represent the thresholds for heatwaves, severe heatwaves and extreme heatwaves.

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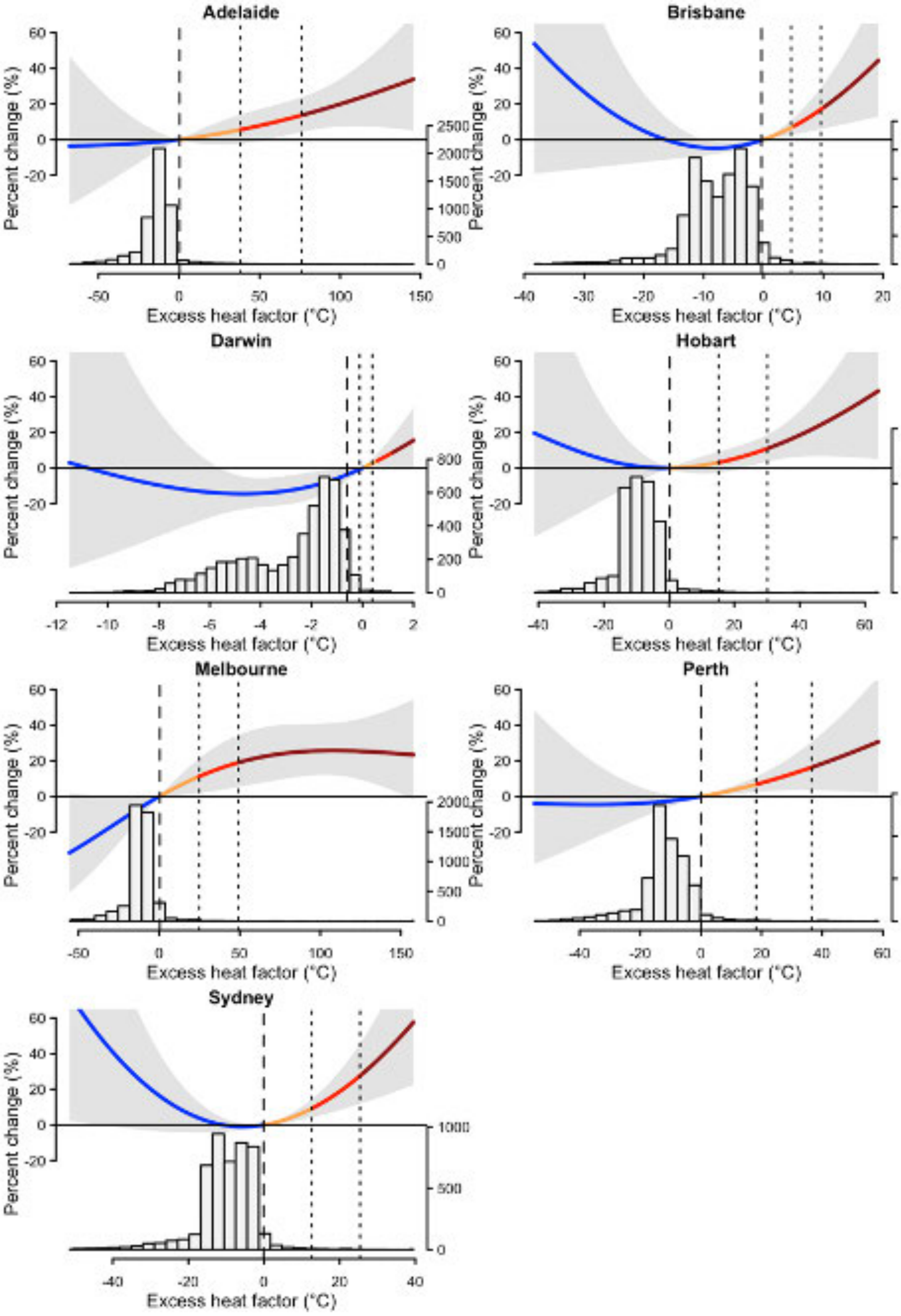


Figure 5.3: Overall cumulative exposure-response relationships for occupational injury- and illness-associated costs in Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth and Sydney. The curves with 95% confidence intervals represent percentage change in costs against Excess Heat Factor. The dashed lines from left to right represent the thresholds for heatwaves, severe heatwaves and extreme heatwaves.

similar estimated cost-AFs. Most OIIs and costs were attributable to low-intensity heatwaves. Collectively, 1,556 (95% eCI: 1,286-1,984) OIIs and AU$56 million (95% eCI: 41-76 million) were observed, equal to 120 OIIs and AU$4.3 million annually (Tables 5.2 and 5.3).

Table 5.2: Number of occupational injuries and illnesses attributable to heatwaves per year

Setting	Heatwaves	Low-intensity heatwaves	Severe heatwaves	Extreme heatwaves
Total, baseline	119.90 (70.92 – 182.38)	60.16 (35.04 – 92.04)	37.97 (22.10 – 57.85)	21.76 (12.38 – 33.14)
- 2030, RCP4.5	162.10 (98.73 – 229.68)	84.56 (48.90 – 121.63)	51.88 (31.37 – 74.66)	25.66 (14.31 – 40.69)
- 2030, RCP8.5	178.27 (107.33 – 261.97)	91.30 (52.72 – 134.99)	56.96 (34.05 – 84.22)	30.01 (16.30 – 49.16)
- 2050, RCP4.5	269.82 (159.33 – 406.02)	134.88 (73.56 – 205.77)	86.40 (51.72 – 127.66)	48.55 (27.22 – 84.40)
- 2050, RCP8.5	349.40 (190.87 – 566.42)	167.55 (80.97 – 276.02)	108.92 (63.55 – 167.80)	72.93 (37.62 – 132.51)
Adelaide, baseline	15.11 (9.64 – 22.22)	8.64 (4.98 – 13.29)	4.64 (3.16 – 6.70)	1.84 (1.19 – 2.64)
- 2030, RCP4.5	19.73 (10.85 – 28.93)	12.16 (5.70 – 18.54)	6.16 (3.71 – 8.78)	1.41 (0.68 – 3.25)
- 2030, RCP8.5	20.66 (11.12 – 31.27)	12.44 (5.61 – 19.46)	6.52 (3.66 – 10.27)	1.69 (0.77 – 2.86)
- 2050, RCP4.5	25.54 (13.30 – 39.86)	15.18 (6.63 – 24.20)	8.42 (4.65 – 13.67)	1.95 (0.97 – 3.35)
- 2050, RCP8.5	29.44 (14.25 – 47.37)	16.56 (6.36 – 27.49)	10.11 (5.27 – 16.97)	2.78 (1.52 – 4.50)
Brisbane, baseline	20.34 (11.28 – 31.48)	10.31 (5.90 – 16.00)	5.70 (3.01 – 8.80)	4.33 (2.26 – 6.80)
- 2030, RCP4.5	25.56 (14.69 – 41.55)	10.84 (6.12 – 17.40)	7.94 (4.35 – 14.10)	6.78 (3.63 – 10.75)
- 2030, RCP8.5	30.30 (17.61 – 45.74)	12.42 (7.02 – 19.09)	9.96 (5.56 – 15.26)	7.92 (4.22 – 12.28)
- 2050, RCP4.5	46.26 (27.04 – 74.22)	18.54 (9.72 – 30.39)	14.94 (8.74 – 22.57)	12.78 (7.10 – 22.62)
- 2050, RCP8.5	66.39 (33.21 – 121.46)	26.46 (10.73 – 50.15)	19.13 (10.02 – 34.01)	20.80 (10.37 – 38.65)
Darwin, baseline	0.45 (0.24 – 0.72)	0.25 (0.14 – 0.39)	0.08 (0.04 – 0.13)	0.11 (0.06 – 0.18)
- 2030, RCP4.5	9.84 (5.75 – 14.42)	1.05 (0.57 – 1.56)	2.59 (1.56 – 3.70)	6.20 (3.27 – 10.07)
- 2030, RCP8.5	11.06 (6.50 – 17.21)	1.03 (0.53 – 1.53)	2.68 (1.58 – 3.85)	7.36 (3.98 – 12.59)
- 2050, RCP4.5	18.20 (10.56 – 27.62)	1.20 (0.47 – 1.92)	3.46 (1.68 – 5.17)	13.54 (7.61 – 21.84)
- 2050, RCP8.5	22.68 (11.64 – 37.67)	0.94 (0.15 – 1.74)	3.24 (0.90 – 5.36)	18.50 (9.47 – 31.88)
Hobart, baseline	2.83 (1.88 – 4.11)	1.39 (0.92 – 2.02)	0.80 (0.53 – 1.16)	0.64 (0.39 – 0.96)
- 2030, RCP4.5	3.43 (1.58 – 5.36)	1.54 (0.47 – 2.64)	1.14 (0.53 – 1.81)	0.76 (0.47 – 1.05)
- 2030, RCP8.5	3.79 (1.69 – 6.39)	1.70 (0.49 – 3.12)	1.24 (0.56 – 2.14)	0.85 (0.50 – 1.29)
- 2050, RCP4.5	5.04 (2.00 – 9.84)	2.23 (0.51 – 4.79)	1.67 (0.71 – 2.93)	1.15 (0.61 – 2.26)
- 2050, RCP8.5	5.65 (2.05 – 10.08)	2.50 (0.44 – 4.94)	1.83 (0.71 – 3.15)	1.32 (0.69 – 2.12)
Melbourne, baseline	15.60 (8.36 – 24.82)	8.24 (3.44 – 14.16)	4.68 (2.64 – 7.34)	2.67 (1.80 – 3.80)
- 2030, RCP4.5	21.46 (10.41 – 34.09)	11.84 (4.59 – 19.44)	6.55 (3.19 – 12.41)	3.07 (1.81 – 4.67)
- 2030, RCP8.5	22.99 (10.92 – 37.34)	12.32 (4.61 – 20.53)	7.37 (3.61 – 13.35)	3.30 (2.00 – 4.85)
- 2050, RCP4.5	35.11 (15.89 – 59.11)	18.77 (6.42 – 32.94)	11.34 (5.48 – 20.43)	5.00 (2.88 – 7.27)
- 2050, RCP8.5	42.31 (17.36 – 72.83)	21.94 (6.49 – 38.37)	14.20 (6.28 – 26.14)	6.17 (3.49 – 10.70)
Perth, baseline	22.71 (14.45 – 33.48)	10.54 (6.97 – 15.33)	5.30 (3.25 – 7.93)	6.86 (3.92 – 10.44)
- 2030, RCP4.5	32.41 (19.67 – 46.07)	15.49 (9.34 – 22.12)	12.14 (7.14 – 17.43)	4.79 (2.50 – 7.81)
- 2030, RCP8.5	32.92 (18.65 – 49.14)	15.90 (9.21 – 24.19)	12.36 (6.54 – 18.26)	4.66 (2.33 – 7.68)
- 2050, RCP4.5	50.77 (29.26 – 72.65)	24.37 (13.82 – 36.00)	18.42 (10.10 – 26.19)	7.98 (4.10 – 12.02)
- 2050, RCP8.5	58.94 (34.13 – 87.71)	27.78 (14.85 – 42.57)	20.53 (12.36 – 29.68)	10.63 (4.97 – 18.34)
Sydney, baseline	42.86 (25.08 – 65.54)	20.78 (12.71 – 30.84)	16.77 (9.45 – 25.80)	5.31 (2.75 – 8.33)
- 2030, RCP4.5	47.08 (27.70 – 69.40)	30.08 (17.82 – 44.57)	14.50 (7.82 – 22.61)	2.50 (0.90 – 6.22)
- 2030, RCP8.5	53.90 (31.80 – 82.45)	33.89 (20.61 – 50.81)	15.95 (8.61 – 25.61)	4.06 (1.01 – 10.03)
- 2050, RCP4.5	84.09 (48.81 – 129.27)	50.80 (29.87 – 76.30)	26.38 (14.92 – 39.28)	6.91 (2.22 – 19.87)
- 2050, RCP8.5	118.78 (66.30 – 201.93)	67.28 (36.52 – 113.33)	37.71 (21.89 – 57.84)	13.80 (4.67 – 35.88)

The number of annual occupational injuries and illnesses attributable to heatwaves across to 2016-45 and 2036-65 centered at 2030 and 2050 with 95% empirical confidence intervals. Projected results do not assume climate adaptation. RCP: Representative Concentration Pathway.

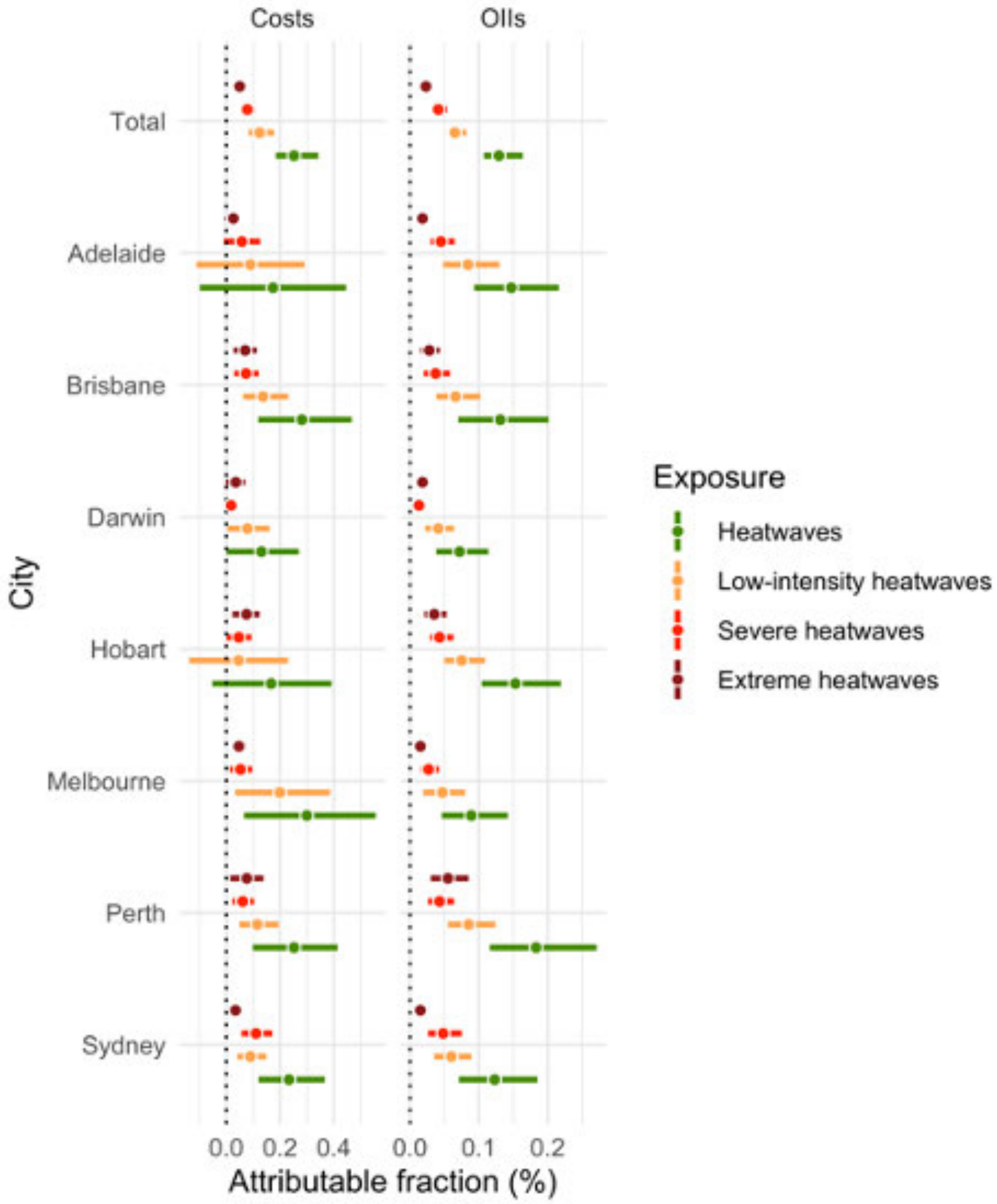


Figure 5.4: Heatwave-attributable fractions for occupational injuries and illnesses (OIIs) and associated costs, with 95% empirical confidence intervals. Results are included for all heatwaves as well as low-intensity, severe and extreme heatwaves.

Table 5.3: Heatwave-attributable costs secondary to occupational injuries and illness per year

Setting	Heatwaves	Low-intensity heatwaves	Severe heatwaves	Extreme heatwaves
Total, baseline	4292.8 (1430.7 – 7434.5)	2107.1 (477.3 – 3932.1)	1336.4 (534.7 – 2224.0)	849.3 (342.6 – 1386.5)
- 2030, RCP4.5	3313.2 (-1332.4 – 7445.1)	1312.4 (-1937.4 – 4214.3)	1232.8 (50.3 – 2344.0)	768.0 (317.0 – 1239.9)
- 2030, RCP8.5	3239.4 (-2549.0 – 8463.4)	1178.5 (-2687.3 – 4606.9)	1230.5 (-291.9 – 2629.1)	830.4 (245.1 – 1485.4)
- 2050, RCP4.5	3552.5 (-7583.5 – 12922.5)	929.8 (-6090.5 – 6849.4)	1509.2 (-1385.8 – 3971.5)	1113.6 (-347.9 – 2437.8)
- 2050, RCP8.5	1226.6 (-18559.7 – 16771.6)	-870.2 (-12381.0 – 8144.2)	1042.4 (-3852.6 – 4964.6)	1054.4 (-2650.0 – 4003.9)
Adelaide, baseline	236.8 (-139.5 – 621.2)	122.5 (-146.1 – 398.0)	78.4 (-12.8 – 171.0)	35.8 (15.5 – 59.0)
- 2030, RCP4.5	303.4 (-319.8 – 879.4)	175.1 (-319.5 – 626.8)	102.6 (-33.6 – 226.5)	25.7 (8.2 – 61.7)
- 2030, RCP8.5	315.0 (-359.2 – 967.5)	177.1 (-343.8 – 672.0)	107.0 (-43.8 – 265.4)	30.9 (10.0 – 57.8)
- 2050, RCP4.5	386.4 (-477.4 – 1217.1)	214.0 (-452.0 – 839.0)	137.3 (-62.4 – 348.1)	35.1 (12.4 – 66.0)
- 2050, RCP8.5	436.0 (-662.8 – 1478.6)	226.5 (-579.0 – 974.0)	160.5 (-118.3 – 451.5)	49.0 (17.1 – 89.6)
Brisbane, baseline	983.0 (401.9 – 1631.4)	480.9 (217.4 – 802.0)	255.9 (104.2 – 427.3)	246.2 (96.0 – 401.4)
- 2030, RCP4.5	183.3 (-837.5 – 972.6)	-116.2 (-786.5 – 384.4)	61.1 (-260.7 – 327.4)	238.3 (100.7 – 400.3)
- 2030, RCP8.5	-9.6 (-1529.9 – 1070.7)	-248.9 (-1187.5 – 438.3)	1.6 (-498.5 – 353.7)	237.8 (77.1 – 379.9)
- 2050, RCP4.5	-478.7 (-3520.9 – 1584.4)	-614.8 (-2357.4 – 665.9)	-147.9 (-1107.3 – 515.8)	284.0 (-109.5 – 518.1)
- 2050, RCP8.5	-1947.6 (-8597.8 – 2284.1)	-1505.6 (-5220.5 – 950.0)	-576.6 (-2545.2 – 657.1)	134.7 (-897.0 – 756.9)
Darwin, baseline	20.4 (-0.1 – 42.1)	12.2 (0.1 – 25.2)	2.7 (-0.1 – 5.6)	5.5 (0.0 – 11.0)
- 2030, RCP4.5	219.6 (-288.9 – 646.1)	10.3 (-82.4 – 92.2)	41.3 (-149.7 – 194.4)	168.0 (-66.8 – 391.6)
- 2030, RCP8.5	204.0 (-550.1 – 831.8)	4.2 (-107.0 – 104.5)	28.3 (-221.7 – 233.4)	171.5 (-231.8 – 525.2)
- 2050, RCP4.5	190.6 (-1583.9 – 1604.5)	-11.1 (-192.8 – 156.2)	-4.1 (-457.9 – 377.9)	205.8 (-971.8 – 1119.5)
- 2050, RCP8.5	-72.7 (-3794.9 – 2681.3)	-25.9 (-225.3 – 156.9)	-65.4 (-729.8 – 478.6)	18.6 (-2889.3 – 2096.9)
Hobart, baseline	47.1 (-11.9 – 109.7)	12.9 (-38.2 – 61.5)	13.2 (0.6 – 26.5)	21.1 (7.2 – 34.7)
- 2030, RCP4.5	-24.1 (-289.0 – 199.9)	-25.9 (-179.7 – 109.7)	-6.2 (-93.7 – 64.0)	8.0 (-16.9 – 27.7)
- 2030, RCP8.5	-30.0 (-341.9 – 235.5)	-30.7 (-212.0 – 129.5)	-7.5 (-107.4 – 73.5)	8.2 (-23.5 – 33.8)
- 2050, RCP4.5	-55.5 (-556.5 – 333.8)	-48.5 (-335.1 – 182.1)	-15.0 (-169.0 – 101.4)	7.9 (-53.8 – 54.8)
- 2050, RCP8.5	-76.1 (-654.9 – 381.2)	-61.1 (-383.2 – 207.1)	-21.4 (-203.9 – 115.3)	6.3 (-69.0 – 61.1)
Melbourne, baseline	997.2 (231.7 – 1830.7)	662.9 (80.0 – 1282.7)	176.7 (39.4 – 323.7)	157.6 (74.9 – 249.7)
- 2030, RCP4.5	1406.5 (295.5 – 2603.6)	917.0 (132.1 – 1705.0)	388.8 (93.5 – 862.5)	100.7 (45.9 – 176.6)
- 2030, RCP8.5	1542.5 (317.1 – 2919.4)	981.9 (143.1 – 1850.1)	448.5 (108.2 – 946.0)	112.0 (52.0 – 195.0)
- 2050, RCP4.5	2447.1 (449.3 – 4821.6)	1548.7 (193.7 – 3067.5)	716.6 (156.7 – 1524.4)	181.9 (77.1 – 309.4)
- 2050, RCP8.5	3106.2 (504.2 – 6136.1)	1906.8 (203.7 – 3671.7)	952.1 (184.7 – 2041.4)	247.3 (97.4 – 553.3)
Perth, baseline	591.4 (241.0 – 975.5)	270.1 (107.7 – 461.6)	142.2 (50.5 – 243.8)	179.1 (39.4 – 326.1)
- 2030, RCP4.5	759.4 (174.6 – 1347.5)	338.6 (-63.2 – 732.7)	291.3 (105.2 – 480.0)	129.5 (40.2 – 229.1)
- 2030, RCP8.5	762.3 (153.1 – 1472.0)	342.1 (-94.0 – 823.4)	294.6 (102.8 – 509.5)	125.7 (37.7 – 222.1)
- 2050, RCP4.5	1144.4 (37.3 – 2300.0)	504.3 (-297.4 – 1318.0)	429.3 (114.0 – 754.2)	210.8 (73.0 – 347.7)
- 2050, RCP8.5	1276.5 (-260.4 – 2870.6)	543.3 (-549.6 – 1632.7)	463.2 (43.5 – 891.0)	270.0 (93.0 – 499.6)
Sydney, baseline	1416.9 (707.6 – 2223.7)	545.7 (256.4 – 901.0)	667.3 (352.8 – 1026.0)	203.9 (109.5 – 304.7)
- 2030, RCP4.5	470.8 (-586.0 – 1336.8)	22.1 (-871.8 – 703.6)	350.8 (77.8 – 643.7)	97.9 (41.2 – 210.3)
- 2030, RCP8.5	463.2 (-1284.3 – 1577.9)	-37.2 (-1433.4 – 781.9)	356.1 (-86.4 – 728.8)	144.3 (45.7 – 280.9)
- 2050, RCP4.5	-8.4 (-3563.5 – 1986.0)	-614.4 (-3443.2 – 963.9)	397.1 (-430.8 – 929.5)	208.9 (81.6 – 451.4)
- 2050, RCP8.5	-1423.2 (-8076.1 – 1980.8)	-1887.3 (-7031.2 – 819.7)	133.3 (-1432.8 – 892.5)	330.9 (120.9 – 667.4)

Heatwave-attributable annual costs secondary to occupational injuries and illnesses at baseline and 2016-45 and 2036-65 centered at 2030 and 2050, respectively. 95% empirical confidence intervals are included. Costs are presented per AU$1000 dollars. Projected results do not assume climate adaptation. RCP: representative concentration pathway.

Without adaptation, OII-AFs nationally were projected to slightly increase relative to baseline to 0.137% (95% eCI: 0.084-0.195) and 0.151% (95% eCI: 0.091-0.222) by 2030 under RCP4.5 and 8.5, respectively (Figure 5.5), representing 162 and 179 additional OIIs annually, respectively (Table 5.4). These increased further to 0.176% (95% eCI: 0.104-0.265) and 0.228% (95% eCI: 0.125-0.370) by 2050 under RCP4.5 and 8.5, respectively, representing 270 and 349 OIIs yearly, respectively. Most cities had similar increases in OII-AF, although Brisbane and Sydney had a slight decrease in 2030s under RCP4.5, and tropical city Darwin had projected increases in AF 17 times greater than baseline (Figure 5.6).

Table 5.4: Attributable fractions by worker and OII characteristics

Factor	Category	OIIs	Costs
Overall	All workers	0.129 (0.107 to 0.165)	0.252 (0.182 to 0.345)
Sex	Male	0.135 (0.109 to 0.176)	0.161 (0.069 to 0.266)
	Female	0.122 (0.053 to 0.202)	0.323 (0.172 to 0.486)
Age (years)	15 to 29	0.165 (0.124 to 0.222)	0.013 (-0.140 to 0.150)
	30 to 49	0.120 (0.075 to 0.177)	0.295 (0.180 to 0.430)
	50 to 75	0.113 (0.071 to 0.166)	0.145 (0.048 to 0.251)
Industries	Indoor	0.126 (0.102 to 0.165)	0.275 (0.201 to 0.371)
	Outdoor	0.144 (0.079 to 0.220)	0.130 (-0.112 to 0.345)
Occupation	Indoor occupations	0.150 (0.127 to 0.191)	0.231 (0.146 to 0.338)
	Outdoor occupations	0.037 (-0.037 to 0.110)	0.182 (-0.229 to 0.496)
	Clerical & administrative workers	0.202 (0.071 to 0.346)	0.160 (-0.415 to 0.553)
	Community & personal service workers	0.130 (-0.020 to 0.276)	0.176 (0.048 to 0.309)
	Laborers	0.194 (0.120 to 0.283)	0.107 (-0.193 to 0.365)
	Machinery operators & drivers	0.195 (0.120 to 0.286)	0.148 (-0.234 to 0.453)
	Managers	0.069 (-0.071 to 0.200)	0.006 (-0.947 to 0.515)
	Professionals	-0.144 (-0.283 to -0.034)	0.197 (-0.053 to 0.415)
	Sales workers	0.141 (-0.080 to 0.336)	-0.084 (-0.709 to 0.288)
	Technicians & trade workers	0.106 (0.054 to 0.168)	0.090 (-0.248 to 0.350)
Injuries	All injuries	0.110 (0.080 to 0.153)	0.146 (0.050 to 0.250)
	Fractures and traumatic joint, ligament, muscle & tendon injuries	0.071 (-0.026 to 0.161)	0.203 (0.079 to 0.335)
	Wounds, lacerations, amputations & internal organ damage	0.104 (0.038 to 0.174)	0.057 (-0.233 to 0.299)
	All other injuries	0.337 (0.216 to 0.485)	-0.598 (-1.917 to 0.029)
Illnesses	Illnesses (diseases/conditions)	0.186 (0.140 to 0.253)	0.429 (0.281 to 0.613)

National heatwave-attributable fractions (%) for the number of occupational injuries and illnesses (OIIs) and associated costs stratified by demographic, occupational and OII characteristics with 95% empirical confidence intervals.

Projected increases in cost-AFs without adaptation were imprecise. National projected cost-AFs were 0.153% (95%eCI: (-0.062 to 0.345) and 0.150% (95%eCI: -0.118 to 0.392) by 2030 under RCP4.5 and 8.5, respectively, and 0.127% (95%eCI: -0.270 to 0.461) and 0.044% (95%eCI: -0.662 to 0.598) in 2050 under RCP4.5 and RCP8.5, respectively. Significant AFs were projected for extreme heatwaves nationally in 2030 but not 2050, and they were about two-thirds that of baseline. In 2030, this represents AU$768k and AU$830k under RCP4.5 and RCP8.5, respectively. Cost-AFs were projected to increase in both 2030 and 2050 in Melbourne and

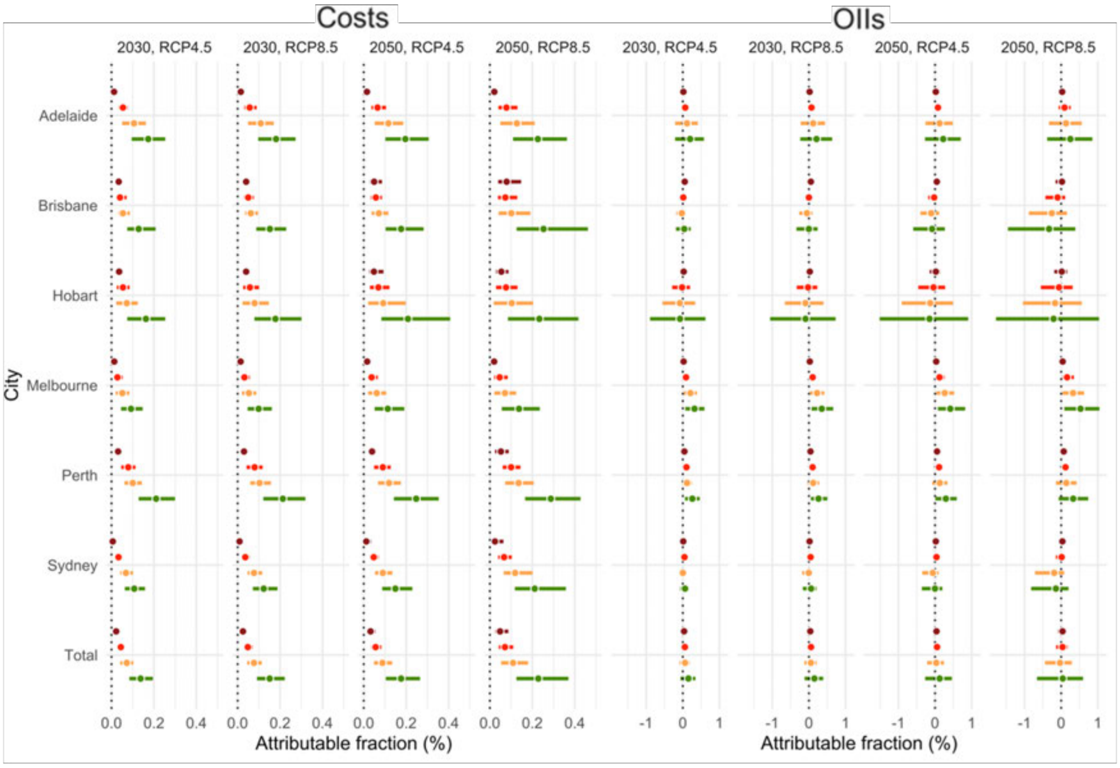


Figure 5.5: Projected attributable fractions for heatwave-attributable occupational injuries and illnesses (OIIs) and associated costs without climate adaptation, with 95% empirical confidence intervals. Results are included for all heatwaves as well as low-intensity, severe and extreme heatwaves. Darwin is not included in this figure.

Perth, with slightly increases relative to baseline.

With adaptation, both OII- and cost-AFs were similar across RCPs and time periods, and were slightly smaller than baseline in most cities, although they approximately doubled in Darwin (Figures 5.5 and 5.7, estimates listed in Appendix Tables D.8 and D.9). Cost-AFs assuming adaptation for heatwaves were generally non-significant in all cities except for Melbourne (similar to baseline) and Perth (slightly smaller than baseline).

Sensitivity analysis showed different modeling choices regarding parameters and inclusion of humidity led to similar baseline, national AFs (Appendix Table D.10). Cost-AFs lowered when only assessing claims submitted no later than June 2014 with payments restricted to up to five financial years post-claim submission but

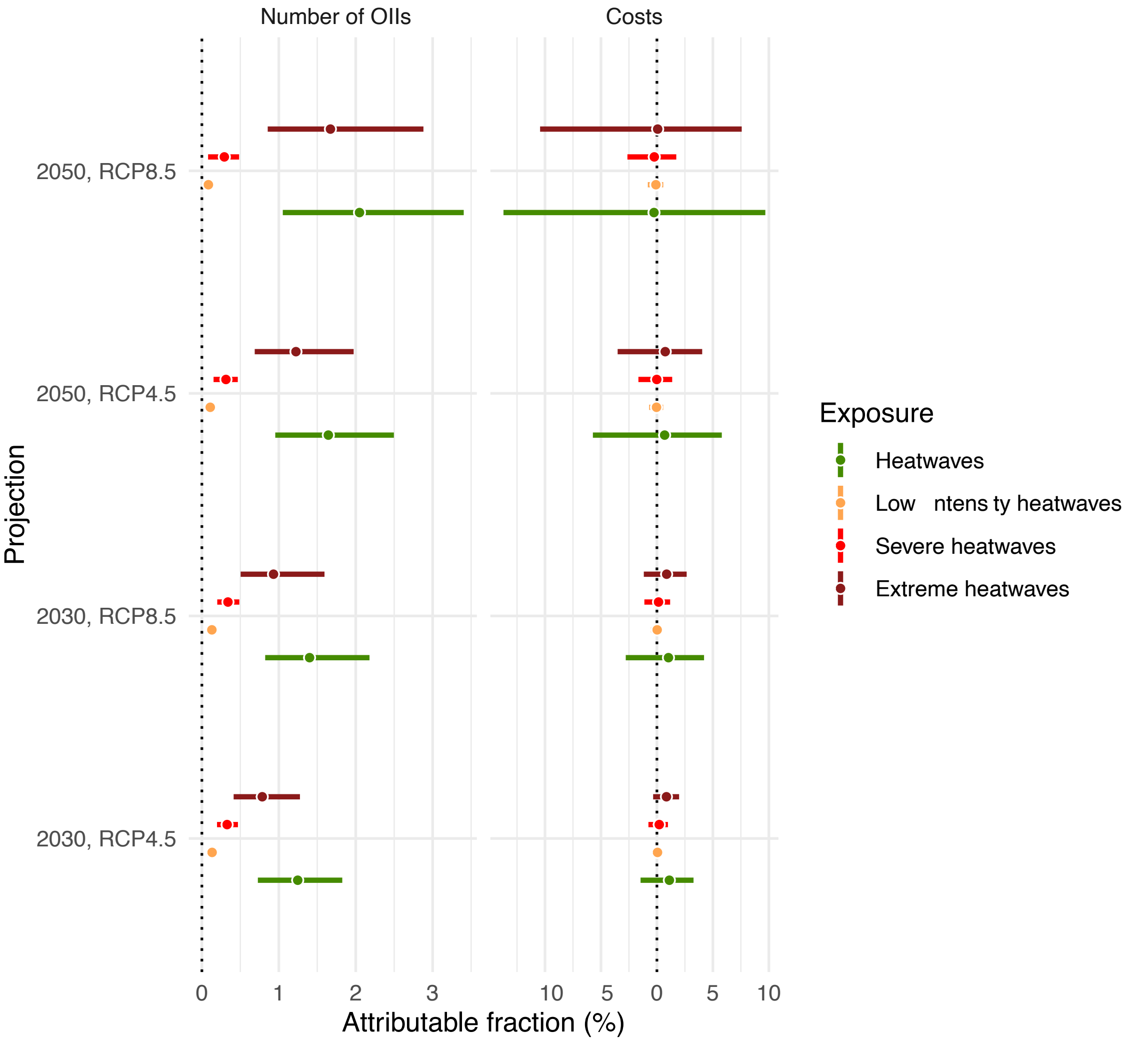


Figure 5.6: Projected attributable fractions for heatwave-attributable occupational injuries and illnesses (OIIs) and associated costs without climate adaptation, with 95% empirical confidence intervals. Results are included for all heatwaves as well as low-intensity, severe and extreme heatwaves.

remained significant. ANs under high, low and unchanged population scenarios without adaptation are listed in Appendix Tables D.11 and D.12.

5.5.4 Claim characteristics

Baseline OII-AFs were similar across different sexes, age groups and industries (indoor vs outdoor) with a slightly higher AF in the 15-29 age group (Table 5.4). Across occupations, indoor occupations, "clerical and administrative workers," "laborers" and "machinery operators and drivers" had higher OII-AFs, with

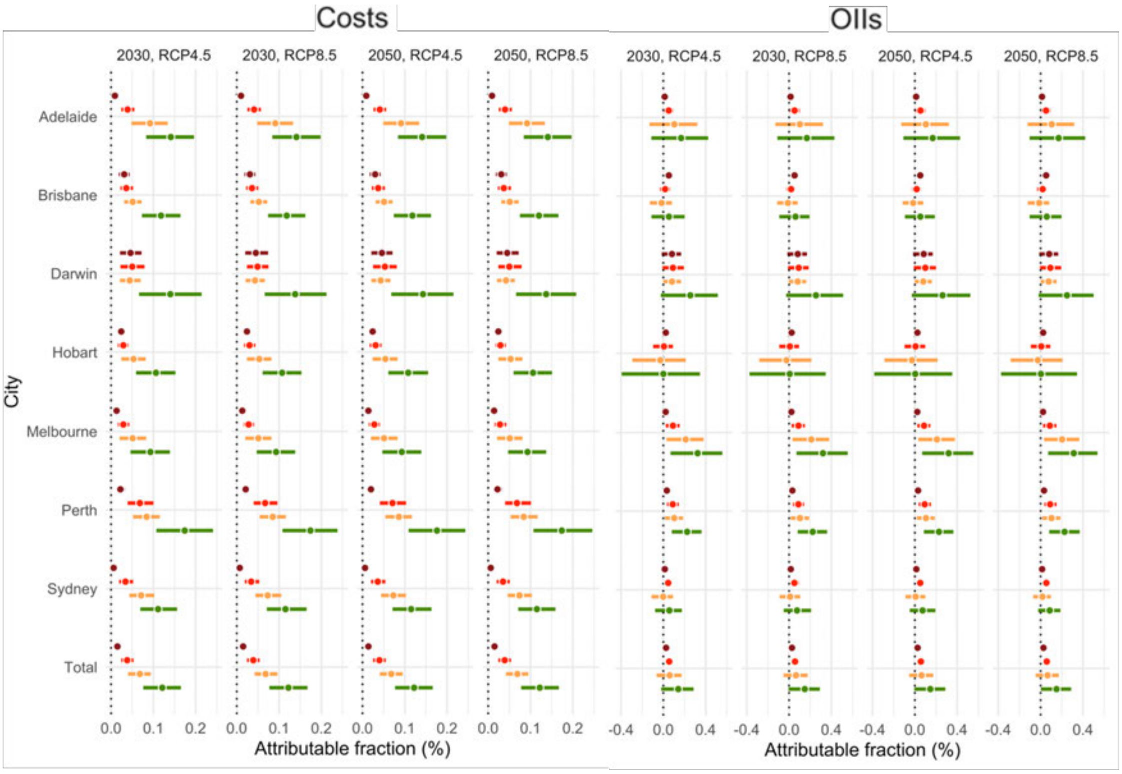


Figure 5.7: Projected attributable fractions for heatwave-attributable occupational injuries and illnesses (OIIs) and associated costs with climate adaptation, with 95% empirical confidence intervals. Results are included for all heatwaves (green) as well as low-intensity (orange), severe (red) and extreme heatwaves (dark red).

heatwave-preventable fractions (negative AFs) observed in "professionals." Illnesses had higher OII-AFs compared to injuries.

Differences across demographic and OII characteristics were generally more pronounced in cost-AFs than OII-AFs. Cost-AFs were highest with females, the 30-49 years age group, indoor workers, and illnesses. Apart from indoor/outdoor classification, there was insufficient power to compare cost-AFs across occupations.

5.6 Discussion

To the authors' knowledge, this is the first study internationally to evaluate the impact of heatwaves on OIIs alongside associated economic costs and project their future impact from climate change. Increased OIIs and costs were observed during heatwaves at baseline, and projected future increases were predicted for OIIs, with some evidence for increases in costs at least for extreme heatwaves. The EHF inherently incorporates heatwave presence, heatwave severity, and climate acclimatization, and long-term adaptation was explored through updating the heatwave threshold.

Workplace and broader public health heat adaptation measures can reduce morbidity from OIIs and associated costs to employees, employers and governments. This impact is likely to increase with global warming, as evidenced by increased projected AFs for OIIs in 2030 and particularly 2050. Workplace interventions for heatwaves include easy access to hydration, shade, air conditioning and (if required) medical services, reduced or no work hours, and minimizing radiant workplace-generated heat (47,165). Public health measures include guidelines and legislation to implementing workplace interventions and educational messages highlighting awareness and prevention of occupational heat stress. As AFs for OIIs were generally similar across different cities and worker characteristics, adaptation measures should be aimed at the national, general working population.

Adaptation was estimated to result in relatively lower future OII- and cost-AFs in most cities that were relatively consistent across time periods and RCPs compared to non-adaptation scenarios. This study assumed a theoretical 100% adaptation rate irrespective of cause (e.g. workplace or lifestyle changes, physiological long-term adaptation). A partial adaptation scenario in between that of the non-adaptation and adaptation scenarios is more likely to occur. Although most projected AFs assuming adaptation were lower than baseline, this likely represents the baseline EHF heatwave threshold which incorporates 15 years (1900-2005) of climate observations occurring before the study period (2005 to 2018). These AFs would likely be more similar if claims data during those 15 years were available and assessed. Climate mitigation (RCP4.5 compared to RCP8.5) was projected to reduce OII-AFs in no-adaptation scenarios. Given that 100% adaptation is an unlikely scenario, limiting greenhouse gas emissions would likely help prevent future OIIs.

The groups with higher cost-AFs include females, middle-aged workers, and indoor employees. This may reflect increased risks of more severe heat-attributable OIIs. Females have been linked with lower sweat rates (194), reduced heat loss during exercise (195) and reduced water intake during work (to avoid using a toilet for hygienic reasons) (196). Middle-aged workers may have longer working hours, because younger workers are more likely to prioritize secondary or tertiary education over work, and older workers may reduce worktime as they approach retirement. Longer working hours require larger compensation payments from worktime loss (63). Indoor workers are often overlooked as being at risk of heat-associated OII. Australian outdoor workers are more often targeted by heat-minimization strategies (197) that may reduce the incidence of severe heatwave-attributable OIIs associated with larger costs.

Although there was substantial heterogeneity across the cost models, the BLUPs still reflect study-specific estimates improved by utilizing information from the other cities (105). The seven cities for analysis include 97% of the metropolitan workforce (55) and hence clinically represent the Australian national metropolitan workforce. Due to the heterogeneity, results are more likely to differ when pooling results with different datasets (or without pooling) than those used in this study, particularly for Adelaide, Darwin and Hobart, the three smallest capital cities.

Larger AF estimates were observed for Darwin, both with and (especially) without adaptation. Although EHF can accurately capture the climate in most Australian cities and partially incorporates humidity through minimum daily temperature (79), it cannot fully capture Darwin's high tropical humidity and very humid heatwaves (187). This was evidenced at baseline by Darwin's little air temperature variation, lower positive EHF values, and smaller AF estimates. Consequently there was a large increase in the projected number of heatwave days due to global warming. Caution is therefore required when interpreting projected attributable risk in Darwin and other highly tropical areas; alternative heatwave metrics should be researched for more accurate evaluations in these areas.

The primary study limitation is that the claims data only include reported OIIs. Mild OIIs are less likely to be reported (171); thus the true quantity of OIIs and associated costs is likely underrepresented. Data for workers not covered by state compensation schemes, in particular self-employed workers and those with separate private schemes that partially or completely cover payments, are not collected (63). Compensation payments due beyond the study period would not be captured in collected data for said claims, particularly affecting claims submitted later in the study period. This was partially addressed with a supplementary analysis. However, most payments occurred in the same or subsequent financial year as claim lodgement. As some claims were removed from the dataset due to missing data, selection bias may exist. Non-meteorological temperature variation including workplace-generated heat and air conditioning could not be analyzed due to data unavailability. However, the impact of air conditioning may have been partially and indirectly assessed (theoretically) through evaluating the impact of future climate adaptation. The projected climate dataset utilized Coupled Model Intercomparison Project [CMIP]5 instead of the newer CMIP6 scenarios that include Shared Socioeconomic Pathways. To the authors' knowledge, no CMIP6 datasets with sufficient resolution to accurately represent Australian cities currently exist. However, different socioeconomic projections were considered through different projected population growths (88). Furthermore, eight GCMs were used, which is relatively more than other studies projecting temperature-attributable outcomes. Finally, there is huge uncertainty in projections, attenuated further by real-life phenomena not captured in the projections such as the SARS-CoV-2 outbreak and its effect on the workforce.

5.7 Conclusion

Heatwaves are responsible for a considerable preventable portion of OIIs and associated economic burden. Heatwave-attributable OIIs are likely to increase in the future. Climate adaptation can potentially prevent this future increase. Workplace and public health action is imperative to reduce heatwave-attributable occupational morbidity and costs.

5.8 Contributors

M.A.B., J.X., O.A., B.V., K.D., D.P., A.H., K.Z., M.R.S. and P.B. were involved in conceptualization. M.A.B., J.X., O.A., B.O., K.D., D.P., A.H., K.Z., M.R.S. and P.B. designed the methodology. M.A.B. and B.O. were involved in programming. M.A.B. conducted the formal analysis and visualization and wrote the draft manuscript. M.A.B., O.A., B.O., B.V. and A.H. were involved in data curation. All authors were involved in revising and editing the manuscript. O.A. and P.B. were involved in project administration. J.X., O.A., K.D., D.P., A.H., K.Z., M.R.S. and P.B. were involved in funding acquisition. J.X., O.A. and P.B. supervised the project.

5.9 Acknowledgements and Data Sharing

The authors thank Dr John Nairn, Professor Lisa Alexander, and A/Prof Peter Smith for their advice with utilizing EHF, advice for usage of projected climate data, and for providing their ANZSCO-NOC cross-walk version for cross-checking, respectively.

This publication uses workers' compensation claims data supplied by Safe Work Australia and has been compiled in collaboration with state, territory and Commonwealth workers' compensation regulators. The views expressed are the responsibility of the authors and are not necessarily the views of Safe Work Australia or the state, territory and Commonwealth workers' compensation regulators. Restrictions apply to the availability of these data which were used under license for the current study. The data used can be requested from SWA at https://www.safeworkaustralia.gov.au/data-and-research/request-data and may be made available with the permission of SWA. SWA has made some of this data publicly available in the Australian workers' compensation statistics report, which provides detailed statistics about workers' compensation claims lodged in Australia from July 2000 to June 2020. This report can be accessed at https://www.safeworkaustralia.gov.au/doc/australian-workers-compensation-statistics-2019-20.

The retrospective climate data were sourced from the Australian Bureau of Meteorology Atmospheric high-resolution Regional Reanalysis: http://www.bom.gov.au/research/projects/reanalysis/. The license under which the data were used is available online: http://www.bom.gov.au/metadata/catalogue/view/ANZCW0503900566.shtml?template=full.

The authors acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modeling groups (listed at https://www.climatechangeinaustralia.gov.au/en/obtain-data/application-ready-data/eight-climate-models-data/) for producing and making available their model output for projected climate data. For CMIP the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals. The license under which the data were used is available online: https://www.climatechangeinaustralia.gov.au/en/overview/abou

t-site/licences-and-acknowledgements/.

The workers' population data were derived from the Australian Bureau of Statistics (ABS) and has been included as supplementary material. The ABS labor force dataset (LM1) is publicly available online: https://www.abs.gov.au/statistics/labour/employment-and-unemployment/labour-force-australia-detailed/latest-release.

The public and school holidays data have been deposited in figshare (https://doi.org/10.25909/6311e7a0dcb3f (154) and https://doi.org/10.25909/6311e7b3bc760 (152), respectively).

6

Discussion and conclusions

6.1 Preface

This thesis' research has evaluated the impact of heat stress on economic burden in the Australian occupational settings. It involved a review of previous literature investigating economic burden (Chapter 2), which was estimated to be substantial. This literature predominantly focused on costs from labor productivity loss. Although there were studies investigating costs from OIIs, this research was limited due to the narrow scope of previous research in the number of studies, locations, and statistical methods. Chapters 3 to 5 focused on estimating the costs from heat-attributable OIIs and their relationships, using work compensation claim data from SWA.

This chapter includes a discussion regarding the findings presented in Chapters 4 and 5 with consideration of previous literature. The key findings from this thesis in relation to the research objectives are summarized in Subchapter 6.2. Discussion of their significance is included in Subchapter 6.3. Strengths and limitations of the research are included in Subchapters 6.4 and 6.5, respectively. Policy and practical recommendations and suggested future research are discussed in Subchapters 6.6

and 6.7, respectively, and the thesis is concluded in Subchapter 6.8.

6.2 Key findings

The key findings are listed below with reference to the thesis objectives. The objective “Summarize existing estimates on previous heat-attributable economic burden, including associated risk factors” is addressed and summarized in Chapter 2.

Create, for the first time, a national Australian profile of temperature-attributable OIIs and their associated economic burden.
Based on WBGT, 1.66% (95% eCI: 1.38-1.94) and 0.66% (95% eCI: 0.45-0.89%) of OIIs were heat-attributable and cold-preventable, respectively. These represent 2965 and 1185 OIIs annually, respectively, or a net number of 1780 OIIs due to anomalous temperatures. Cost-AFs were 1.53% (95% eCI: 0.77-2.27%) and 1.33% (95% eCI: 0.66-1.97%) for higher and lower WBGT values, representing AU$50 million and AU$44 million (AU$94 million in total) annually, respectively. Heatwaves were associated with 0.13% (95%eCI: 0.11-0.16%) of OIIs and 0.25% of costs (95%eCI: 0.18-0.34%), equivalent to 120 (70-181) OIIs and AU$4.3 (95%eCI: 1.4-7.4) million per year, respectively. Most OIIs and costs were attributable to low-intensity heatwaves, although larger relative risks were observed in severe and extreme heatwaves.

OII-AFs were generally similar across cities with regards to both WBGT and heatwaves. OII-AFs from high WBGT values were higher for workers in Sydney, Melbourne, and Perth, and heatwave-AFs were higher in Perth. OII-cold-PFs were higher in Adelaide and Darwin. For costs in relation to WBGT, heat-AFs were largest in Darwin, followed by Brisbane and Perth, and cold-AFs were larger in Adelaide and smaller in Brisbane and Darwin. Cost-AFs for heatwaves generally were significant in all cities except Adelaide and Hobart, although these cities had significant AFs for extreme heatwaves (and severe heatwaves in Hobart).

Investigate the relationships between OII-associated costs and apparent temperature, including differences in the relationships between OIIs and their costs.
WBGT had a curvilinear relationship with the numbers of OIIs. OIIs slightly decreased during colder temperatures and increased during warmer temperatures. However, OII-associated costs had a U-shaped relationship with temperature, where costs increased both during colder and warmer temperatures. This was reflective of an increased cost per OII during cold temperatures despite fewer OIIs occurring during the cold. There was no significant change in costs per OII during higher temperatures or heatwaves. Overall, observed relationships between OIIs and costs were similar during heat but very different during cold.

Estimate OII-associated costs attributable to extreme heat and the potential impact of global warming.
Projected national OII-AFs for heatwaves were estimated in 2030 as 0.137% (95% eCI: 0.084-0.195) and 0.151% (95% eCI: 0.091-0.222) under RCP4.5 and RCP8.5, respectively. These estimates in 2050 were 0.17% (95%eCI: 0.10-0.27%) and 0.23% (95%eCI: 0.13-0.37%), respectively. Cost-AFs for 2030 were 0.13% (95%eCI: -0.27-0.46%) and 0.04% (95%eCI: -0.66-0.60) under RCP4.5 and RCP8.5, respectively, with significant cost-AFs associated with extreme heatwaves in 2030 (0.04%, 95%eCI: 0.02-0.06%) and 0.04% (95%eCI: 0.01-0.07), respectively. There was insufficient statistical power to observe any significant changes nationally in 2050. All OII- and cost-AFs were approximately similar to baseline when assuming theoretical climate adaptation.

Explore higher risk groups for increased heat-attributable OII-associated costs and if they were identical to those of OIIs.
Males were observed to have a stronger exposure-response relationship with OIIs, demonstrated by both a larger increase and decrease with higher and lower WBGT

values, respectively, in the number of OIIs. Males also had a slightly larger, although overall similar OII-AF than females during heatwaves. Inversely, cost-AFs for higher WBGT values and heatwaves were larger in females, and larger in males for cold-AFs.

Younger workers (15 to 29 years old) had increased OIIs attributable to both WBGT values above the mean and heatwaves relative to middle-aged (30 to 49 years old) and older (50 to 75 years old) workers. Middle-aged workers had large cost-AFs instead. During cold OIIs, older workers had increased instead of decreased cost-OIIs, and both older and younger workers had larger cost-AFs.

This research observed higher heat-AFs (from higher temperatures or heatwaves) for OIIs in outdoor workers compared to indoor workers when classified by occupation, but the inverse when classified by industry. Higher cost-AFs were observed in both indoor occupations and industries relative to their outdoor counterparts.

Across both studies, the only occupational group with multiple significant associations were "Machinery operators and drivers." They had higher OIIs-AFs both with high WBGT values and heatwaves, a decreased OII-AF with low WBGT values, and higher cost-AFs during extremely high WBGT values. There was insufficient statistical power to compare heat-attributable cost-AFs between occupations in association with heatwaves.

Illnesses were associated with higher AFs for both costs and number of OIIs compared to injuries with both higher temperatures and during heatwaves (although cost-AFs were not significant during higher temperatures for both injuries and illnesses). During cold OIIs, a decrease in injuries was observed, with no clear relationship for illnesses.

6.3 Significance of research

6.3.1 Practical significance

This research adds to the increasing knowledge base evaluating the potential negative impacts of global warming and the urgent need for climate mitigation (3,4). A large number of OIIs and associated costs were attributable to heat as defined by (1) WBGT values exceeding the mean and (2) during heatwaves. This demonstrates the considerable burden that heat-attributable OIIs have on workers in Australia. Although the costs were high, they were far lower than those due to heat-induced labor productivity loss not associated with OIIs, in particular when compared to a previous estimate of US$6.2 billion within the Australian workforce (32). Estimates of the financial burden of occupational heat stress should consider both labor productivity loss in the general population and costs secondary to OIIs to produce more comprehensive assessments of economic expenses.

The findings have implications for reducing occupational heat stress not just within Australia but also internationally. Implementing heat adaptation strategies may provide not just a morbidity benefit but also a financial benefit. Compensation payouts practically represent portions of employers' funds dedicated to financially covering OIIs because compensation schemes are funded by employers' premium (66). As the premium rates increase if projected and previous compensation payouts are greater (66,67), reduced OIIs and associated payouts result in lower premium rates. This reduces expenses incurred by employers. The savings can be invested into production, promoting consumer spending and business growth, and benefiting the wider economy. Savings can also be invested to increase worker wages, improve workers' overall well-being, and/or provide funding to hire new staff, reducing unemployment. The fact that the RRs associated with costs increased with increasing WBGT and EHF values also provides evidence to support escalating heat protective measures based on the degree of heat stress, for example more stringent measures during severe heatwaves.

WBGT can be measured on-site with specialized equipment (41), and the BoM issues warnings when heatwaves are to occur within the next few days (198). Hence the risk of heat stress can be calculated on-the-spot (WBGT) or within a few days prior to onset (heatwaves) using measures that can both be correlated with the findings from these studies and implemented into workplace heat stress guidelines. Analyzing WBGT in both its indoor and outdoor formats enabled more clinically accurate assessment of heat exposure by applying the effect of solar radiation and wind speed to outdoor but not indoor workers (41,199). To the best of the author's knowledge, the study in Chapter 4 is the first to stratify by indoor/outdoor exposure and combine the indoor and outdoor models using multivariate meta-analysis, resulting in overall estimates incorporating both indoor and outdoor exposure simultaneously. This research's study design and methodology can be applied to other populations in similar studies if access to humidity, wind speed, and solar radiation data is available.

Workers and employers are the primary parties affected by heat-attributable OIIs and their compensation. Reducing and managing OIIs are of relevance to occupational health and safety (OHS) professionals and healthcare workers. Compensation payouts concern the relevant insurance companies and industrial shareholders. Other stakeholders, based on both the labor output from workers and the companies' financial performance, include the affected businesses' regular customers, suppliers, creditors, and investors (200). The findings may also be of interest to climate change activists and environmental epidemiologists due to their association with global warming, economists due to the potential wider impact of costs on the economy, and lawyers through potential legal costs, although they are unlikely to be direct stakeholders.

6.3.2 Significance in relation to similar studies

Increasing costs with higher temperatures were also estimated in Guangzhou, China (89) and Spain (31), and a previous study in Adelaide that observed increased compensation payouts from OHIs when maximum temperature exceeded 32.9°C (130). This thesis' findings regarding the relationship between OII-associated costs and cold represent unique findings for which there is no valid comparison. Although the only other study identified to estimate costs from OIIs in relation to cold temperatures (31) observed an association between colder temperatures and increased OIIs in Spain, their exposure-response relationship was determined by modeling occupational injuries instead of costs. Studies investigating OII-associated costs should not assume that their relationship is identical to that of the number OIIs, since costs are affected by additional factors such as OII severity. In this research, with lower WBGT values, the number of OIIs decreased but the costs increased. Assuming that costs have the same relationship could lead to inaccurate assumptions about the costs' distribution and variability, leading to potentially extremely biased estimates (in Chapter 4, this would have resulted in negative instead of positive cold-attributable cost estimates). This was explained by observed increased costs per OII with colder but not warmer temperatures.

To the best of the author's knowledge, temperature-attributable OIIs in Australia have only been analyzed previously in Adelaide, Brisbane, Melbourne, and Perth (29,39,40,135,136). This is the first study to produce a national estimate for Australia and city-based estimates for Darwin, Hobart, and Sydney. Darwin represents the only Australian capital city in a tropical zone, and Sydney is the largest Australian city. This extends the generalizability of the association between OIIs and heat, particularly within Australia. Only one previous study projected OIIs attributable to temperature, which was limited to one city (Adelaide) and did not have sufficient statistical power to detect a difference in the future (29). This research provides national evidence showing statistically significant estimates for a projected increase in heatwave-attributable OIIs due to global warming, and weak evidence for an increase in costs.

6.4 Overall strengths

There are many strengths to this research. This research is the first, worldwide, to report a national cost profile of heat-attributable OIIs by modeling costs directly. Chapter 4 additionally included cold-attributable OIIs, and Chapter 5 was the first study globally to project the financial impact of heat-attributable OIIs.

Seven cities were included for analysis across four different climate zones to support the results across a range of different study settings. Information from each city was combined using meta-analysis to derive both national estimates and BLUPs representing improved individual model estimates (104). Such findings may have international implications for locations with similar climatic and socioeconomic characteristics.

There were over four million compensation claims records for analysis which covered most injured workers across the seven Australian capital cities (55,63,171). The large quantity of data enabled a large number of analyses stratified by demographic, work, and OII-associated factors. The impact of different exposures on indoor/outdoor workers was considered. Two different methods for classifying indoor/outdoor workers were used. The occupational method is theoretically more accurate than the other (more commonly used) method of industry, as it is less prone to occupational misclassification and has been previously shown to have a high correlation with outdoor exposure in Australia (134). Both indoor and outdoor heat exposure was considered with regards to WBGT, enabling more clinically accurate portrayals of heat exposure in workers.

Two outcome measures were analyzed to assess the impact of occupational heat stress: OIIs and their associated costs. The compensation payouts holistically represented a range of direct costs. These were income replacement (and hence labor productivity loss), healthcare, mortality, non-economic, legal, and administrative costs (64).

The two meteorological datasets utilized were of high quality as they were based on multiple data sources, were bias-corrected, and (for the projected data) used the GCMs with a high performance ranking, reducing the likelihood of exposure bias (76,85,143). The impact of heat was primarily assessed with two heat metrics: WBGT and EHF. WBGT incorporated humidity exposure and also wind speed and solar radiation for outdoor exposure where applicable (41). WBGT was calculated using accurate empirical equations instead of the commonly used simplified WBGT used by the BoM, which can be highly biased (41,173,174). EHF was a continuous measure of heatwaves incorporating heatwave categories, heatwaves severity, short-term acclimatisation, and long-term adaptation to the climate (79). Both the retrospective (baseline) and projected effects of heatwaves were considered, including theoretical 100% long-term climate adaptation. Multiple other heat metrics, including different measurements of WBGT and EHF, were considered in sensitivity analyses.

This research utilized advanced and contemporary statistical methodology techniques. DLNMs, multivariate meta-analysis and attributable risk are advanced yet commonly used techniques for ecological studies. They enable analysis of the lagged non-linear effects of heat (151), the pooling of these non-linear effects across a range of locations (103,104), and estimates that reflect an accumulation of RR values across the desired range of temperature or EHF values, respectively (157). Attributable risk also has policy implications by quantifying the preventable burden from temperature and/or heatwaves (157). The Tweedie distribution, although used for studies concerning finances (113) and rainfall (201), has to the best of the author's knowledge not previously been used for assessing OII-associated costs in relation to temperature and alongside the aforementioned statistical techniques. This enabled the analysis of semi-continuous, highly right skewed data with a single set of model estimates outputted. Model testing was undertaken to identify influential days that, when included as variables in the model, improved AIC and residual fit. These days primarily concerned the Christmas holiday period and specific public holidays. Finally, multiple sensitivity analyses were undertaken to test modeling assumptions regarding the seasonality trend df and both exposure- and lag-response relationships.

6.5 Overall limitations

The most significant limitations concern the compensation claims data. These data only include reported OIIs. Employees may not report their OIIs to at least one of their supervisors/line manager, OHS representative, or employer; this applied to approximately 13% of employees in the 2017 financial year (171). Workers may feel it is unnecessary to report mild OIIs, be unwilling to undertake the compensation claims process which some workers may find daunting (202), be unaware of their eligibility, or fear that it may negatively impact their work or current or future employment (potentially because they feel they were responsible for causing their OIIs or if there is workplace pressure to not report OIIs) or when undertaking illegal professions without formal employment such as sex work (27,171,203). Employers may also elect not to report OIIs if they feel the OIIs are not work-related (204) or decide to compensate the payments themselves without officially reporting the claims (171).

The claims data do not include workers not covered by the state compensation schemes. This excludes self-employed workers, employees with separate private schemes that partially or completely cover payments, and workers with national compensation schemes (government employees, defence force personnel, and seafarers) (63). Some claims were removed due to missing data (4.1-6.5%), or when the workplace postcode could not be determined as occurring in the capital city (when postcodes were associated with multiple locations both in and outside the GCCSA, 2.73% of claims), hence selection bias may exist.

Although the claims data incorporates a range of direct costs, they may still omit relevant costs. There are limits on the compensations payouts provided, and depending on the initial severity of the OII, payouts may cease before the workers have fully recovered from the OIIs and return to full-time work (63,205). Mental stress regarding OIIs or the compensation claims process may lead to indirect costs through impaired work performance and additional medical costs regarding mental stress that cannot be convincingly linked to the OII in order to be eligible for compensation (202,206). Worker costs that are not compensated are covered by the workers and/or, in the case of medical costs, the public healthcare system. Claims may involve future payments that arise beyond the study period, although most payouts did occur in the same or subsequent financial year as the claim lodgment; this would capture most of the payouts, even for claims submitted at the end of the study period. Costs to employers not directly involving the worker are excluded. These include all payouts during the employer excess period, costs for hiring and training replacement staff, legal costs paid by the employers, and loss of labor productivity due to the workers' absence and/or decreased ability to work. Claim costs for mortality are compensation to workers' families, but they exclude costs to employers regarding lost labor productivity from the workers' absence and medical costs that occur during the employer excess period, which are likely considerably larger than those for non-fatal OIIs (207,208). Finally, weekly benefits are based on workers' pre-OII wages. These may cover less than the expected payrates due to underestimating or excluding pay from overtime work and future increases in wages (63). Although there were data for workers' wages and weekly workhours, these data were frequently missing (missing wages alone affected 15% of data for analysis) with uneven distributions across cities. This could create substantial bias not only from the quantity of missing data but also because these data could be "missing not at random" (209) e.g. wage rates or worktime were more likely to be missing if values were high or low.

There were no data available pertaining to the subjects' medical history, medications, migration status, and level of heat acclimatisation, which are known risk factors for heat stress (3,15). Similar to most environmental epidemiologic studies, exposure misclassification bias likely exists. The workplace postcode was used to define the study area. This may not be identical to the area of OII occurrence, which was not recorded. Furthermore, the meteorological data measure heat exposure based on the climate in the general area instead of estimating individuals' personal exposure. Non-climatological temperature variation such as air conditioning and workplace-generated heat was not analyzed. However, the confounding impact from air conditioning is partially mitigated by stratifying workers (and heat exposure in Chapter 4) as indoors/outdoors. The effect of air pollution on temperature was not considered (210). However, there is evidence to show that adjusting for air pollution may lead to biased instead of improved estimates of temperature, because air pollution is a mediator instead of a confounder (211) and that adjusting for air pollution only leads to small changes (155). Also similar to most other ecological studies, the results are less likely to be applicable to countries with different climates, in particular those that do not have a predominantly temperate climate like Australia (56).

Modeling by the date of OII instead of the date of claim submission was necessary to establish temporal relationships between temperature/heatwave and OIIs/costs. SWA legislation is generally based on the claim of submission instead of the date of OII (63). Thus the impacts of changes in legislation cannot be modeled as categorical variables occurring on set dates (71). Their impacts are instead, partially and indirectly, incorporated in the model seasonality trend variables and cannot be separated from other seasonal effects, which may have affected the model estimates.

The statistical analyses for costs required greater statistical power compared to OIIs owing to the costs' increased variance and greater skew. Despite the large number of compensation claims, there were an overall low number of claims in Darwin and Hobart due to their smaller population sizes. This necessitated grouping together occupational factors (miners and agriculture workers) and certain OIIs for the stratified analyses that generally have a high association with heat stress, because they had low counts in the Australian working population (13,39). These OIIs of interest included heat-related illnesses, cardiovascular diseases, and kidney diseases (3). However, these OIIs were all illnesses, and illnesses were associated with higher heat-AFs compared to injuries in this research. The increased statistical power requirements, in addition to the uncertainty in climate projections across GCMs (191), also resulted in underpowered projected cost-AFs, despite having enough power to project OIIs.

A minor limitation concerns the calculation of attributable risk. This may be slightly underestimated, because it estimates risk as due to a given exposure event instead of a series of past exposure events; the latter is impossible to calculate after reducing the lag-dimension with meta-analysis (157). However, this bias is likely very low (157), especially when considering the long duration of the study period.

Finally, the results may not be generalisable to other populations and regions. Other countries have different socioeconomic factors (212), different workers' compensation systems that have different cover and payout policies, and it may not be mandatory for employers to pay for their workers' compensation insurance. Six of the seven cities for study had temperate climates, whilst the other city, Darwin, had a tropical climate (56). The other previous study to model associated costs from occupational injuries directly against heat was also based (entirely) within a temperate climate zone (89) (Guangzhou, China, has a humid subtropical climate, similar to Brisbane). Hence the currently known relationships between

OII-associated costs are almost entirely restricted to temperate climate zones.

6.6 Policy and practical recommendations

A multi-disciplinary approach between employers, healthcare workers, government bodies, policy makers, OHS professionals, and public health professionals is required to improve workplace heat safety by promoting awareness, prompting behavioural changes and implementing preventative measures. Strategies should be focused on preventing, detecting, and managing occupational heat stress and OIIs. Preventing heat stress can reduce the incidence of heat-attributable OIIs. Detecting and managing heat stress can both prevent OIIs (including OIIs both in general and progression of heat stress to heat-related illnesses) and reduce the severity of OIIs that do occur. Detection is also important to identify OIIs that workers may have otherwise not noticed, including both (acute) injuries and (often insidious) illnesses. Both OII incidence and severity are associated with preventable costs.

Significant heat-attributable associations with OIIs and costs were observed both with workers in general and within the majority of the stratified analyses, including both indoor and outdoor workers. Heat adaptation strategies should be aimed at all workers. Strategies focusing on heat stress prevention may have a larger impact in groups associated with larger heat-attributable risks for OIIs. Based on this research's findings, this included males and younger workers. Similarly, detecting and managing OIIs may be more effective in strata associated with larger heat-attributable risks for costs, which in this research included females and middle-aged workers. "Machinery operators and drivers" was the group of occupations most consistently associated with increased heat-attributable outcomes; this group should be particularly targeted for prevention, detection, and management of OIIs.

6.6.1 Industries and employers

Potential strategies that can be addressed by workplace policies are summarized in Table 6.1. Guidelines by the International Organization for Standardization and National Institute for Occupational Safety and Health (NIOSH) provide recommendations that address these strategies and can be adopted into workplaces (145,213,214). These include work-to-rest ratios (including cessation of work) based on WBGT thresholds whilst considering physical workload, clothing, and acclimatisation to heat (145,165,213,214). On-site measurements of heat exposure are recommended to represent local conditions more accurately, although measurements from nearby climate stations including empirically estimated heat metrics are suitable alternatives (215). Cooling methods include air conditioning, fans, and cooling garments; the latter option is preferred in scenarios where electrical power is not available (165). Other strategies for preventing heat stress include easy access to clean water (ideally at about 10°C), working and resting indoors or in the shade wherever possible, acclimatisation plans up to 14 days in duration for new workers and those returning to work, use of PPE that minimizes unnecessary heat gain, and rescheduling work to avoid the hottest parts of the day (213,215,216). Methods to detect heat stress include increased worker supervision, either by OHS staff or by pairing workers as part of a "buddy system" (215), and employee health checks in high-risk settings (medical examination and/or physiological monitoring systems). Dedicated strategies for managing heat stress that occurs include emergency action plans and providing easy and quick access to first aid and medical services (215). Managers and supervisors should formally implement guidelines into mandated workforce practice as standard operating procedures.

Table 6.1: Workplace heat adaptation strategies by prevention (P), detection (D) and management (M)

Strategies	Goals
Regulated work-to-rest ratios, especially on hot days	P
Cessation of work during extremely hot days or heatwaves	P
Working and resting indoors or in the shade wherever possible	P
Graduated heat acclimatisation program for new workers and workers returning from leave	P
If PPE required, use PPE that minimizes heat gain	P
Reschedule work to avoid hottest parts of the days	P
On-site environmental measurements to guide workplace policy	P
OHS supervision of workers, particularly during high-risk settings	D
Pair workers to monitor each other ("buddy system")	D
Medical examination of employees in high-risk settings	D
Physiological monitoring systems for employees in high-risk settings	D
Easy and quick access to first aid and medical services	M
Emergency action plan(s) in the event of heat stress	M
Easy access to clean water	P, M
Easy access to air conditioning and/or ventilation	P, M
Portable cooling modalities where power not available such as cooling garments	P, M
Education and training regarding occupational heat stress	P, D, M
Detailed workplace assessments of heat stress risk with workplace activities	P, D, M
Regular reviews of workplace policy regarding heat stress	P, D, M

6.6.2 Government and policy-makers

Strategies that can be undertaken by governments and policy-makers are briefly summarized in Table 6.2. Heat adaptation workplace policies can be mandated by law (35,217). Despite mandatory OHS workplace practices in Australia (218), a previous survey in Australia among OHS professionals observed that 54% of professionals believed that polices regarding OHS safety were not adhered to (216). Policy development should involve OHS staff and stakeholders so that this development is more transparent, and policies can be better tailored to workforces (219). Field visits by OHS staff should be conducted to promote policy adherence, and progress reports should be undertaken to both track adherence and gauge their effectiveness (219) by assessing heat stress outcomes including labor productivity during hot days, OIIs, and costs from OIIs. Heatwave warning systems should include workers as a targeted population. Government urban planning includes a vast array of strategies that will likely take many years to implement. These include constructing new buildings with designs that minimize heat retention (such as coatings, glazing, insulation, window shading, and natural/passive ventilation), increasing greenspace, and reducing heat and greenhouse gas emissions by reducing vehicle density (by promoting public transport, walking, and cycling), and promoting electric vehicles over petrol vehicles (165,217). Urban planning can reduce urban heat islands which have been associated with considerable economic burden (220). New buildings can also be rented to businesses, and these workers can benefit from their improved designs. During heatwaves and summer, economies should ensure there is sufficient electrical power to meet the increased demand for air conditioning whilst avoiding a power blackout (hot days are associated with an increased likelihood of blackouts) (165,215). Climate mitigation can reduce future burden from occupational heat stress by reducing global warming. Such strategies are diverse and include using renewable energy sources, reducing waste of resources, and designing buildings with a low carbon footprint (215,221). Governments should review their policies yearly and ensure there is sufficient funding for healthcare services in preparation for hot weather and communicate workplace heat safety measures publicly during and in the lead-up to summer.

6.6.3 Healthcare workers

Hospitals should be prepared for an increase in emergency presentations and hospital admissions with longer duration of stay during hot weather in the general population (91) (and workers). This would require sufficient staff numbers, equipment and facilities, and healthcare worker training for reducing heat stress and treating heat-related illnesses. General practitioners should work alongside occupational health physicians and rehabilitation staff to provide patient education concerning occupational heat stress, and manage an expected increase in demand for patient

Table 6.2: Government and policy heat strategies to reduce heat stress burden by prevention (P), detection (D) and management (M)

Strategies	Goals
Heatwave warning systems including workers as a targeted population	P
Urban planning	P
Availability of electrical power on hot days	P
Climate mitigation	P
Mandating heat adaptation workplace policies	P, D, M
Transparent and multidisciplinary approach to workplace policy development	P, D, M
Monitoring workplace policy adherence and effectiveness	P, D, M
Sufficient funding of healthcare services in preparation for hot days	P, D, M
Advertising workplace heat safety measures	P, D, M
Regular reviews of government policy regarding heat stress	P, D, M

care (detecting and treating OIIs, and rehabilitation of ill/injured workers and preparing them for returning to work) (222). Although OIIs in remote and rural areas were not assessed in this research, easy access of healthcare and rehabilitation should also be made available to workers in rural and remote areas, including mining sites.

6.6.4 Workforce WHS education

Education should be targeted at workers, including managers and supervisors, to promote workplace heat safety measures (223). These should address simple strategies that workers can follow without the implementation of workplace guidelines, such as adequate hydration, maintaining adequate sleep and when unwell, taking time off work and (if required) seeking relevant medical advice (215). General health advice that can promote strong physical and mental health that may reduce the risk of OIIs, such as adequate nutrition, fitness, and sleep (215), should be included as part of these strategies. The symptoms of heat-related illnesses and their management (first aid and, if heat stroke is suspected, emergency procedures) (3,223) should also be taught. In a national Australian survey from 2017 to 2018 including 307 OHS professionals, only 42% of professionals reported that there was heat stress training at workplaces they manage or visit, and the largest barrier to preventing OIIs during hot weather was lack of awareness amongst workers that heat can be associated with OIIs (reported by only 43% of professionals) (216). This highlights the need for additional training despite mandatory OHS workplace practices (218). Yearly mandatory training should be provided to workers by OHS staff, with both on-site and online options, prior to summer, and completion of the training should be recorded and tracked by employers to encourage workers to complete the training.

6.7 Further research

Although this research's findings contribute new insights into the economic and morbidity burden of occupational heat stress, further studies are required to better understand this burden and how to minimize it.

6.7.1 Assessing occupational heat stress in work populations in other regions

Associated economic costs from OIIs should be evaluated in other countries to determine if they align with this study's results. Costs should be evaluated in cities with different climates, particularly arid, continental and polar/alpine climates which were not assessed in this research. This thesis research was only conducted in metropolitan Australia. Further research should be conducted in LMICs, where workers are considered more vulnerable to heat stress and likely have less access to heat-prevention measures such as air conditioning and OHS policies. Research in LMICs may be limited by reduced coverage of workers' compensation insurance, lower reporting rates for OIIs, and under-recording of OIIs (224). Analyzing heat-attributable OIIs in rural regions for high-income countries can extend the generalizability of results to these regions and potentially identify new associations, although obtaining a sufficient sample size for analysis in these regions would likely be more difficult compared to metropolitan areas. As this study did not have statistical power to evaluate the costs in certain high-risk workforces such as agricultural workers and miners, this should be targeted by further research with access to a sufficient sample size. Evaluating costs per OII would also be useful to determine if this research's observation of increasing costs per OII during colder temperatures is observed in different settings and if it occurs regardless of whether the OIIs increase or decrease with colder temperatures.

6.7.2 Minimizing economic impact

Chapter 5 evaluated the impact of theoretical adaptation. Further research should assess the financial impact of man-made heat adaptation measures such as air conditioning and policy changes in reducing occupational heat stress. An important goal would be to determine whether the heat-attributable costs averted from use of adaptation measures exceed the costs of implementing and utilizing them, resulting in a net financial benefit. This may require the creation of new datasets or surveys regarding the use of heat adaptation measures in labor forces. A heat stress awareness program in Texas was associated with decreased median costs per worker from OHIs in outdoor workers (46). Similarly, the effectiveness of heatwave warnings systems in reducing occupational heatwave-attributable burden should be assessed. A heatwave warning system in Adelaide has been associated with decreased morbidity and healthcare costs in the general population (225,226). As discussed in Chapter 3, previous research has already evaluated the financial impact of adaptation measures on minimizing heat-induced labor productivity loss, but further research is required to assess a wider range of measures and different population settings.

6.7.3 Future economic impact of OIIs

Given the lack of statistical power for determining a change in OII-associated costs secondary to heatwaves, the projected impact of global warming on OII-associated costs should be further investigated in larger datasets. Such an analysis could be done in countries with larger populations, or by analyzing and pooling results across multiple countries (155). This information could better guide projected economic analyses regarding the future costs of global warming and the benefits of climate mitigation and adaptation.

6.7.4 Data linkage with compensations claims data

Workers' OIIs are underreported worldwide (224). A study in Melbourne identified different patterns of occupational injuries captured in compensation claims and hospital (ED and inpatient admissions) datasets, with more injuries from younger workers being captured in the ED data and the claims data capturing more data from older workers (227). Future research should investigate the feasibility of data linkage between the claims dataset and other datasets that may increase the coverage of OIIs and associated costs (227,228). Medical datasets could include those for inpatient hospital admissions, ED admissions, ambulance call-outs, and outpatient health service care such as general practitioner and rehabilitation clinics. This could aid analysis of OIIs by enabling access to more OII records for analysis and including additional information regarding workers, such as workers' medical information and non-compensated medical costs, for more comprehensive analysis of costs and associated factors.

6.8 Conclusions

The financial impact of occupational heat stress is substantial yet underexplored. This impact is predominantly due to heat-induced labor productivity loss independent of morbidity. However, financial expenses associated with heat-attributable OIIs are also considerable. These expenses are likely to increase with higher levels of heat stress and during heatwaves. This applies to workers in general, including both indoor and outdoor workers. Heat stress is important in terms of both OHS and finances.

Workplace heat stress is particularly relevant with regards to global warming. Occupational health and financial burdens are likely to increase in the future, although further research is required to more precisely estimate the future impact on costs. These burdens are preventable. Both employees and employers, as well as wider economies, would benefit from heat adaptation strategies targeted at workers.

Appendices

A

Chapter 2 Supplementary Material

This appendix includes the supplementary material associated with the manuscript include in Chapter 2.3. The format of this chapter is identical to that of the published supplementary material, which is also available online (47).

Appendix A: Literature search strategy

Database	Keywords and terms			
	Heat	AND Work	AND (Medical cost	OR Productivity)
PubMed	hot temperature[mh] OR heat stress disorders[mh] OR global warming[mh] OR infrared ray[mh] OR heatwave*[tw] OR heat wave*[tw] OR heat injur*[tw] OR heat illness*[tw] OR heat-related illness*[tw] OR heat-related injur*[tw] OR high temperature*[tw] OR hot temperature*[tw] OR high air temperature*[tw] OR hot air temperature*[tw] OR high ambient temperature*[tw] OR hot ambient temperature*[tw] OR high environmental temperature*[tw] OR hot environmental temperature*[tw] OR high outdoor temperature*[tw] OR hot outdoor temperature*[tw] OR high seasonal temperature*[tw] OR hot seasonal temperature*[tw] OR air heat[tw] OR ambient heat[tw] OR environmental heat[tw] OR outdoor heat[tw] OR seasonal heat[tw] OR heat exposure[tw] OR thermal exposure[tw] OR heat stress*[tw] OR hot climate*[tw] OR hot weather*[tw] OR global warming*[tw] OR summer*[tw]	accidents, occupational[mh] OR occupational injuries[mh] OR occupational diseases[mh] OR occupation[mh] OR worker's compensation[mh] OR work-related[tw] OR workplace*[tw] OR worker*[tw] OR workman[tw] OR workmen[tw] OR working people[tw] OR occupation*[tw] OR employee[tw] OR employees[tw] OR manual labo*[tw] OR career*[tw] OR work*[ti]	cost of illness[mh] OR health care cost[mh] OR health expenditure[mh] OR health resource[mh] OR Economics, medical[mh] OR Economics, nursing[mh] OR costs and cost analysis[mh] OR occupational Injuries/economics[mh] OR cost of illness*[tw] OR health care cost*[tw] OR health expenditure*[tw] OR health resource*[tw] OR medical cost*[tw] OR medical expenditure*[tw] OR hospitalisation cost*[tw] OR hospitalisation cost*[tw]	efficiency[mh] OR efficien*[tw] OR produc*[tw] OR capacity[tw] OR capacities[tw] OR workload*[tw] OR work engagement[tw] OR work time*[tw] OR working time*[tw] OR job performance*[tw] OR absenteeism*[tw] OR presenteeism*[tw]
Embase	heat/syn OR ‘body temperature’/syn OR ‘heat injury’/syn OR ‘heat sensitivity’/syn OR ‘heat shock’/syn OR ‘thermal exposure’/syn OR ‘heat stress’/syn OR heatwave/syn OR ‘heat wave’/syn OR ‘hot temperature’/syn OR ‘high temperature’/syn OR ‘heat wave*’:ab,ti OR heatwave*:ab,ti OR ‘heat injur*’:ab,ti OR ‘heat illness*’:ab,ti OR ‘heat-related injur*’:ab,ti OR ‘heat-related illness*’:ab,ti OR ‘high temperature*’:ab,ti OR ‘hot temperature*’:ab,ti OR	‘occupational accident’/syn OR ‘manual labor’/syn OR ‘workman compensation’/syn OR career/syn OR occupational/syn OR ‘work-related’:ab,ti OR workplace*:ab,ti OR worker*:ab,ti OR workm?n:ab,ti OR ‘working people’:ab,ti OR occupation*;ab,ti OR employee:ab,ti OR employees:ab,ti OR ‘manual labo*’:ab,ti OR career*:ab,ti OR work:ti	‘cost of illness’/syn OR ‘cost effectiveness analysis’/syn OR ‘health care cost’/syn OR ‘hospitalization cost’/syn OR ‘cost of illness*’:ab,ti OR ‘health care cost*’:ab,ti OR ‘health expenditure*’:ab,ti OR ‘health resource*’:ab,ti OR ‘medical cost*’:ab,ti OR ‘medical expenditure*’:ab,ti OR ‘hospitali?ation cost*’:ab,ti	productivity/syn OR ‘work engagement’/syn OR ‘working time’/syn OR workload/syn OR absenteeism/syn OR ‘job performance’/syn OR presenteeism/syn OR capacity:ab,ti OR capacities:ab,ti OR efficiency:ab,ti OR productivity:ab,ti OR ‘work engagement’:ab,ti OR ‘work time*’:ab,ti OR ‘working time*’:ab,ti OR workload*:ab,ti OR absenteeism*:ab,ti OR ‘job performance*’:ab,ti OR presenteeism*:ab,ti

	‘high air temperature*’:ab,ti OR ‘hot air temperature*’:ab,ti OR ‘high ambient temperature*’:ab,ti OR ‘hot ambient temperature*’:ab,ti OR ‘high environmental temperature*’:ab,ti OR ‘hot environmental temperature*’:ab,ti OR ‘high outdoor temperature*’:ab,ti OR ‘hot outdoor temperature*’:ab,ti OR ‘high seasonal temperature*’:ab,ti OR ‘hot seasonal temperature*’:ab,ti OR ‘air heat’:ab,ti OR ‘ambient heat’:ab,ti OR ‘environmental heat’:ab,ti OR ‘outdoor heat’:ab,ti OR ‘seasonal heat’:ab,ti OR ‘heat stress’:ab,ti OR ‘thermal exposure*’:ab,ti OR ‘heat exposure*’:ab,ti OR summer*:ab,ti OR ‘hot weather’:ab,ti OR ‘hot climate*’:ab,ti OR ‘global warming’:ab,ti			
Scopus	TITLE-ABS-KEY(heatwave* OR “heat wave*” OR “heat injur*” OR “heat illness*” OR “heat-related injur*” OR “heat-related illness*” OR “high temperature*” OR “hot temperature*” OR "high air temperature*" OR "hot air temperature*" OR "high ambient temperature*" OR "hot ambient temperature*" OR "high environmental temperature*" OR "hot environmental temperature*" OR "high outdoor temperature*" OR "hot outdoor temperature*" OR “high seasonal temperature*” OR "hot seasonal temperature*" OR “air heat” OR “ambient heat” OR “environmental heat” OR “outdoor heat” OR “seasonal heat” OR "heat exposure*" OR "thermal exposure*" OR "heat stress*" OR “hot climate*” OR “hot weather” OR "global warming" OR “summer*”)	TITLE-ABS-KEY("work-related" OR workplace* OR worker* OR workm?n OR “working people” OR occupation* OR employee OR employees OR “manual labo*” OR career*) OR TITLE(work) OR KEY(work)	TITLE-ABS-KEY(“cost of illness*” OR “health care cost*” OR “health expenditure*” OR “health resource*” OR “medical cost*” OR “medical expenditure*” OR “hospitali?ation cost*”)	TITLE-ABS-KEY(productivit* OR efficienc* OR capacity OR capacities OR workload* OR “work engagement” OR “work time*” OR “working time*” OR “job performance*” OR absenteeism* OR presenteeism*)

The filters used in PubMed and Embase were restriction to studies in English and involving human populations.

The filters used in Scopus were restriction to studies in English and including at least one of the following subject areas relating to human health, environmental sciences or economics and finance:

- Business, Management and Accounting
- Decision Sciences
- Dentistry
- Economics, Econometrics and Finance
- Environmental Science
- Health Professions
- Immunology and Microbiology
- Medicine
- Nursing
- Pharmacology, Toxicology and Pharmaceutics
- Psychology
- Social Sciences

Appendix B: Currency exchange rate

USD	Australian Dollar	Canadian Dollar	Chinese Yuan	Euro	Indian Rupees	Malaysian Ringgit
1.00	1.45	1.33	7.08	0.90	71.02	4.17

Exchange rates between currencies compared to 1 United States Dollar (USD). These rates were sourced from Google Finance using the exchange rate on 14th September 2019.

Reference:

Reuters T. Google Finance. Morningstar for Currency and Coinbase for Cryptocurrency; [cited 14 September 2019]. Available from: https://www.google.com/intl/en/googlefinance/disclaimer/#!#disclaimers

Appendix C: Future projection scenarios

The different climate projection scenarios utilized by included studies and their associated increases in global average air temperature ($T_{average}$) are listed in Table C.1. This table includes likely ranges for the increases (a predicted probability of 0 to 66%) except for the increase with the ENSEMBLES E1 scenario where a likely range could not be determined (1).

The earliest set of projection scenarios used in this review's included the studies are the Special Report on Emissions Scenarios (SRES) A1B, A2 and B2. They project both climate and socioeconomic future scenarios based on future economic activity up to the year 2100 (3, 4). The ENSEMBLES E1 Scenario, developed by the European Commission with an ensemble of general circulation models, represents a climate mitigation scenario where greenhouse gases are stabilized at 450ppm CO_2-equivalent (1, 7). The representative concentration pathways (RCPs) predict future climate scenarios representing different projections of greenhouse gas concentrations by the level of radiative forcing (5, 9). The predicted rise in $T_{average}$ increases with higher radiative forcing values (2). RCP8.5 assumes no government action to lower greenhouse gas emissions whereas lower levels assume increasingly higher levels of action (5).

Table C.1: Future climate projection scenarios included in this review

Scenario	Definition	Baseline period	Projected period	Predicted increase in average global air temperature (°C)	
				Estimate	Likely range
SRES A1B	Rapid economic growth, with a balanced emphasis on all energy sources	1980-1999	2090-2099	2.8	1.7 – 4.4
SRES A2	Regionally oriented economic development	1980-1999	2090-2099	3.4	2.0 – 5.4
SRES B1	Global environmental sustainability	1980-1999	2090-2099	1.8	1.1 – 2.9
ENSEMBLES E1	Atmospheric greenhouse gas concentrations stabilized at 450ppm CO2-equivalent	1961-1990	2071-2100	1.5	N/A
RCP2.6	Radiative forcing: 2.6 W/m2	1980-1999	2081-2100	1.1	0.4 to 1.8
RCP4.5	Radiative forcing: 4.5 W/m2	1980-1999	2081-2100	1.9	1.2 to 2.7
RCP6.0	Radiative forcing: 6.0 W/m2	1980-1999	2081-2100	2.3	1.5 to 3.2
RCP8.5	Radiative forcing: 8.5 W/m2	1980-1999	2081-2100	3.8	2.7 to 4.9

The Shared Socioeconomic Pathways (SSPs) are future narratives of global socioeconomic change and how they would affect the socioeconomic difficulty of climate change adaptation and mitigation (6, 8). Higher difficulties reflect greater economic burdens. The included studies by Takakura et al. (2017 and 2018) and Orlov et al. (2020) use SSP1, SSP2 and SSP3 concurrently with RCPs to predict future economic burden secondary to global warming. The SSPs are summarized in Table C.2.

Table C.2: Shared Socioeconomic Pathways

Pathway	Scenario	Difficulty of dealing with climate change	
		Adaptation	Mitigation
SSP1	Sustainable development	Low	Low
SSP2	Middle of the Road (business as usual)	Moderate	Moderate
SSP3	Regional rivalry	High	High
SSP4	Inequality	High	Low
SSP5	Fossil-fueled development	Low	High

References:

1) Christensen OB, Goodess CM, Harris I, Watkiss P, 2011. European and Global Climate Change Projections: Discussion of Climate Change Model Outputs, Scenarios and Uncertainty in the EC RTD ClimateCost Project. Sweden: ClimateCost; [cited 26 April 2020]. Available from: http://www.climatecost.cc/images/Policy_brief_1_Projections_05_lowres.pdf
2) Department of the Environment, 2013. Representative Concentration Pathways (RCPs). Canberra, Australia: Australian Government; [cited 7 September 2019]. Available from: https://www.environment.gov.au/system/files/resources/492978e6-d26b-4202-ae51-5eba10c0b51a/files/wa-rcp-fact-sheet.pdf
3) Intergovernmental Panel on Climate Change, 2000. Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press; [cited 9 November 2020]. Available from: https://www.ipcc.ch/site/assets/uploads/2018/03/emissions_scenarios-1.pdf
4) Intergovernmental Panel on Climate Change, 2007. Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: Intergovernmental Panel on Climate Change; [cited 4 October 2019]. Available from: https://www.ipcc.ch/assessment-report/ar4/
5) Intergovernmental Panel on Climate Change, 2015. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: Intergovernmental Panel on Climate Change; [cited 3 April 2020]. Available from: https://www.ipcc.ch/assessment-report/ar5/
6) O'Neill BC, Kriegler E, Riahi K, Ebi KL, Hallegatte S, Carter TR, et al. A new scenario framework for climate change research: the concept of shared socioeconomic pathways. Clim Change. 2013; 122(3):387-400. DOI: 10.1007/s10584-013-0905-2.
7) van der Linden P, Mitchell JFB, 2014. ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. United Kingdom: European Commission; [cited 26 April 2020]. Available from: http://ensembles-eu.metoffice.com/docs/Ensembles_final_report_Nov09.pdf
8) Van Vuuren DP, Carter TR. Climate and socio-economic scenarios for climate change research and assessment: reconciling the new with the old. Clim Change. 2014; 122(3):415-29. DOI: 10.1007/s10584-013-0974-2.
9) Van Vuuren DP, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K, et al. The representative concentration pathways: an overview. Clim Change. 2011; 109(1-2):5-31. DOI: 10.1007/s10584-011-0148-z.

B

Chapter 3 Supplementary Material

This supplementary material includes extracted sections from the online SWA annual publications titled "Comparison of workers' compensation arrangements in Australia and New Zealand" in 2019 and 2021 (63,65).

B.1 Appendix 1: Summary of workers' compensation entitlements as at 30 September 2018

This extract was from “Comparison of workers' compensation arrangements in Australia and New Zealand 2019, 27th Edition” (65).

Table 2.5: Summary of entitlements as at 30 September 2018

	New South Wales	Victoria	Queensland	Western Australia	South Australia	Tasmania	Northern Territory	Australian Capital Territory	C'wealth Comcare	C'wealth Seacare	C'wealth DVA	New Zealand
What pre-injury weekly earning includes												
Overtime	Yes, for the first 52 weeks of weekly payments.	Yes, for first 52 weeks of weekly payments.	Yes (NWE)	Yes, for the first 13 weeks. No from week 14 onward.	Yes	No, with some exceptions (see note)[a].	Yes, if regular and established.	Yes, if regular and required.	Yes, if regular and required.	Yes, if regular and required.	*Military Rehabilitation and Compensation Act 2004* (MRCA) – Yes. *Safety, Rehabilitation and Compensation (Defence-related Claims) Act 1988* (DRCA) – Yes.	Yes
Bonuses	No	No	Yes	Yes, for the first 13 weeks. No from week 14 onward.	Yes	No (s70(2)(ac))	No	No	No (some allowances are payable).	No (some allowances are payable).	MRCA – No (some allowances are payable). DRCA – No (some allowances are payable).	No
Entitlements expressed as a percentage of pre-injury earnings for award wage earners[b]												
0–13 weeks (total incapacity)	95% less any deductibles (subject to max cap)*.	95% up to max	85% of NWE[c] (or 100% under industrial agreement).	100%	100%	100% s69B(1)(a)	100%	100%	100%	100%	MRCA – 100% DRCA – 100%	80%
14–26 weeks (total incapacity)	80% less any deductibles (subject to max cap)*.	80% up to max	85% of NWE[c] (or 100% under industrial agreement).	100%	100%	100% s69B(1)(a)	100%	100%	100%	100%	MRCA – 100% DRCA – 100%	80%
27–52 weeks (total incapacity)	80% less any deductibles (subject to max cap)*.	80% up to max	75% NWE or 70% QOTE[c]	100%	100%	90% (95% in some circumstances) s69B(1)(b)	75–90%	65% or Stat Floor	27–45 wks. 100%. 46–52 wks. 100% x adjustment percentage (75% if not employed, increasing in 5% increments until employee is working 100% of normal weekly hours).	27–45 wks — 100%. 46–52 wks — 75%	MRCA 27–45 wks. — 100%. 46–52 wks. — 75% DRCA 27–45 wks. — 100%. 46–52 wks. — 75%. Payments are further reduced by any employer	80%

	New South Wales	Victoria	Queensland	Western Australia	South Australia	Tasmania	Northern Territory	Australian Capital Territory	C'wealth Comcare	C'wealth Seacare	C'wealth DVA	New Zealand
											funded superannuation benefit (weekly equivalent if lump sum is involved) received, plus a 5% "notional" superannuation deduction under the DRCA where superannuation is being received.	
53–104 weeks (total incapacity)	80% less any deductibles (subject to max cap and excludes overtime and shift allowance)*.	80% up to max	75% NWE or 70% QOTE[c]	100%	80%	53–78 weeks 90% (or 95%), s69B(1)(b) 79–104 weeks 80% (85% in some circumstances. s69B(1)(c)	75–90%	65% or Stat Floor	75% or adjusted percentage If an employee retires or is retired - 70% less any employer funded superannuation benefit (weekly equivalent if lump sum is involved) received.	75% If an employee retires or is retired - 70% less any employer funded superannuation benefit (weekly equivalent if lump sum is involved) received.	MRCA – 75% DRCA – 75% Payments are further reduced by any employer funded superannuation benefit (weekly equivalent if lump sum is involved) received, plus a 5% "notional" superannuation deduction under the DRCA where superannuation is being received.	80%
104+ weeks (total incapacity)	80% less any deductibles (subject to max cap, excludes overtime and shift allowance, subject to meeting requirements of s38 of *Workers Compensation Act 1987*. These provisions apply after week 130.) Payments cease at five years unless permanent impairment of >20%.	80% (up to max, subject to work capacity test after 130 weeks)	If >15% degree of permanent impairment can be demonstrated, 75% NWE or 70% QOTE, otherwise single pension rate[d].	100%	80% for seriously injured workers (WPI of 30% or more) s41(1). No entitlements for non-seriously injured workers s39(3) beyond 104 weeks.	80% (or 85%) The maximum payment period varies according to the assessed percentage of whole person impairment. s69B(1)(c)	75–90% Compensation ceases after 260 weeks unless 15% or greater WPI.	65% or Stat Floor.	75% If an employee retires or is retired, 70% less any employer funded superannuation benefit (weekly equivalent if lump sum is involved) received.	75% If an employee retires or is retired, 70% less any employer funded superannuation benefit (weekly equivalent if lump sum is involved) received.	MRCA – 75% DRCA – 75% Payments are further reduced by any employer funded superannuation benefit (weekly equivalent if lump sum is involved) received, plus a 5% "notional" superannuation deduction under the DRCA where superannuation is being received.	80%

	New South Wales	Victoria	Queensland	Western Australia	South Australia	Tasmania	Northern Territory	Australian Capital Territory	C'wealth Comcare	C'wealth Seacare	C'wealth DVA	New Zealand
Other entitlements												
Permanent impairment	Date of injury on or from 5th August 2015 - maximum amount payable for permanent impairment is $577,050 (plus additional 5% for back impairment) Indexed to $610,930 on 1 July 2018. Date of injury prior to 5th August 2015 maximum amount payable for permanent impairment is $220,000 (plus additional 5% for back impairment).	$623,950	$330,240 permanent impairment plus $374,100 gratuitous care.	$228,307 + up to $175,230.25 in special circumstances.	Lump sum of up to $372,614 – economic loss s55(8). Lump sum of up to $502,497 – non economic loss s58(4).	$359,987.60	$336,232 (208 times AWE) – s71. For injuries prior to 15 October 1991, maximum $168,116 (104 times AWE).	$216,335.00	$189,310.19 (Economic) $ 70,991.36 (non-economic loss).	$189,310.19 (Economic) $ 70,991.36 (non-economic loss.	MRCA Up to $347.24 per week (which can be converted to a maximum lump sum of up to $464,364.05) + $89,393 for each dependent child if on 80 or more impairment points. $2,636.71 in compensation for financial and legal advice is also payable if on 50 or more impairment points. DRCA Lump sum up to $260,301.55 + $80,918.19 in cases of severe injury.	Up to $138,209.55 lump sum payment.
Limits—medical and hospital	Medical 1) if over 20% permanent impairment - No compensation period limit 2) if 11-20% permanent impairment, 5 years after weekly payments cease to be payable or from the date of claim if no weekly payments are payable 3) if <11% permanent impairment, 2 years after	52 weeks from cessation of weekly payments[d].	Medical — no limit. Hospital — 4 days (>4 days if reasonable).	$68,492 + $50,000 in special circumstances.	No financial limit, but entitlements for non-seriously injured workers cease 1 year after end of weekly payments or 1 year after claim was made s33(20). For seriously injured workers, lifetime care and support s33(21).	No limit, but entitlements cease either after 1 year of weekly benefits cessation or 1 year after claim was made. unless the Tribunal makes a relevant determination s75.	No limit After 260 weeks of paid weekly compensation, medical entitlement ceases after a further 12 months if WPI is less than 15%.	No limit	No limit	No limit	No limit	No limit

	New South Wales	Victoria	Queensland	Western Australia	South Australia	Tasmania	Northern Territory	Australian Capital Territory	C'wealth Comcare	C'wealth Seacare	C'wealth DVA	New Zealand
	weekly payments cease to be payable or from the date of claim if no weekly payments are payable (see further s59A 1987 Act). Some medical treatment and services are exempt. See s59A, 1987 Act.											
Special entitlements	—	—	Worker who has sustained an injury that is pneumoconiosis : up to $123,700 based on a graduated scale calculated on the basis of— (a) the worker's pneumoconiosis score; and (b) the worker's lodgement age.	—	—	—	—	—	—	—	—	—
Death entitlements (all jurisdictions pay funeral expenses to differing amounts)	$791,850 + $141 80 pw for each dependent child. Funeral expenses: maximum $15,000.	$623,950 (shared) + pre-injury earnings-related pensions to a maximum of $2,310 pw for dependant partner/s and children.	$618,565 + $16,540 to dependant spouse + $33,060 for each dependant family member under 16 or student + $122.25 pw per child to spouse while children are under 6 yrs. + $152.80 pw per dependent child/family member while children/family members under 16 yrs. or a student.	$570,768 + $135 pw for each dependent child.	$502,497 + Up to: 50% worker's NWE for spouse 25% worker's NWE for orphaned child 12.5% worker's NWE for non-orphaned child. Funeral benefit: up to $10,605.	$359,987.60+ 100% weekly payment— 0–26 weeks, 90% weekly payment — 27–78 weeks, 80% weekly payment — 79–104 weeks + $128 37 pw for each dependent child. s67A	Funeral $16,811.60 (20% of annual equivalent of AWE). Death benefit $588,406 (364 times AWE). Dependant children's benefit $161.65 weekly payment per child (10% of AWE – maximum 10 children).	$550,321 (lump sum) cpi indexed + $151.34 (cpi indexed) pw for each dependent child. Funeral expense: $12,053.62 (CPI indexed).	$550,321.42 lump sum + $12,053.62 funeral + $151.34 pw for each dependent child.	$550,321.42 lump sum + $6,555.03 funeral + $151.34 for each dependent child.	MRCA Dependent partner receives $470.80 + $148,988.34 additional compensation for service related death + up to $2,636.71 for financial and legal advice + for each dependent child ($89,393 lump sum + a periodic payment of $148.68 per week while the child remains an "eligible young person").	Up to $138,209.55 lump sum + Survivors grant of $6,668.03+ Funeral grant of $6,219.44. Child care payments of $141.79 pw for one child, $85.07 pw each for two children, or $198 51 pw in total for three or more children.

	New South Wales	Victoria	Queensland	Western Australia	South Australia	Tasmania	Northern Territory	Australian Capital Territory	C'wealth Comcare	C'wealth Seacare	C'wealth DVA	New Zealand
											A lump sum up to $89,393 is also payable for anyone who qualifies as an 'other dependent'. <u>DRCA</u> $550,321.42 lump sum + $151.34 pw for each dependent child + additional death benefit lump sum for the surviving spouse of $60,756.25 + $89,301.98 for each dependent child + reimbursement up to $1,706.17 financial advice. Funeral compensation is also payable up to $12,053.62.	

Entitlements benefits in New South Wales, Western Australia, Victoria, Tasmania, Queensland, Northern Territory, Australian Capital Territory and New Zealand do not include superannuation contributions. Compensation in the form of superannuation contribution is payable in Victoria after 52 weeks of weekly payments.

a. No, unless overtime was a requirement of the worker's contract of employment, the overtime was worked in accordance with a regular and established pattern and in accordance with a roster, the pattern was substantially uniform as to the number of overtime hours worked and the worker would have continued to work overtime in accordance with the established pattern if the worker had not been incapacitated s70(2)(ab).
b. Payment thresholds and specific benefit arrangements may also apply. The relevant jurisdiction should be contacted directly if further information is required.
c. NWE — normal weekly earnings (except South Australia where NWE denotes notional weekly earnings), QOTE — the amount of Queensland full-time adult persons ordinary time earnings declared by the Australian Statistician in the original series of the statistician's average weekly earnings publication most recently published before the start of the financial year, or, if that amount is less than QOTE for the previous financial year—the amount that is QOTE for the previous financial year. QOTE for 2018-19 is $1,527.80.
d. Lump sums maximum and Death entitlements are updated on annual basis and may since have been changed.
e. Lump sum shared under statutory formulae between spouse and children. Pension payable to partner for 3 years and to children until age of 16 (or 21 in full-time study).

* NSW Exemptions:

- police officers, paramedics and fire fighters
- workers injured while working in or around a coal mine
- bush fire fighter and emergency service volunteers (Rural Fire Service, Surf Life Savers, SES volunteers), and
- people with a dust disease claim under the *Workers' Compensation (Dust Diseases) Act 1942*.

Claims by these exempt workers continue to be managed and administered as though the June 2012 changes never occurred.

B.2 Appendix 2: Employer excess for Australian workers' compensation claims as at 30 September 2018

This extract was from "Comparison of workers' compensation arrangements in Australia and New Zealand 2019, 27th Edition" (65).

Table 2.11: Employer excess

	New South Wales	Victoria	Queensland	Western Australia	South Australia	Tasmania	Northern Territory	Australian Capital Territory	C'wealth Comcare	C'wealth Seacare	C'wealth DVA	New Zealand
Excess	Yes — s160 (*Workers Compensation Act 1987*).	Yes — s72	Yes — s65	No	Yes — s34 (transportation) and s64 (income support).	No	Yes — s56	No	No	Not prescribed under legislation but may be negotiated between employer and insurer.	N/A	Yes — s98
Period of incapacity	One week's weekly compensation up to a maximum amount prescribed in the Market Practice and Premium Guidelines.	First 10 days	The lesser of: 100% of Qld full-time adult's ordinary time earnings (QOTE), or he injured worker's weekly compensation rate. QOTE is $1,527.80 (as at 30 September 2018)	—	First two weeks of the period of incapacity per worker per calendar year.	—	Any part day lost on day of injury	If an employer does not provide an injury notice to an insurer within 48 hours, the employer is liable for weekly compensation payments from the date of injury until the employer gives the insurer the injury notice s93(2) and s95(2).	Any part day lost on day of injury.	—	N/A	First week
Cost of benefits	—	First $707 of medical costs	$1,527.80 (max)	—	Differs depending upon cost of 2 weeks income support for worker.	—	—	As above	N/A	—	N/A	N/A
Buyout option	Excess is waived if the claim is reported to an insurer within 5 calendar days of the employer becoming aware of the injury.	Yes - employers can waive claims excess by paying an additional 10% on their premium	No	—	See s64(14)	—	—	N/A	N/A	—	N/A	N/A

B.3 Appendix 3: History of workers' compensation schemes in Australia and New Zealand

This extract was from "Comparison of workers' compensation arrangements in Australia and New Zealand 2021, 28th Edition" (63).

Chapter 1:

History of workers’ compensation schemes in Australia and New Zealand

Overview

This section provides an historical overview of the development of workers' compensation schemes in Australia at both the national and jurisdictional level, and for New Zealand.

In preparing this section the following publications were used: Kevin Purse, 'The Evolution of workers' compensation policy in Australia', 2005, from the Health Sociology Review; the CCH Workers' Compensation Guide, Volume 1; and the Productivity Commission's *National Workers' Compensation and Occupational Health and Safety Frameworks* report of 2004.

The national perspective

There are 11 main workers' compensation systems in Australia. Each of the eight Australian states and territories have developed their own workers' compensation scheme and there are three Commonwealth schemes: the first is for Australian Government employees and the employees of licensed self-insurers under the Safety, Rehabilitation and Compensation Act 1988 (SRC Act), and Australian Defence Force personnel with service prior to 1 July 2004 under the Safety, Rehabilitation and Compensation (Defence-related Claims) Act 1988 (DRCA); the second is for certain seafarers under the Seafarers Rehabilitation and Compensation Act 1992; and the third is for Australian Defence Force personnel for service on or after 1 July 2004 under the Military Rehabilitation and Compensation Act 2004 (MRCA). The Veterans' Entitlements Act 1986 (VEA) also provides compensation coverage to veterans and other Australian Defence Force personnel with certain periods of service prior to 1 July 2004.

The origin of these Australian workers' compensation systems lies in 19th century British law. Before the implementation of workers' compensation arrangements an injured worker's only means of receiving compensation was to sue their employer for negligence at common law. However, workers rarely succeeded in these actions due to what has been described as the 'unholy trinity' of legal defences: common employment, voluntary assumption of risk and contributory negligence. To limit the application of those defences, the *Employment Liability Act 1880* was enacted in Britain. This Act was adopted in the Australian colonies between 1882 and 1895. While these Acts were well intentioned, taking them up did not lead to any significant improvement in outcomes for injured workers.

New workers' compensation laws incorporating a 'no-fault' principle came about after Federation in Australia. New laws were prompted by the failure of the *Employment Liability Act 1880* to improve conditions for injured workers, increasing industrialisation and the rise of the labour movement and popular support for state intervention on behalf of workers. To be eligible for workers' compensation under the no-fault principle, workers covered by the legislation merely had to prove that their injuries were work related. It was no longer necessary to prove negligence on the part of an employer. Nonetheless early no-fault coverage for workers' compensation was limited. Firstly, although laws provided for some benefits, the taking out of insurance by employers was not compulsory. Secondly, to be eligible for workers' compensation, an injury had to be found to have arisen out of and in the course of employment.

In keeping with contemporary attitudes, the first workers' compensation laws in Australia were generally known as workmen's compensation and did not expressly cover female workers until challenged by the women's movement of the 1970s. Coverage for workers' compensation gradually expanded to include most workers, and lump sum payments for loss of body parts were introduced. By 1926 New South Wales had introduced compulsory insurance which became the model for most workers' compensation schemes around Australia.

Between the 1920s and 1970s incremental reforms took place across the jurisdictions. Eligibility continued to widen with the broadening of the definition of injury to 'arising out of or in the course of employment'. Reforms from the 1970s to the mid-1980s generally improved compensation benefits for workers. However, economic difficulties in the mid 1980s and early 1990s shifted the focus onto reducing the cost of workplace injuries, containing insurance premiums, underwriting arrangements and administrative efficiency.

In the last quarter of the twentieth century there was a shift in emphasis in the schemes to strengthen the role of work health and safety and to highlight the need for rehabilitation of injured workers. This shift was expected to place downward pressure on costs but did not achieve the level of success expected. Further reform attempts focussed on cutting back benefits and making premiums more competitive. By the mid 1990s, workers' compensation costs had fallen by 20 per cent as a percentage of total labour costs, easing pressure for reform of premiums and costs, although each jurisdiction continues to grapple with these issues.

Since the introduction of the first workers' compensation laws, each jurisdiction has developed its own arrangements. This has resulted in differences in the operation and application of workers' compensation laws. Some of the differences include scheme funding, common law access, level of entitlements, return to work and coverage. These differences can be attributed in part to the varying industry profiles and economic environments of each jurisdiction and judicial decisions that have led to legislative amendments. However, as businesses and workers become increasingly mobile, the need to understand the various workers' compensation systems at the national level is becoming increasingly important.

In the 21st century workers' compensation systems have continued to adapt to changing societal expectations and increasing knowledge regarding the impact of work on health. This is reflected through reviews into the impact of the gig economy, additional diseases such as silicosis added to deemed disease lists and the introduction of presumptive legislation. In particular, presumptive legislation for firefighters and first responders which acknowledge that these occupations have an increased risk of developing certain forms of cancers and post-traumatic stress disorder (PTSD).

The recent global pandemic can also be reflected in legislative developments for workers' compensation schemes with the utilisation of presumptive laws in certain jurisdictions for occupations with an increased risk of contracting COVID-19 in the workplace and a number of jurisdictions which have made other adjustments to their benefits and payments.

It is anticipated that workers' compensation schemes will continue to evolve to meet emerging societal trends in relation to the changing nature of work.

New South Wales (NSW)

1910–1987

New South Wales introduced the *Workmen's Compensation Act 1910*. It applied to personal injury by accident arising in the course of employment, which was limited to defined 'dangerous occupations'. Compulsory insurance for employers and the first specialised workers' compensation tribunal in Australia, the Workers' Compensation Commission, were introduced in the *Workers' Compensation Act 1926*. This Act remained essentially unchanged until the mid-1980s.

1987–2012

The *Workers Compensation Act 1987* repealed the 1926 Act and introduced a radically different scheme which included public underwriting of the scheme and removing the right of workers to make common law damages claims against their employers. In 1989 the *Workers Compensation (Compensation Court Amendment) Act 1989* re-established common law rights and set out the role of the Compensation Court.

From 1987 to 1991 the workers' compensation scheme performed well and in the early 1990s premium levels were reduced and there were a number of legislative amendments that expanded the range and level of benefits. However, the previous surplus of almost $1 billion quickly eroded and by mid 1996 there was a $454 million deficit. The Grellman Inquiry of 1997 was initiated to address continuing financial problems. The inquiry recommended structural changes including stakeholder management, accountability controls and greater incentives for injury management.

Changes in the period 2000–2005 continued to focus on greater competition and choice for employers, improved outcomes for injured workers and reducing the scheme's deficit, which was eliminated in mid 2006.

The improved performance of the NSW WorkCover Scheme saw the target premium collection rate for NSW employers reduced by an average 30 per cent between November 2005 and 2008. A 10 per cent increase in lump sum compensation benefits for permanent impairment was also implemented for injuries received on or after 1 January 2007.

The structure of the Scheme also continued to evolve. In 2005 the Scheme transitioned from using insurers on open-ended licences to appointing Scheme Agents on commercial performance contracts for claims management and policy administration services that commenced on 1 January 2006. The contracts made Agents more accountable for delivering good Scheme outcomes and improved service standards.

From 30 June 2008 employers whose annual wages are $7,500 or less receive automatic coverage and are no longer required to hold workers' compensation insurance, except where an employer engages an apprentice or trainee or is a member of a group of companies for workers' compensation purposes.

In December 2008 the compensation available to families of workers who die as a result of a workplace injury or illness was increased for deaths occurring on or after 24 October 2007. The lump sum death benefit was increased from $343,550 to $425,000 (indexed). The changes also required payment of the lump sum to be made to a deceased worker's estate where they leave no financial dependants. Previously only financial dependants were entitled to the lump sum payment.

An optional alternative premium calculation method for large employers based on commercial retro-paid loss premium arrangements was introduced from 30 June 2009. The retro-paid loss premium method derives an employer's premium almost entirely from their individual claims experience and success in injury prevention and claims management during the period of the insurance policy. This provides a strong financial incentive for these employers to reduce the number and cost of workers' compensation claims.

2012

In June 2012 the NSW Government introduced significant changes to the NSW workers' compensation system. The *Workers Compensation Legislation Amendment Act 2012* was assented on 27 June 2012 and amended the *Workers Compensation Act 1987* and the *Workplace Injury*

Management and Workers Compensation Act 1998. The changes affected all new and existing workers' compensation claims, except for claims from:

- police officers, paramedics and fire fighters
- workers injured while working in or around a coal mine
- bush fire fighter and emergency service volunteers (Rural Fire Service, Surf Life Savers, SES volunteers), and
- people with a dust disease claim under the *Workers' Compensation (Dust Diseases) Act 1942*.

Claims by these exempt workers will continue to be managed and administered as though the June 2012 changes never occurred. The changes came into effect in stages and included:

- changes to permanent impairment lump sum compensation claims made on or after 19 June 2012
- changes to parameters around journey claims, heart attack and stroke injuries and disease injuries for an injury received on or after 19 June 2012
- reforms for seriously injured workers (injured workers with a permanent impairment of more than 30 per cent) which came into effect on 17 September 2012
- changes to weekly payments (1 October 2012 for new claims, 1 January 2013 for existing claims) including calculation methods, step-downs and caps
- the introduction of work capacity assessments
- the establishment of the WorkCover Independent Review Officer (now Workers' Compensation Independent Review Officer) from 1 October 2012, and
- changes to medical and related treatment (1 October 2012 for new claims, and 1 January 2013 for existing claims).

2014

The *Workers Compensation Amendment (Existing Claims) Regulation 2014* was made on 3 September 2014 and applies some benefit reforms to workers who made a claim for compensation before 1 October 2012.

2015

In August 2015, the NSW Government announced a $1 billion staged reform package with three elements:

- enhanced benefits for injured workers, including changes to lump sum compensation for permanent impairment, increased death benefit lump sum and funeral expenses, extension of weekly payments beyond retiring age, extended medical entitlements, the introduction of work capacity decision 'stay', the introduction of new return to work assistance benefits, the regulation of legal costs for work capacity decision reviews and the regulation of pre-injury average weekly earnings.
- premium reductions for employers with good safety and return to work records
- structural reform for better service and regulation

On 1 September 2015 the *State Insurance and Care Governance Act 2015* commenced, paving the way for three new organisations - Insurance & Care NSW (icare), the State Insurance Regulatory Authority (SIRA), and SafeWork NSW. icare manages approximately $30 billion in assets and $26 billion in liabilities, making it the largest general insurer service provider in Australia.

SIRA is a statutory body governed by an independent Board and regulates workers' compensation insurance and related activities, motor accidents CTP insurance and home building compensation insurance in NSW. SIRA approves premium, licensing and policy frameworks for insurers, supervises insurers, and monitors the financial solvency and performance of the three compulsory insurance schemes. SIRA also plays a role in funding, promoting and informing injury prevention in relation to the schemes it regulates. SIRA also has specific functions within the Lifetime Care and Support

Scheme and the Dust Diseases Scheme. SIRA aims to ensure that people who suffer injury or loss are supported, and insurance is affordable, well managed and sustainable.

2016

From 2016-17, annual Market Practice and Premiums Guidelines replaced the publication of the WorkCover Insurance Premiums Order, and provided a new mechanism for the setting and assessment of workers' compensation premiums.

The Workers Compensation Amendment (Legal Costs) Regulation 2016 was made on 16 December 2016 and provides for the recovery of legal costs for merit reviews of work capacity decisions. Further transitional arrangements for workers receiving weekly payments of compensation before 1 October 2012 were also made on 16 December 2016 under the Workers Compensation Amendment (Transitional Arrangements for Weekly Payments) Regulation 2016.

Victoria

Victoria introduced the *Workers' Compensation Act 1914* with benefits payable to workers arising 'out of and in the course of' employment. The *Workers' Compensation Act 1946* changed to arising 'out of or in the course' of employment. Major amendments were made in 1984 and the *Accident Compensation Act 1985* was introduced. The *Accident Compensation Act 1985* made sweeping changes to the system including public underwriting, vocational rehabilitation, work health and safety reforms and a new dispute resolution system.

The Act has been constantly updated with major reforms as follows:

1992

- restricting weekly benefits for workers with a partial work capacity
- introducing a non-adversarial dispute resolution system via conciliation
- establishing expert Medical Panels to determine medical questions
- limiting access to common law to seriously injured workers, and
- reinstating the right to sue for economic loss.

1993

- introducing the premium system.

1997

- removing access to common law
- significantly changing the structure of weekly benefits
- introducing impairment benefits to replace the Table of Maims, and
- restructuring death benefits.

2000

- reinstating access to common law damages for seriously injured workers with a new threshold for economic loss.

2004

- improving the efficiency of the claims process, and
- facilitating early and sustainable return to work.

2005

- making provision for previously injured workers whose employers exit the Victorian scheme to become licensed corporations under the Comcare scheme.

2006

- enhancing existing benefits including death benefits and the extension of the weekly benefits entitlement period from 104 to 130 weeks with increased payments for workers with a partial work capacity.

2007

- clarifying the financial guarantee requirements on employers who exit the Victorian WorkCover scheme (or Victorian self-insurer arrangements) to self insure under the federal Comcare scheme

- mandating the return of the management of tail claim liabilities to the Victorian WorkCover Authority (WorkSafe Victoria) for Victorian self-insurers who cease their self-insurance arrangements under the Victorian scheme
- restoring the original approach to the assessment of permanent impairment for injured workers who suffer spinal injuries prior to the decision of the Full Court of the Supreme Court in Mountain Pine Furniture Pty Ltd v Taylor
- confirming that compulsory employer superannuation payments are not taken into account in the calculation of weekly benefit compensation
- improving counselling benefits for the families of deceased or seriously injured workers, and
- contributions towards the purchase price of a car where the current car is unsuitable for modification, home relocation costs and portable semi-detachable units in addition to car and home modifications.

2008

- preservation of the higher impairment rating regime for workers with musculoskeletal injuries assessed under Chapter 3 of the American Medical Association Guides (4th edition) in place since 2003
- retrospective amendments to the Act to maintain the status quo regarding recovery rights against negligent third parties that contribute to the compensation costs payable for a worker's injury, and
- workers with asbestos-related conditions can claim provisional damages and access expedited processes to bring on court proceedings quickly where the worker is at imminent risk of death.

2009

- on 17 June 2009 the Victorian Government responded to 151 recommendations made in a commissioned report following a review undertaken in 2008 by Mr Peter Hanks QC of the *Accident Compensation Act 1985* and associated legislation, and
- improvements to benefit both workers and employers and aimed at enhancing the scheme as a whole were introduced into Parliament in December 2009.

2010

The *Accident Compensation Amendment Act 2010* was passed with the majority of the reforms commencing from 5 April 2010, except for new return to work rights and obligations commencing from 1 July 2010. The Act introduced the following changes:

- almost a doubling of lump sum death benefits, and improved access to pensions for dependants of deceased workers

For injured workers who suffer a permanent impairment, the reforms provided:

- a 10 per cent increase in no-fault lump sum benefits for workers with spinal impairments
- a 25 per cent increase in the maximum impairment benefit, increasing no-fault lump sum benefits for the most profoundly injured workers, and
- a five-fold increase in benefits awarded to workers who suffer a serious psychiatric impairment.

For injured workers who receive weekly payments:

- an increase in the rate of compensation from 75 per cent to 80 per cent of income after workers have received compensation for 13 weeks
- a superannuation contribution for long term injured workers
- the extension of the inclusion of overtime and shift allowances from 26 weeks to 52 weeks when calculating a worker's weekly payments
- increasing the statutory maximum for weekly payments to twice the state average weekly earnings, and

- payment of limited further weekly payments for workers who have returned to work, but who require surgery for their work-related injury.

Other changes include:

- the replacement of prescriptive return to work requirements with a performance based regulatory framework from 1 July 2010 and the appointment of a Return to Work (RTW) Inspectorate with the power to enter workplaces and issue return to work improvement notices for any contravention by an employer of the return to work part of the Act
- greater accountability and transparency of decisions made by Victorian WorkCover Authority and its agents, including the right of employers to request written reasons for agents' claims decisions and to appeal premium determinations, and
- less red tape for employers and improved understanding and usability of the legislation by the removal or reform of anomalous, obsolete, inoperative or unclear provisions.

Further reforms were introduced in the latter half of 2010 with amendments to:

- streamline the provision that sets out the calculation of pre-injury average weekly earnings (PIAWE) and correct an anomaly in relation to the incorporation of commissions into PIAWE
- codify current policies that relate to the impact on remuneration of salary packaging and injury prior to taking up a promotion, on the calculation of PIAWE
- restructure and streamline the provisions that govern the coverage of contractors
- align the value of impairment benefits for injured workers assessed at 71 per cent WPI or above with the equivalent value of common law damages payable for pain and suffering on an ongoing basis
- introduce greater clarity and equity for dependants of deceased workers in relation to medical and like benefits, how earnings are calculated and how partial dependant partners of deceased workers are compensated
- improve the usability of provisions relating to medical expenses, and
- extend an existing provision in the Act to allow the making of a Governor in Council Order that would permit the introduction of a fixed costs model (FCM), with built-in increases linked to inflation, for plaintiff's legal costs in the litigated phase of serious injury applications.

2011

On 1 July 2011, the new ANZSIC 2006 based WorkCover Industry Classification (WIC) system commenced.

2013

The *Workplace Injury Rehabilitation and Compensation Act 2013* commenced on 1 July 2014. The Act recasts the *Accident Compensation Act 1985* and the *Accident Compensation (WorkCover Insurance) Act 1993* into a single Act.

Queensland

1905–1990

Queensland's first workers' compensation legislation was the *Workers' Compensation Act 1905*. This limited scheme was repealed and replaced by the *Workers' Compensation Act 1916*, which became the foundation for workers' compensation until 1990. In the 1970s benefits were increased and a new Workers' Compensation Board was created.

1990

By the late 1980s the legislation in Queensland had become outdated and unwieldy and a review resulted in the *Workers' Compensation Act 1990*. Key features included increased and additional benefits for workers, rehabilitation initiatives, increased employer and worker representation on the Workers' Compensation Board, increased penalties for fraud and failure of employers to insure, and streamlined administrative arrangements.

1996

In 1996 a further inquiry was held to address financial, regulatory and operational difficulties resulting in the *WorkCover Queensland Act 1996*. It repealed the 1990 Act and 'effected a total rewrite of the workers' compensation legislation'.

2003

Following a review under National Competition Policy, the *Workers' Compensation and Rehabilitation Act 2003* repealed the 1996 Act and introduced separate delivery and regulation of the workers' compensation scheme.

2010

Legislative amendments capping damages and increasing the onus on plaintiffs to prove negligence (in line with aspects of civil liability legislation) were passed in June 2010.

2013

Legislative amendments were passed in response to the Inquiry into the Operation of Queensland's Workers' Compensation Scheme by the Queensland Parliament's Finance and Administration Committee. A greater than five per cent degree of permanent impairment threshold was introduced for injured workers seeking damages. Regulatory functions were merged into the Department of Justice and Attorney-General.

2015

The common law threshold was removed effective 31 January 2015 and deeming provisions for firefighters with prescribed diseases were introduced.

2016

The National Injury Insurance Scheme for workplace accidents connected with Queensland was introduced to provide eligible seriously injured workers with a statutory entitlement to lifetime treatment, care and support payments (from 1 July 2016).

2017

New entitlements for current and former workers with Coal Workers' Pneumoconiosis or other Coal Mine Dust Lung Diseases introduced.

2018

The second five-yearly review of the operation of the Queensland workers' compensation scheme required under section 584A of the *Workers' Compensation and Rehabilitation Act 2003* was completed. The report of the review made 57 recommendations.

2019

Legislative amendments included:

- a mandatory requirement to refer an injured worker to an accredited rehabilitation and return to work program if the worker is receiving compensation and makes a request, or the worker's entitlement to compensation has ceased and the worker has not returned to work because of the injury;
- requiring self-insured employers to notify their insurer when a worker sustains an injury for which compensation may be payable;
- clarifying that insurers have a discretion to accept claims submitted more than six months after the injury is diagnosed, if the injured worker has lodged a claim within 20 days of developing an incapacity for work from their injury;
- deeming unpaid interns as workers entitled to access workers' compensation benefits;
- amending the meaning of psychiatric or psychological injury to remove 'the major' as a qualifier for employment's 'significant contributing factor' to the injury; and
- requiring insurers to take all reasonable steps to provide claimants with psychiatric or psychological injuries access to reasonable support services relating to their injury during claim determination.

2021

Presumptive workers' compensation laws for first responders and eligible employees diagnosed with post-traumatic stress disorder (PTSD) commenced. The presumption applies to workers or relevant volunteers who are first responders responding to time-critical, often life-threatening incidents (e.g. police officers, paramedics, firefighters) and eligible employees in certain first responder departments who experience repeated or extreme exposure to graphic details of traumatic incidents.

Western Australia (WA)

Western Australia introduced the *Workers' Compensation Act 1902*. There were frequent and complex amendments over the next 79 years until the *Workers' Compensation and Assistance Act 1981* amended and consolidated the law. In 1991 the Act was renamed the *Workers' Compensation and Rehabilitation Act 1981*, reflecting a general shift of emphasis to rehabilitation.

A number of reviews and reports between 1999–2001 recommended changes and the Workers' Compensation Reform Bill 2004 introduced changes to statutory benefits, injury management, access to common law, employer incentives in relation to return to work for disabled workers, and fairness in dispute resolution. As part of the reforms the Act was renamed the *Workers' Compensation and Injury Management Act 1981* which reflects an emphasis on injury management within the workers' compensation scheme in Western Australia.

Legislative Review

In 2009 a further review of the *Workers' Compensation and Injury Management Act 1981* was undertaken. Consequently, the first stage of legislative change saw the:

- removal of all aged based limits on workers' compensation entitlements
- extension of the safety net arrangement for workers awarded common law damages against uninsured employers, and
- inclusion of various amendments of an administrative nature (including the removal of time limit for writ lodgement after election and the incorporation of diffuse pleural fibrosis into the industrial disease provisions of the legislation).

The establishment of the Conciliation and Arbitration Service and other changes to the dispute resolution process commenced on 1 December 2011.

The second stage of the legislative review progressed in 2013/2014 and saw the release of the *Review of Workers' Compensation and Injury Management Act 1981 Discussion Paper*. Stakeholder feedback on the discussion paper informed the subsequent *Review of Workers' Compensation and Injury Management Act 1981 Final Report* (Final Report).

The final report was tabled in Parliament on 26 June 2014. The report contains 171 recommendations for inclusion in the new statute. Drafting of a bill commenced in 2015/16 but was placed on hold until the conclusion of the 2017 WA State election.

On 11 August 2021 WorkCover WA commenced consultation on the draft Workers Compensation and Injury Management Bill 2021.

The draft Bill modernises WA's workers compensation laws and is based on recommendations from WorkCover WA's 2014 Review of the Workers' Compensation and Injury Management Act 1981: Final Report.

The draft Bill was prepared for public comment before its introduction into State Parliament, continuing WorkCover WA's open and consultative approach on the legislative review.

WorkCover WA invited written submissions on the draft Bill for a public consultation period which concluded in November 2021.

In addition to the submissions process, WorkCover WA undertook a number of public information seminars and held several meetings with stakeholders to discuss the draft Bill.

South Australia (SA)

South Australia introduced the *Workmens' Compensation Act 1900* which was consolidated in 1932 and remained essentially in that form until the introduction of the *Workers' Compensation Act 1971*. The 1971 Act completely restructured the workers' compensation legislation in the state. The Act increased the amounts of compensation payable and broadened the grounds for which a worker could gain compensation.

In June 1978 the Government established a Committee of Inquiry, chaired by D. E. Byrne, to examine and report on the most effective means of compensating those injured at work. In September 1980 the Committee released the report entitled 'A Workers' Rehabilitation and Compensation Board for South Australia — the key to rapid rehabilitation and equitable compensation for those injured at work (*'Byrne Report'*). Included among the Committee's recommendations was that a new Act be introduced repealing the *Workers' Compensation Act 1971*, that a Board be established to administer a workers' compensation scheme and that the Board be responsible for overseeing and confirming rehabilitation programs.

A Joint Committee was established to investigate those areas where employers and the unions were in agreement or disagreement with respect to changing the workers' compensation system. Essentially, the Joint Committee reviewed the Byrne Committee recommendations to determine which of those should be implemented. A joint agreement was reached that led to the drafting of new legislation that was considered by Parliament in 1986 and the establishment of WorkCover in September 1987.

Amendments to the *Workers' Rehabilitation and Compensation Act 1986* were made in 1992 (abolishment of common law), 1994 (compensability, redemptions, hearing loss), 1996 (dispute resolution, rehabilitation and return to work plans, two year reviews and more), and 2006 (territorial).

In 2008 legislative amendments followed an independent review by the South Australia Government to reassess the structure of the Scheme.

The 2008 amendments included the introduction of work capacity assessments, Medical Panels, restrictions on redemptions and changes to weekly payments (commonly referred to as 'step-downs'). The Amendment Act also included a requirement for the Minister for Industrial Relations, to initiate a further independent review in 2011 to consider the impact of the 2008 changes.

In 2008 WorkCover commenced a review of all regulations supporting the Act. All SA regulations expire after being 10 years in force (under the *Subordinate Legislation Act 1978*). In June 2010 Cabinet approved the Workers' Rehabilitation and Compensation Regulations 2010. The regulations were made by the Governor and published in the SA Government Gazette on 24 June 2010 and commenced on 1 November 2010.

The review (generally referred to as the Cossey Review) of the 2008 legislative amendments was undertaken by Mr Bill Cossey and Mr Chris Latham, with the report tabled in Parliament on 23 June 2011. The review found that overall it was too soon for the long term impacts of the 2008 amendments to be known. Emerging trends were identified where possible noting that trends were based on limited experience, limited data and it was unclear if they would prevail in the longer term.

On 13 September 2011, the Government made a statement in relation to the Cossey Review to announce that it would continue to work on developing the Government's response, including consideration of recent court judgements and other reform proposals and working closely with employee and employer representatives, the WorkCover Board and Executive and other interested parties.

On 27 October 2012, the Premier announced the Workers' Compensation Improvement Project. Phase one outcomes included a new WorkCover Charter and Performance Statement signed on 19 August 2013, with a range of initiatives that were expected of WorkCover to place a greater focus on early intervention and return to work. These initiatives were intended to cap the growing unfunded liability. Amendments were also made to the *WorkCover Corporation Act 1994* in November 2013 to put the Board on a more commercial footing. Phase two of the Workers' Compensation Improvement Project was announced to include a root and branch recasting of the fundamental characteristics of the legislation.

On 30 October 2014 new legislation to reform workers' compensation in South Australia was passed by Parliament. The *Return to Work Act 2014* and the *South Australian Employment Tribunal Act 2014* replace the *Workers Rehabilitation and Compensation Act 1986* and establish the Return to Work scheme.

The Return to Work scheme is underpinned by the following key principles:

- a strong focus on early intervention, targeted return to work services and provision of retraining (where required)
- recognition that workers who are seriously injured require different services and support to those workers who are not seriously injured
- clearly articulated rights and obligations for all parties: workers, employers and the Corporation
- a simple and efficient dispute resolution process with an improved framework including clear boundaries and requirements for evidence-based decision making.

The Return to Work scheme became operational on 1 July 2015.

On 2 February 2015 the *WorkCover Corporation Act 1994* was amended to the *Return to Work Corporation of South Australia Act 1994*. These amendments arising from *the Return to Work Act 2014* provide for the name change of the Corporation.

On 6 February 2015 ReturnToWorkSA (RTWSA) was launched. RTWSA is responsible for insuring and regulating the Return to Work scheme. RTWSA continued to administer the WorkCover scheme until it was replaced by the Return to Work scheme on 1 July 2015.

Section 203 of the Return to Work Act 2014 required a review of the legislation after the expiry of three years from its commencement. The review was conducted by the Hon John Mansfield AM QC who provided the Government with his report and recommendations on 4 June 2018. The report was tabled in both Houses of Parliament on 26 July 2018.

Tasmania

Tasmania first introduced workers' compensation in 1910. The *Workers' Compensation Act 1927* repealed earlier Acts and introduced compulsory insurance against injury to workers. A 1986 Tasmanian Law Reform Commission report recommended sweeping changes to the system and led to the *Workers Rehabilitation and Compensation Act 1988*. This Act introduced many new features to the Tasmanian workers' compensation scheme, including:

- the establishment of the Workers' Compensation Board which included representatives of employers, employees, insurers and the medical profession
- extension of coverage to police officers, ministers of religion and sportsmen (restricted)
- revision of payment of the costs of treatment, counselling, retraining or necessary modifications to an injured worker's home or workplace, and
- licensing of insurers and self-insurers.

1995

During 1995 amendments were made to strengthen the rehabilitation and return to work aspects of the Act, including a requirement for:

- an employer to hold an injured worker's pre-injury position open for 12 months
- an employer to provide suitable alternative duties to an injured worker for a period of 12 months
- a return to work plan to be developed if a worker is incapacitated for more than 14 days, and
- an employer with more than 20 employees to have a rehabilitation policy.

The amendments also removed a worker's right to compensation on the journey to and from work (in most circumstances) and introduced the first step-down provisions in relation to weekly benefits.

2000

In response to rising costs and concerns from unions and other groups about the fairness of the scheme, a Joint Select Committee of Inquiry into the Tasmanian workers' compensation system was initiated. Its 1998 report recommended significant changes to the workers' compensation system and resulted in the establishment of the new WorkCover Tasmania Board. Many of the recommendations of this Report were incorporated into the Workers Rehabilitation and Compensation Amendment Bill 2000 including:

- access to common law being restricted to those workers who had suffered a Whole Person Impairment of 30 per cent or more
- replacing the monetary cap on weekly payments with a 10 year limit
- without prejudice commencement of weekly payments to injured workers on receipt of a workers' compensation claim form and medical certificate
- an increase in the level of benefits to the dependants of deceased workers, and
- increases in the levels of step-downs in weekly payments.

2004

In 2003 the Government initiated a review to investigate concerns that the step-downs in weekly benefits were causing hardship for some workers. The Rutherford Report was completed in March 2004 and contained a number of recommendations for both the government and the WorkCover Tasmania Board. As a result of Rutherford's report, the legislation was amended to retain the first step-down provision of 85 per cent of Normal Weekly Earnings but increase its duration to 78 weeks and reduce the impact of the second step-down from 70 per cent to 80 per cent of NWE. To offset the additional cost to employers of this change, the maximum period of entitlement was reduced from 10 to nine years. The time limit for deciding initial liability was also increased from 28 days to 12 weeks.

2007

In 2007 Parliament passed the *Workers Rehabilitation and Compensation Amendment Act 2007*. The aim of this Act was to make the system fairer and provide greater certainty for all parties. The key changes included:

- improved compensation for industrial deafness. In the past some workers were unable to establish a claim for industrial deafness because their employer had failed to conduct baseline audiometric testing — the amendments rectified this
- a fairer method of calculating the rate of weekly compensation, especially for workers who have a short employment history and where the award does not include an 'ordinary-time rate of pay'
- workers' compensation coverage for jockeys
- amendments to address a Supreme Court decision that limited the ability of employers to recover compensation costs from a negligent third party
- clarification of coverage of luxury hire car drivers and consolidation of provisions relating to taxi drivers
- amendments to the work-relatedness test for injury from 'arising out of and in the course of' to 'arising out of or in the course of', so it is clear that injuries can be compensable even when symptoms only become apparent after the worker has left the relevant employment (however, to be compensable all injuries and diseases must be caused by work), and
- measures to better deal with disputes between insurers or disputes between employers.

2009

The *Workers Rehabilitation and Compensation Amendment Act 2009* was passed by Parliament in late 2009 and commenced on 1 July 2010. The amendments had four main purposes:

- to implement the Government's response to the Clayton Report
- to establish the legal framework for the WorkCover Return to Work and Injury Management Model
- to amend the timing and level of weekly payment step-downs, and
- to reduce the common law threshold from 30 per cent WPI to 20 per cent.

The amendments:

- introduced a statement of scheme goals
- encourage early reporting by holding the employer liable for claims expenses until the claim is reported
- provide for the payment of counselling services for families of deceased workers
- provide for the payment of medical and other expenses for up to 12 months after a worker ceases to be entitled to weekly compensation (with the possibility of extension on application to the Tribunal)
- increase the maximum lump sum payable to a dependant on the death of a worker to $266,376.05 (indexed annually)
- increase weekly payments payable to a dependant child of a deceased worker from 10 per cent basic salary to 15 per cent basic salary
- increase the maximum lump sum payable for permanent impairment to $266,376.05 (indexed annually)
- provide for the extension of weekly payments from nine years to 12 years for workers with a WPI between 15 per cent and 19 per cent, to 20 years for workers with a WPI of between 20 per cent and 29 per cent and until the age of retirement for workers with a WPI of 30 per cent or more
- amend the first step-down to 90 per cent of NWE rather than 85 per cent of NWE

- delay the operation of the first step-down, so that it comes into effect at 26 weeks of incapacity rather than 13 weeks
- provide that the step-downs are not to apply where a worker has returned to work for at least 50 per cent of his or her pre-injury hours or duties
- provide that the step-downs are to be discounted in circumstances where an employer refuses or is unable to provide suitable alternative duties
- reduce the threshold for access to common law damages from 30 per cent WPI to 20 per cent WPI, and
- repeal s138AB requiring a worker to make an election to pursue common law damages.

The amendments also included a range of measures that support the WorkCover Return to Work and Injury Management Model including:

- requirements for return to work and injury management plans
- obligations on employers to encourage early reporting of injuries and claims
- providing an entitlement to the payment of limited medical costs before the claim is accepted, and
- introduction of an injury management coordinator to oversee the injury management process.

2012 amendments

The *Workers Rehabilitation and Compensation Amendment (Validation) Act 2012* (the 2012 Validation Act) commenced on 30 August 2012. It amended the *Workers Rehabilitation and Compensation Act 1988* (the Act) to remove any doubts about the validity of versions two and three of the *Guidelines for the Assessment of Permanent Impairment* (the Guidelines). The amendments also clarified that version two of the Guidelines took effect on and from 1 April 2011 to Online Claims Workers Compensation Certificate Course Australia (australianonlinecourses.com.au) 2012 and version three of the Guidelines took effect on and from 1 October 2011. The Guidelines are used to assess the degree of WPI under both the Act and the *Asbestos-Related Diseases (Occupational Exposure) Compensation Act 2011*. Both Acts provide lump sum compensation based on the percentage of impairment. Under the Act the level of impairment is also relevant in relation to weekly compensation and for access to common law damages.

2013 amendments

The Workers Rehabilitation and Compensation Amendment (Fire-Fighters) Bill 2013 was passed by Parliament on 26 September 2013 and commenced operation on 21 October 2013.

The legislation establishes a rebuttable presumption that particular forms of cancer developed by career and volunteer firefighters are work related for the purpose of the Act. The amendments will make the process of claiming workers' compensation less cumbersome for firefighters and recognises that firefighters are at greater risk of developing certain types of cancers as a result of exposure to hazardous substances while performing firefighting activities. Under the presumption, if a career firefighter is diagnosed with one of the 12 cancers listed in the schedule, and served as a firefighter for the relevant qualifying period, it will be presumed that the cancer is an occupational disease and is therefore compensable. For volunteer firefighters there is an additional requirement that the person must have attended at least 150 exposure events within any five year period for brain cancer and leukaemia, and within 10 years for the remaining 10 cancers. This requirement ensures that the presumption only applies to volunteers who have had a significant level of exposure to the hazards of fire.

The legislation limits the operation of the presumption to diseases that occurred during the period of employment or up to 10 years post retirement or resignation as a firefighter. It will only apply to firefighters, both career and volunteer, appointed or employed under the *Fire Service Act 1979.*

The Parliament endorsed an amendment to the Bill to require a review of the legislation after 12 months of operation and every 12 months thereafter. This will provide an opportunity to assess the fairness and effectiveness of the legislation and to take into account any developments in medical research.

2017 amendments

In 2017 the *Workers Rehabilitation and Compensation Act 1988* was amended by the *Workers Rehabilitation and Compensation Amendment Act 2017* and the *Workers Rehabilitation and Compensation Amendment (Presumption of Cause of Disease) Act 2017*.

The *Workers Rehabilitation and Compensation Amendment Act 2017* focussed on opportunities to reduce unnecessary administrative burden on workers' compensation scheme participants by moving away from unnecessary administrative processes to instead focus on achieving positive outcomes for all workers, employers and insurers. Two significant changes resulting from those amendments are:

- Structure of the WorkCover Tasmania Board
  The membership and voting structure of the WorkCover Tasmania Board has been redesigned to ensure all members are equipped with the necessary skills and experience to advise and make decisions. The new structure brings the Tasmanian Board into closer alignment with equivalent bodies in other Australian jurisdictions, and positions the Board to further advance the aims of the workers' compensation scheme.
- Removal of age restrictions for older workers The amendments future-proof the Act from related changes to Commonwealth legislation by removing references to the specific age of 65 years and, instead, link access to weekly benefits to a person's eligibility to the Age Pension under the *Social Security Act 1991* (Cth). This allows the legislation to keep pace with any future changes in retirement age.
  Existing protections under the Act for older workers are retained, whereby a person injured close to retirement age is entitled to receive weekly payments for up to twelve months from the date of their injury.

The *Workers Rehabilitation and Compensation Amendment (Presumption of Cause of Disease) Act 2017* removed the requirement for volunteer fire-fighters to attend a specified number of exposure events before being eligible for a presumption that some cancers may be linked to occupational exposure.

2019 Amendments

In 2019 the *Workers Rehabilitation and Compensation Act 1988* was amended by the *Workers Rehabilitation and Compensation Amendment (Presumption as to Cause of Disease) Act 2019* and the *Workers Rehabilitation and Compensation Amendment Act 2019.*

The *Workers Rehabilitation and Compensation Amendment (Presumption as to Cause of Disease) Act 2019* provided presumption as to the cause of PTSD for relevant workers. These workers were defined as a worker who is employed by:

- the Crown or appointed under an Act of the State
- a Government Business Enterprise, within the meaning of the *Government Business Enterprises Act 1995*
- a State-owned company, within the meaning of the *Government Business Enterprises Act 1995*.

The *Workers Rehabilitation and Compensation Amendment Act 2019 amended* section 69B of the *Workers Rehabilitation and Compensation Act 1988* to exempt police officers from a decrease in the weekly benefit payment made to an injured worker, after set periods of time. This amendment specifically applies to police officers who are injured whilst on front line duty.

Asbestos-Related Diseases (Occupational Exposure) Compensation Act 2011

The *Asbestos-Related Diseases (Occupational Exposure) Compensation Act 2011* commenced on 31 October 2011. The Act establishes a scheme for the payment of compensation to workers who develop or developed asbestos-related diseases (ARD) through exposure to asbestos during the course of their employment. A person may still come within the scope of the Act notwithstanding that he or she may have retired some time ago. Compensation may also be available to certain family members of a worker that has died from an ARD.

Compensation is not available where a worker has already received compensation for the same ARD at common law or under legislation in another jurisdiction or under the *Tasmanian Workers Rehabilitation and Compensation Act 1988* or the *Workers' Compensation Act 1927*.

To be entitled to compensation under the Act, the worker must have or have had a compensable disease. A person has a compensable disease if:

- the person has an ARD, and
- the contraction by the person of the disease is reasonably attributable to exposure to asbestos in the course of the person's employment as a worker during a relevant employment period in which the person's employment is connected with Tasmania.

Compensation under the Act

Where the worker has an imminently fatal compensable ARD (less than two years' life expectancy from the date of correct diagnosis):

- the worker is entitled to lump sum compensation of 360 compensation units (plus a further age-based payment up to a maximum of 360 compensation units (if under 80 years of age). As at 1 January 2022 one compensation unit was $975.12, and
- the worker is also entitled to have their reasonable medical expenses paid for by the scheme. However, when total medical expenses reach 125 compensation units a review is to be held to enable the ongoing payment of medical expenses.

Where the worker has a non-imminently fatal compensable ARD (more than two years' life expectancy from the date of correct diagnosis):

- a worker with a non-imminently fatal ARD must undergo an impairment assessment. Compensation is only payable if the worker has a WPI of 10 per cent or more
- three lump sum payments are payable to the worker depending on the degree of impairment up to a total of 360 compensation units. However, if the worker is assessed at 51 per cent or more WPI at their first assessment, they will receive all three lump sums at the same time — 360 compensation units
- the worker is also entitled to the payment of reasonable medical expenses. There is no dollar cap on the payment of these expenses
- where the worker is employed, or was employed for a certain period, weekly payments are payable for incapacity due ARD, and
- where a worker has received compensation in relation to a non-imminently fatal ARD which is subsequently diagnosed as being imminently fatal or they develop a different imminently fatal ARD, they will be paid any remaining lump sum compensation up to 360 compensation units. They will also receive the age-based payment if eligible.

Members of the family:

- where a worker has died from a compensable ARD, the members of the worker's family are entitled to the same amount of lump sum compensation (excluding medical expenses or weekly payments) that the worker would have received had they not died. They may also be entitled to funeral expenses in relation to the deceased worker, and
- members of the family include a spouse (including a person in a significant relationship with the worker within the meaning of the *Relationships Act 2003*), and a child who is less than 22 years of age (natural child, adopted child and in some circumstances, a step-child).

Further information can be found at:

- WorkSafe Tasmania – Asbestos safety
- WorkSafe Tasmania – Asbestos compensation
- Tasmanian Asbestos Compensation Information
- Guide to Asbestos Compensation in Tasmania

Northern Territory (NT)

The first workers' compensation statute introduced in the NT was the *Workmens' Compensation Act 1920*. Before then, the *Employer's Liability Act 1884* applied. In 1985 the name of the Act was changed to the *Workers' Compensation Act*.

A review of the legislation in 1984 resulted in the *Work Health Act 1986*, which contained provisions for both work health and safety and workers' compensation. This Act provided for a scheme which is privately underwritten, featured pension based benefits and promotes rehabilitation and an early return to work. There is no access to common law for injured workers.

Cross-Border Amendments

'Cross border' amendments to the *Work Health Act 1986* commenced on 26 April 2007 so employers are only required to maintain a workers' compensation policy in the NT when they employ workers with a 'State of Connection' to the NT. The new cross-border arrangements reduce red tape for employers and make it easier to do business by removing the need for the majority of employers to obtain multiple workers' compensation policies for workers who are temporarily working interstate. All the other Australian states and territories have introduced cross-border provisions that allow workers to work across their borders for temporary periods, under an existing NT workers' compensation policy.

2007

In December 2007 the Legislative Assembly passed the *Workplace Health and Safety Act* and the *Law Reform (Work Health) Amendment Act 2007*. These Acts separated the work health and safety and rehabilitation and workers' compensation provisions of the previous *Work Health Act 1986* into the new *Workplace Health and Safety Act* and the *Workers' Rehabilitation and Compensation Act*. The rehabilitation and workers' compensation provisions of the *Work Health Act 1986* were transferred almost unchanged into the new *Workers' Rehabilitation and Compensation Act*.

2008

On 1 July 2008 the *Workplace Health and Safety Act* and parts of the *Workers' Rehabilitation and Compensation Act* came into effect.

Prior to taking effect however, the *Workplace Health and Safety Act* underwent a number of amendments. The amendments made relate to three areas:

- prescribed volunteers are no longer eligible for compensation for life, but instead will now be eligible for compensation similar to that provided to other injured workers
- if an employer/insurer defers a decision on liability but fails to make a decision to accept or dispute liability within the prescribed timeframe (56 days), then the employer/insurer is deemed to have accepted the claim until 14 days after the day on which the employer notifies the claimant of a decision to accept or dispute liability
- parties are now required to provide all written medical reports and other specified written material relating to the disputed matters to NT WorkSafe so they can be considered by the parties and mediator prior to the mediation process. The mediation process must now be completed within 21 days instead of 28 days, and
- GIO became an approved insurer pursuant to s121(1) of the *Workers' Rehabilitation and Compensation Act* on 30 June 2008, bringing the total number of approved insurers in the jurisdiction to five.

2012

The *Workers' Rehabilitation and Compensation Legislation Amendment Bill 2011* was passed in Parliament on 28 March 2012. The amendments came into effect on 1 July 2012 and are:

- Section 3 of the Act - definition of 'worker' was amended to remove the reference to the Australian Business Number (ABN) and to apply the 'Results Test' so that: A person performing work for another person will be a worker unless, in relation to the work, the following tests apply:

  - The person is paid to achieve a stated outcome; and
  - The person has to supply the plant and equipment or tools of trade needed to carry out the work; and
  - The person is, or would be, liable for the cost of rectifying any defect in the work carried out.
  - The new laws also provide that a person will not be considered a ‘worker’ for workers’ compensation purposes where there is a personal services business determination in effect for the person performing the work under the *Income Tax Assessment Act 1997* (Cth).

- Section 65B of the Act was amended to allow access to compensation by workers injured in Australia but who reside overseas. The change will provide for weekly payments to continue if an injured worker is living outside Australia. The key elements of the change are as follows:
  - For weekly compensation payments to continue the injured worker must, at not less than 3 month intervals, provide proof of identity and proof of ongoing incapacity.
  - The duration of compensation payments will be a maximum of 104 weeks from when the worker starts living outside Australia.
  - Flexibility will exist for applications to be made to the Work Health Court for payments beyond 104 weeks if the worker is permanently and totally incapacitated, or exceptional circumstances apply. However, any such extension by the Court must be a single period that does not exceed 104 weeks.
- Section 65 of the Act was amended to provide immediate and fairer access to compensation for older workers who are injured and to reflect the Australian Government’s decision to increase the qualifying age for the aged pension:
  - The new legislation establishes a link to the qualifying age for the age pension under the Social Security Act. This will mean that the age limit in the Workers’ Rehabilitation and Compensation Act will increase in stages between 2017 and 2023 in line with the increase in the pension age.
  - In addition, the legislation establishes a transitional benefit for workers who sustain a work injury after 1 July 2012 and who at the time of injury are 63 years of age or over. These workers will be entitled to weekly compensation for a maximum period of 104 weeks or until the worker attains 67 years of age, whichever occurs first.
  - It should be noted that workers who are older than 67 years when they are injured, will be entitled to weekly compensation for up to 26 weeks (no change from the past situation).
- Section 49 of the Act was amended to provide certainty of the types of non-cash benefits that can be taken into account in calculating the worker’s NWE for the purposes of payment of weekly compensation. These are limited to accommodation, meals and electricity.
- Section 89 of the Act was amended to bring the interest rate payable on late payments of weekly compensation in line with the interest rate applicable to Supreme Court judgment debts.
- Section 116 of the Act was amended to provide specific power of the Supreme Court to remit matters back to the Work Health Court in appropriate circumstances.

2015

The Workers’ Rehabilitation and Compensation Legislation Amendment Bill 2015, was tabled in February 2015, passed in March 2015 and came into effect 1 July 2015. The key amendments are:

- **Legislation name change**
  The name of the legislation has changed to ‘*Return to Work Act*’ and Regulations. The change is to reflect the primary objective of the legislation, which is to assist injured workers to return to work.

- **Presumptive legislation for firefighters and volunteers**
  Presumptive legislation has been introduced to make it easier for firefighters and volunteer firefighters to claim workers' compensation if they are diagnosed with one of the 12 cancers listed in the legislation schedule. This change recognises that fire fighters are at greater risk of developing certain types of cancers as a result of exposure to hazardous substances while performing firefighting activities.
- **Definition of worker**
  The definition of worker has been aligned with the PAYG definition used by the Australian Taxation Office (ATO). This change will make it easier for employers and workers to identify who is covered for workers' compensation.
- **Increased period of compensation for older workers**
  This change recognised that Territorians are staying in the workforce beyond the pension age. The period of compensation for workers aged 67 years or older has increased from 26 weeks to 104 weeks, providing older workers with a more reasonable level of financial protection should they get injured at work.
- **Five year cap on benefits for less serious injuries**
  Under this change, workers who suffer a less serious injury will be limited to five years of compensation, with a maximum of one additional year for medical and other costs. This change does not affect workers who have suffered a more serious injury and have been evaluated as having a permanent impairment of 15 per cent or higher. These more seriously injured workers depending on work capacity may be entitled to compensation payments until pension age.
- **Increase in death and funeral benefits**
  The death benefit for the dependants of a deceased worker has increased from 260 times to 364 times the average weekly earnings.
- **Stroke and heart attack claims**
  Compensation will not be provided for stroke or heart attacks that are not caused by work. Compensation will be paid if it is established that a person's employment is the real, proximate or effective cause of the heart attack or stroke.
- **Capping the calculation for normal weekly earnings**
  During the first 26 weeks when a worker is unable to work, their compensation payments are paid at their normal weekly earnings. After 26 weeks, compensation payments are paid at 75 per cent of their normal weekly earnings. There is now a cap on the calculation of a worker's normal weekly earnings after 26 weeks to 250 per cent of the average weekly earnings. This provision will only affect very high income earners, and in such cases will provide incentive, for both the worker and the employer to focus on return to work.
- **Clarification on when compensation payments are reduced to 75 per cent of normal weekly earnings**
  The legislation has been amended to clarify that compensation payments to an injured worker are reduced to 75 per cent of their normal weekly earnings after receiving a total of 26 weeks of compensation payments, rather than the period of 26 weeks from the date they were injured.

The Return to Work Legislation Amendment Bill 2015, was tabled in June 2015, passed in August 2015 and came into effect on 1 October 2015. The key amendments are:

- **Payment of reasonable expenses for family counselling**
  This provision relates to broader counselling and support at an early stage, including in relation to a worker's family to assist the process of rehabilitation. The amount payable will be to a maximum of 1.5 times Average Weekly Earnings.
- **Reasonable payment for medical and rehabilitation costs during deferment**
  Where a decision is made to defer liability of a claim, there is a requirement on the employer to make weekly payments of compensation and, in the case of claims for mental stress, engage in rehabilitation.
  Now for all deferred claims, payments for treatment and rehabilitation during the deferral period will ensure that a worker's recovery is not compromised by lack of treatment or rehabilitation during that period. This benefit excludes hospital inpatient and associated surgical costs as well as costs of interstate evacuations.

- **Mental stress claims**
  The former defence to a mental injury claim was based on reasonable administrative action and reasonable disciplinary action.
  Reasonable administrative action is now replaced with management action. Management action has been defined in the legislation and will include any communication in connection with identified actions.
- **Formal notice to be provided to the worker of any pending step down or cancellation**
  Formal notice is required to be provided to the worker of the pending step down (or cancellation), and the step down not to take effect until 14 days after the worker has been notified. This applies to all step downs 26 weeks, 260 weeks and 104 weeks (age).
- **Payment for legal advice at mediation**
- A mediator may recommend workers receive paid legal advice of and incidental to the mediation for an amount up to one times AWE. The entitlement is subject to approval by NT WorkSafe. Access to a lawyer will not be provided as a right, however the mediator can recommend to the Authority that legal advice be paid for by the employer where the mediator believes it will facilitate the mediation. Examples would be a more complex matter or where a worker is mentally impaired.
- **Negotiated settlements**
  There is now provision for the finalisation of the claim by the payment of a lump sum through negotiated settlement.
  The legislation requires a qualifying period of 104 weeks before a negotiated settlement. This will minimise the possibility of negotiated settlements preventing effective rehabilitation.
  Any settlement will involve mandatory independent legal advice funded by the employer (insurer).
  Financial advice funded by the employer (insurer) is to be provided on the request of the worker.
  It will not apply to claimants that are catastrophically injured and covered by the NIIS.
- **Settlement of disputed claims**
  There is provision to allow for the settlement of disputed claims for compensation (whether disputed on a question of fact or law or both) and settlement of contested applications to the Work Health Court.
  As with negotiated settlements, any settlement will involve mandatory independent legal advice funded by the employer (insurer) and financial advice at the request of the worker also to be funded by the employer (insurer). Any settlement within the first 104 weeks from injury will be subject to a six month cooling off period. In other words, the settlement is not binding until six months has elapsed.
- **Exclusion of journey claims**
  This provision excludes claims for all journeys to and from work. Journeys that are considered to be in the course of employment are not excluded. Examples are where the journey is to or from a workplace other than the worker's normal workplace at the request of the employer or where the worker is required to work outside their normal hours of work and is paid for the time taken for the journey to or from work.
- **Enforcement of compulsory insurance provisions by ability to stop work**
  If an employer does not hold the necessary workers' compensation insurance policy there is the power to order the employer to stop work until such time as the situation is rectified.
- **Involvement of support persons at mediation**
  Mediators will now be able to consent to a person, who is not a legal representative, to represent a claimant during the mediation.
  If the mediator considers that a claimant is not best equipped to fully present their own case and that the mediation will be best facilitated if assistance is provided by an advocate, then the mediator may consent to the claimant being represented by an advocate.
- **Improving return to work outcomes**
  To assist in improving return to work outcomes the legislation includes the following:

- The employer must produce a return to work plan, developed and agreed between the employer and worker for any injury that involves incapacity of more than 28 days.
- An employer will be unable to dismiss a worker for a period of six months following the date of injury unless during that period the worker ceases to be totally or partially incapacitated because of the injury.
- This is not to apply if the employer proves the worker was dismissed on the grounds of serious and wilful misconduct.

2016

Deemed Diseases

The Northern Territory has adopted the recommended list from the report "Deemed Diseases in Australia" as commissioned by Safe Work Australia, effective 1 July 2016 – see Return to Work Regulations, Schedule 2.

2017

Permanent Impairment

On 1 September 2017, the Northern Territory implemented the national template guide for the evaluation of permanent impairment. The NT WorkSafe Guidelines for the Evaluation of Permanent *Impairment* calls up AMA 5th Edition.

2018

Permanent Impairment

In August 2018, NT WorkSafe made a variation to part 1.15 of the Guidelines to acknowledge that a worker with a terminal illness from a progressive disease would not be able to fulfil the definition of maximum medical improvement and would therefore be precluded from having a valid permanent impairment assessment. The variation provides that where an assessment for a progressive disease is conducted, the claimant will be considered to have reached maximum medical improvement based on the assessment of the person as they present on the day of the assessment, provided the disease is in the course of its natural progression and is unlikely to substantially improve in the next 12 months.

This variation to the NT WorkSafe Guidelines for the Evaluation of Permanent Impairment (v1.1) applies for all assessments conducted on or after 10 August 2018. A copy of the guide is located on the NT WorkSafe website.

2020

The *Return to Work Legislation Amendment Act 2020*, was tabled in February 2020, and came into effect 1 July 2020. The Bill reversed a number of changes made to the legislation in 2015 and improves the operation of the Northern Territory Workers Compensation Scheme. Along with numerous administrative and technical changes, further changes included:

- **Meaning of worker**

Has been expanded to clarify that a person is a worker if they are an employee for PAYG purposes even if the employer is not complying with the PAYG provisions and that an Australian Business Number is not a determinant factor in establishing whether or not a person is a worker.

Deems that all individuals who work for a labour hire organisation are workers under the Act.

Expands the definition so that any immediate family member who is not living with the employer will be covered for workers compensation whether named on the policy or not.

Expands the categories of domestic workers that can be covered for workers compensation.

- **Inclusion of journey claims**

Reinstates the coverage for journey claims as applicable prior to the 2015 amendments with minor amendments.

● Labour hire definitions

Introduces definitions of ‘Labour Hire Arrangement’ and ‘Provider of labour hire services’ which are terms needed to ensure individuals under a labour hire arrangement are deemed workers.

● Normal weekly earnings

Removal of the cap on normal weekly earnings for payments made after 26 weeks or incapacity.

● Refusal to pay for medical treatment

Wording strengthened to ensure the employer/insurer can’t avoid liability for ‘proposed treatment’ unless they have supporting opinion.

● Recovery from worker

New section to the Act, which sets out that if an overpayment is made under the Act, overpayments cannot be recovered from the worker to whom the overpayments were made if:

- the benefit payable was incorrectly calculated by the employer or insurer who made the payment
- the payment was made in respect of a period more than six months before the date on which recovery of the overpaid amount was sought, unless otherwise ordered by the Court.

● Attendant care services

Moved to make relevant to all of PART 5, Division 3 of the Act.

● Return to work plans

Amended to allow for proposal for a return to work plan to be developed by employers without the mandated use of vocational rehabilitation providers.

● Other rehabilitation

Amended to clarify that household services include overnight childcare where the normal care provider is the injured worker who is required to be hospitalised or undergoing surgery.

● Settlements

Introduces provision for preclusion of settlement of amounts payable to a person who has suffered a catastrophic injury. Introduces catastrophic injury criteria to align with the National Injury Insurance Scheme (NIIS).

● Lump sum agreement for particular period

Amendment to ensure that a lump sum payable is not required to be for ‘all amounts otherwise payable’.

● Mediation – legal representation or legal advice

Clarifies that the amount payable for legal representation and legal advice is a combined total, not a separate amount for each component.

● Nominal Insurer funding

Moves the current methodology for contributions set out in the Act into Regulation to make it easier to amend the methodology to allow for more flexible funding arrangements for the future.

● Nominal Insurer claims management

Amended to clarify that an uninsured employer cannot self-manage a claim from an injured worker and that the Nominal Insurer has full rights to manage the claim.

● Statement of fitness for work

Current ‘statement of fitness for work’ is replaced by ‘medical certificate of capacity’.

Amendments of Return to Work Regulations 1986

- introduced a new reporting standard for insurer claim and policy data submissions under the ACT's private sector workers' compensation scheme. The new reporting standard, the *National Insurer Data Specifications,* was developed cooperatively by the privately underwritten workers' compensation jurisdictions and the Insurance Council of Australia.

2016

The *Workers Compensation Amendment Act 2016* was passed by the ACT Legislative Assembly in February 2016 and modernised employer obligations on return to work by introducing a requirement on all self-insurers and employers with an annual premium of $200 000 or greater to appoint a suitably qualified or experienced return to work coordinator.

In May 2016, the ACT passed legislation which extended the ACT Lifetime Care and Support Scheme (LTCS) to cover catastrophic workplace injuries sustained by private sector workers in the ACT. The new Scheme commenced on 1 July 2016. The expanded LTCS gave effect to the ACT's commitment to establish a National Injury Insurance Scheme (NIIS) that meets the agreed national minimum NIIS benchmarks. There will be an ACT LTCS Commissioner, however claims management/administration services will be carried out by the NSW LTCS Authority. Insurers and self-insurers are levied under the LTCS legislation to fund the scheme.

The *Workers Compensation Amendment Act (No 2)* (the Act) was passed by the ACT Legislative Assembly in June 2016, with commencement on 1 July 2017. The Act introduced amendments to ensure workers who suffer from an imminently fatal asbestos-related disease receive equitable and timely access to statutory compensation.

The *Road Transport (Taxi Industry Innovation) Legislation Amendment Regulation 2016* (No 1) introduced changes to the *Workers Compensation Regulation 2002* from 1 November 2016 such that:

- a transport booking service would be responsible for paying for workers' compensation for any drivers it asks to work for it *exclusively*;
- a contract of bailment with a driver would create a responsibility for the operator to purchase a workers' compensation policy for the driver; and
- owner drivers who do not engage other drivers to drive their vehicle would continue to be treated as sole traders and will not require workers' compensation insurance.

2017

In October 2017, the *Workers Compensation Amendment Act 2017* (the Act) was passed by the ACT Legislative Assembly. The Act introduced amendments to increase death entitlements, weekly compensation, modernise the employment-related diseases list and introduced a penalty provision aimed at employers who fail to pay an injured worker following receipt of a claim. All amendments other than weekly compensation commenced on 13 December 2017. The amendments to weekly compensation had a retrospective effect commencing 1 July 2017 to align with Australian Government aged pension reforms.

The death entitlement payments increased to approximately double the previous entitlement, bringing payments to a level consistent with the Commonwealth's Comcare scheme, this creates equity for the families of ACT private and public sector workers.

The Australian Government is incrementally increasing the qualifying age for the age pension from 65 to 67 years between 2017 and 2023. On 1 July 2017, the qualifying age for the pension increased to 65.5 years.

Prior to the amendments, the ACT workers' compensation laws provided that workers injured before their 63rd birthday were not entitled to weekly compensation payments once they reached age 65. Reforms to weekly benefit eligibility align the workers' compensation laws with the Commonwealth age pension age, ensuring that injured workers can transition from weekly compensation to the age pension without any gap in income.

These amendments also adopted the updated list of Deemed Diseases published by Safe Work Australia and in doing so, expanded the number of deemed diseases from 28 to 48.

The reforms introduced a penalty provision against an employer who fails to pay a worker weekly compensation after being provided with a notice of a work-related injury. This penalty was introduced to encourage compliance with the legislation and protect worker rights.

2018

In November 2018, the *Workers Compensation Act 1951* was amended by the *Statute Law Amendment Act 2018* to reinstate an entitlement to compensation that was inadvertently removed. This entitlement related to the payment of weekly compensation for up to 2 years following the initial date of incapacity to workers who are pension age or older when incapacitated.

2019

On 1 March 2019, the ACT Government became a self-insurer under the *Safety and Rehabilitation Compensation Act 1988* (Cth).

In September 2019, the *Workers Compensation Act 1951* was amended by the *Workers Compensation Amendment Act 2020* to ensure that the Default Insurance Fund can provide workers' compensation benefits to workers in situations where both a contractor and principal contractor are uninsured. Amendments were also made to ensure that family day care educators have access to workers' compensation.

B.4 Appendix 4: Summary of workers' compensation and self-insurance coverage as at 30 September 2018

This extract was from "Comparison of workers' compensation arrangements in Australia and New Zealand 2019, 27th Edition" (65).

Table 6.1: Workers' compensation and self-insurance coverage

	New South Wales	Victoria	Queensland	Western Australia	South Australia	Tasmania	Northern Territory	Australian Capital Territory	C'wealth Comcare	New Zealand
Employees covered by workers' compensation 2016–17[1]	4,334,786 (approx.)	2,607,300	2,182,500	103,032	500,000 (approx)	251,000 (approx)	121,053	139,600 (private sector approx)	394,822[5] (Scheme FTE inc. ACT Gov as at 30 September 2018).	2,663,000 (includes part-time)[6]
Employees covered by self-insurance	812,860 (approx)	170,104[3] (approx)	169,100	103,521	Data not collected	10,710	5,752 (does not include government employees)	3,174 (approx)	188,158 (FTE as at 30 September 2018)	Approximately 353,000 (FTE)
Employees covered by self-insurance (%)	18.8	7.0 by remuneration (as at June 2018)	7.8	—	36.86 by remuneration (as at July 2018)	4.3	4.75	<1	48 (as at 30 September 2018)	23 (FTE)
Number of self-insurer licences	58, plus 6 specialised insurers.	40	28	25	71 self-insured employer groups.	11	5	7	36 (as at 30 September 2018)	137 Contracts
Number of self-insured employers[1]	37 self-insurers 21 group self-insurers with 160 subsidiaries	305	282	25	70 private and approx 41 Crown	11	5 self-insurers and the Northern Territory Government self-insures for public sector employees	8	36 (as at 30 September 2018)	392
Employers covered by self-insurance (%)	N/A	0.14[4]	0.2 (approx)	—	N/A	N/A	N/A	<1	17.5 (of employers as at 30 September 2018)	<1

1. The figures in this table aim to give the reader an indication of the number of self-insurers in each scheme. For exact details on self-insurance statistics, readers should contact the relevant jurisdictional authority.
2. Includes number of employees covered by self and specialised insurer workers' compensation arrangements. Includes government employees covered by the Treasury Managed Fund administered by the NSW Self-insurance Corporation.
3. For Victoria this figure does not include the self-insured employee numbers. The figure provided is the total FTEs of all self-insurers as at 30 September 2018.
4. Self-insurers represent 7.7% of the Victorian scheme by remuneration. Although there are a relatively small number of self-insured bodies corporate, they represent some of the largest companies in Victoria. The two biggest self-insurers, in terms of employee numbers, are Wesfarmers Limited and Woolworths Group Limited.
5. Contractors working for the Commonwealth will be recorded against their State of usual residence and hence all employed persons are recorded as being covered by workers' compensation, again in these figures there is an inherent potential degree of inaccuracy.
6. For New Zealand this figure includes self-insurers and self-employed persons who are covered by the Scheme.

C
Chapter 4 Supplementary Material

C.1 Supplementary Equations: meteorological variables

Maximum, minimum and average temperatures

The Australian Bureau of Meteorology definitions were used to define maximum, minimum and average temperature (22), which match the recommended approaches from the World Meteorological Organization (77). Maximum temperature was the highest air temperature recorded from 9am on the day to 9am the next day, which usually occurs in the afternoon on the same day. Minimum temperature was the lowest air temperature recorded from 9am on the day to 9am the preceding day, which usually occurs overnight on the same day. Average temperature was the average of the maximum and minimum temperature for the given day. All maximum and minimum apparent temperature metrics were calculated at the time of maximum and minimum air temperature, respectively. Apparent temperature metrics were calculated at the time of maximum or minimum temperatures.

Humidity calculations

Vapour pressure (V) was calculated using specific humidity and air pressure as recommended by the Bureau of Meteorology (172). The equation was derived from Wallace and Hobbs as (229):

$V = \frac{PQ}{m+(1-m)H_S}$, where m = $\frac{18.01528}{28.9634}$, P = air pressure at 20m elevation (hPa) and H_S = specific humidity (kg/kg).

Saturation vapour pressure (hPa) and dew point temperature were estimated using Buck's 1996 equations (230). They include an enhancement factor to adjust the equations for use with moist air instead of pure water vapour:

$6.1121e^{T\frac{18.678-T/234.5}{257.14+T}}(1+10^{-4}(7.2+P(0.0320+5.9*10^{-6}T^2)))$, T > 0°C

$6.1115e^{T\frac{23.036-T/333.7}{279.82+T}}(1+10^{-4}(2.2+P(0.0383+6.4*10^{-6}T^2)))$, T $\leq$ 0°C

T = air temperature (°C), P = air pressure (hPa), and e is a mathematical constant $\approx$ 2.718.

Relative humidity was defined as vapour pressure divided by saturation vapour pressure expressed as a percentage, capped at 100%.

Wet bulb globe temperature (WBGT)

Indoor and outdoor WBGT were calculated using Bernard's (146) and Liligren's (147) formulae, which are considered the most reliable estimates for indoor and outdoor WBGT, respectively (41). These are complex iterative formulae applied using the R package *HeatStress* (159). In brief, they are designed to stimulate the following WBGT equations:

Indoor: $0.7T_{nwb} + 0.3T_g$

Outdoor: $0.7T_{nwb} + 0.2T_g + 0.1T$

Where T_{nwb} = natural wet bulb temperature, T_g = black globe temperature and T = air temperature (dry bulb). Both the indoor and outdoor calculations used air temperature (°C) and dew point temperature (°C), whereas the outdoor calculations also considered solar radiation (W/m^2) and wind speed (m/s).

Steadman's apparent temperature

Outdoor apparent temperature $= T + 0.348V - 0.70S + 0.70 * \frac{Q}{S+10} - 4.25$

Indoor apparent temperature $= 0.89T + 0.382V - 2.56$

Where T = air temperature (°C), V = water vapour pressure (hPa), S = wind speed (m/s) at an elevation of 10 metres and Q = rate of heat flow per unit area of body surface (W/m^2).

The calculation for Q is equal to Q$_{\text{ingoing}}$ - Q$_{\text{outgoing}}$ where (83,199):

Q$_{\text{ingoing}}$ $= \frac{Q_D + Q_d}{6}$

Q$_{\text{outgoing}}$ $= (1 - \frac{\phi_4^2}{2})(T + 103)(1 - e^{-0.11L} + e^{-0.11L-1.1})e^{-0.01V}$

Q$_{\text{D}}$ = direct solar radiation on a horizontal surface (W/m^2), Q$_{\text{d}}$ = diffuse solar radiation on a horizontal surface (W/m^2), ϕ_4 = fraction of the sky covered by cloud, T = air temperature (°C), L = elevation above sea level (km, obtained using Google Maps (57)), V = water vapour pressure (hPa) and e is a mathematical constant ≈ 2.718.

Heat index

The formulation for the heat index (HI) changes depending on the values for air temperature (T, in °F) and relative humidity (H$_{\text{R}}$, in %) (148,231). If:

T ≤ 40°F: $HI = T$

40 < T < 80°F, $HI = 1.1T + 0.047H - 10.3$

T ≥ 80°F, $HI = -42.379 + 2.04901523T + 10.14333127H - 0.22475541TH - 0.00683783T^2 - 0.05481717H^2 + 0.00122874T^2H + .00085282TH^2 - 0.00000199T^2H^2$. This formulation is further modified if:

80 ≤ T < 112°F and H <= 13%; subtract from HI: $\frac{13-H}{4}\sqrt{\frac{17-|T-95|}{17}}$

$80 \leq$ T $<$ 87°F and H $>$ 85%; add to HI: $\frac{(H-85)(87-T)}{50}$

Humidex

Humidex is calculated as $T + \frac{5(V-10)}{9}$, where T = air temperature (°C) and V = water vapour pressure (hPa) (149,232).

C.2 Supplementary Tables

Table C.1: Australian and New Zealand Standard Classification of Occupations units and their assigned indoors or outdoors status

Unit	Description	Location
1111	Chief Executives and Managing Directors	Indoors
1112	General Managers	Indoors
1113	Legislators	Indoors
1211	Aquaculture Farmers	Outdoors
1212	Crop Farmers	Outdoors
1213	Livestock Farmers	Outdoors
1214	Mixed Crop and Livestock Farmers	Outdoors
1311	Advertising, Public Relations and Sales Managers	Indoors
1321	Corporate Services Managers	Indoors
1322	Finance Managers	Indoors
1323	Human Resource Managers	Indoors
1324	Policy and Planning Managers	Indoors
1325	Research and Development Managers	Indoors
1331	Construction Managers	Indoors
1332	Engineering Managers	Indoors
1333	Importers, Exporters and Wholesalers	Indoors
1334	Manufacturers	Indoors
1335	Production Managers	Indoors
1336	Supply, Distribution and Procurement Managers	Indoors
1341	Child Care Centre Managers	Indoors
1342	Health and Welfare Services Managers	Indoors
1343	School Principals	Indoors
1344	Other Education Managers	Indoors
1351	ICT Managers	Indoors
1391	Commissioned Officers (Management)	Indoors
1392	Senior Non-commissioned Defence Force Members	Indoors
1399	Other Specialist Managers	Indoors
1411	Cafe and Restaurant Managers	Indoors
1412	Caravan Park and Camping Ground Managers	Indoors
1413	Hotel and Motel Managers	Indoors
1414	Licensed Club Managers	Indoors
1419	Other Accommodation and Hospitality Managers	Indoors
1421	Retail Managers	Indoors
1491	Amusement, Fitness and Sports Centre Managers	Indoors
1492	Call or Contact Centre and Customer Service Managers	Indoors
1493	Conference and Event Organisers	Indoors
1494	Transport Services Managers	Indoors
1499	Other Hospitality, Retail and Service Managers	Indoors
2111	Actors, Dancers and Other Entertainers	Indoors
2112	Music Professionals	Outdoors
2113	Photographers	Outdoors

Table C.1: Australian and New Zealand Standard Classification of Occupations units and their assigned indoors or outdoors status *(continued)*

Unit	Description	Location
2114	Visual Arts and Crafts Professionals	Indoors
2121	Artistic Directors, and Media Producers and Presenters	Indoors
2122	Authors, and Book and Script Editors	Indoors
2123	Film, Television, Radio and Stage Directors	Outdoors
2124	Journalists and Other Writers	Indoors
2211	Accountants	Indoors
2212	Auditors, Company Secretaries and Corporate Treasurers	Indoors
2221	Financial Brokers	Indoors
2222	Financial Dealers	Indoors
2223	Financial Investment Advisers and Managers	Indoors
2231	Human Resource Professionals	Indoors
2232	ICT Trainers	Indoors
2233	Training and Development Professionals	Indoors
2241	Actuaries, Mathematicians and Statisticians	Indoors
2242	Archivists, Curators and Records Managers	Indoors
2243	Economists	Indoors
2244	Intelligence and Policy Analysts	Indoors
2245	Land Economists and Valuers	Indoors
2246	Librarians	Indoors
2247	Management and Organisation Analysts	Indoors
2249	Other Information and Organisation Professionals	Indoors
2251	Advertising and Marketing Professionals	Indoors
2252	ICT Sales Professionals	Indoors
2253	Public Relations Professionals	Indoors
2254	Technical Sales Representatives	Indoors
2311	Air Transport Professionals	Indoors
2312	Marine Transport Professionals	Indoors
2321	Architects and Landscape Architects	Indoors
2322	Surveyors and Spatial Scientists	Indoors
2323	Fashion, Industrial and Jewellery Designers	Indoors
2324	Graphic and Web Designers, and Illustrators	Indoors
2325	Interior Designers	Indoors
2326	Urban and Regional Planners	Indoors
2331	Chemical and Materials Engineers	Indoors
2332	Civil Engineering Professionals	Outdoors
2333	Electrical Engineers	Indoors
2334	Electronics Engineers	Indoors
2335	Industrial, Mechanical and Production Engineers	Indoors
2336	Mining Engineers	Indoors
2339	Other Engineering Professionals	Indoors
2341	Agricultural and Forestry Scientists	Indoors

Table C.1: Australian and New Zealand Standard Classification of Occupations units and their assigned indoors or outdoors status *(continued)*

Unit	Description	Location
2342	Chemists, and Food and Wine Scientists	Indoors
2343	Environmental Scientists	Outdoors
2344	Geologists, Geophysicists and Hydrogeologists	Outdoors
2345	Life Scientists	Outdoors
2346	Medical Laboratory Scientists	Indoors
2347	Veterinarians	Outdoors
2349	Other Natural and Physical Science Professionals	Indoors
2411	Early Childhood (Pre-primary School) Teachers	Outdoors
2412	Primary School Teachers	Outdoors
2413	Middle School Teachers / Intermediate School Teachers	Outdoors
2414	Secondary School Teachers	Indoors
2415	Special Education Teachers	Indoors
2421	University Lecturers and Tutors	Indoors
2422	Vocational Education Teachers / Polytechnic Teachers	Indoors
2491	Education Advisers and Reviewers	Indoors
2492	Private Tutors and Teachers	Indoors
2493	Teachers of English to Speakers of Other Languages	Indoors
2511	Nutrition Professionals	Indoors
2512	Medical Imaging Professionals	Indoors
2513	Occupational and Environmental Health Professionals	Outdoors
2514	Optometrists and Orthoptists	Indoors
2515	Pharmacists	Indoors
2519	Other Health Diagnostic and Promotion Professionals	Indoors
2521	Chiropractors and Osteopaths	Indoors
2522	Complementary Health Therapists	Indoors
2523	Dental Practitioners	Indoors
2524	Occupational Therapists	Indoors
2525	Physiotherapists	Indoors
2526	Podiatrists	Indoors
2527	Audiologists and Speech Pathologists / Therapists	Indoors
2531	General Practitioners and Resident Medical Officers	Indoors
2532	Anaesthetists	Indoors
2533	Specialist Physicians	Indoors
2534	Psychiatrists	Indoors
2535	Surgeons	Indoors
2539	Other Medical Practitioners	Indoors
2541	Midwives	Indoors
2542	Nurse Educators and Researchers	Indoors
2543	Nurse Managers	Indoors
2544	Registered Nurses	Indoors
2611	ICT Business and Systems Analysts	Indoors

Table C.1: Australian and New Zealand Standard Classification of Occupations units and their assigned indoors or outdoors status *(continued)*

Unit	Description	Location
2612	Multimedia Specialists and Web Developers	Indoors
2613	Software and Applications Programmers	Indoors
2621	Database & Systems Administrators, and ICT Security Specialists	Indoors
2631	Computer Network Professionals	Indoors
2632	ICT Support and Test Engineers	Indoors
2633	Telecommunications Engineering Professionals	Indoors
2711	Barristers	Indoors
2712	Judicial and Other Legal Professionals	Indoors
2713	Solicitors	Indoors
2721	Counsellors	Indoors
2722	Ministers of Religion	Indoors
2723	Psychologists	Indoors
2724	Social Professionals	Indoors
2725	Social Workers	Indoors
2726	Welfare, Recreation and Community Arts Workers	Indoors
3111	Agricultural Technicians	Outdoors
3112	Medical Technicians	Indoors
3113	Primary Products Inspectors	Outdoors
3114	Science Technicians	Indoors
3121	Architectural, Building and Surveying Technicians	Outdoors
3122	Civil Engineering Draftspersons and Technicians	Indoors
3123	Electrical Engineering Draftspersons and Technicians	Indoors
3124	Electronic Engineering Draftspersons and Technicians	Indoors
3125	Mechanical Engineering Draftspersons and Technicians	Indoors
3126	Safety Inspectors	Outdoors
3129	Other Building and Engineering Technicians	Indoors
3131	ICT Support Technicians	Indoors
3132	Telecommunications Technical Specialists	Indoors
3211	Automotive Electricians	Indoors
3212	Motor Mechanics	Indoors
3221	Metal Casting, Forging and Finishing Trades Workers	Indoors
3222	Sheetmetal Trades Workers	Outdoors
3223	Structural Steel and Welding Trades Workers	Outdoors
3231	Aircraft Maintenance Engineers	Indoors
3232	Metal Fitters and Machinists	Indoors
3233	Precision Metal Trades Workers	Indoors
3234	Toolmakers and Engineering Patternmakers	Indoors
3241	Panelbeaters	Indoors
3242	Vehicle Body Builders and Trimmers	Indoors
3243	Vehicle Painters	Indoors
3311	Bricklayers and Stonemasons	Outdoors

Table C.1: Australian and New Zealand Standard Classification of Occupations units and their assigned indoors or outdoors status *(continued)*

Unit	Description	Location
3312	Carpenters and Joiners	Outdoors
3321	Floor Finishers	Indoors
3322	Painting Trades Workers	Outdoors
3331	Glaziers	Outdoors
3332	Plasterers	Indoors
3333	Roof Tilers	Outdoors
3334	Wall and Floor Tilers	Outdoors
3341	Plumbers	Outdoors
3411	Electricians	Indoors
3421	Airconditioning and Refrigeration Mechanics	Indoors
3422	Electrical Distribution Trades Workers	Outdoors
3423	Electronics Trades Workers	Indoors
3424	Telecommunications Trades Workers	Indoors
3511	Bakers and Pastrycooks	Indoors
3512	Butchers and Smallgoods Makers	Indoors
3513	Chefs	Indoors
3514	Cooks	Indoors
3611	Animal Attendants and Trainers	Outdoors
3612	Shearers	Outdoors
3613	Veterinary Nurses	Indoors
3621	Florists	Indoors
3622	Gardeners	Outdoors
3623	Greenkeepers	Outdoors
3624	Nurserypersons	Outdoors
3911	Hairdressers	Indoors
3921	Print Finishers and Screen Printers	Indoors
3922	Graphic Pre-press Trades Workers	Indoors
3923	Printers	Indoors
3931	Canvas and Leather Goods Makers	Indoors
3932	Clothing Trades Workers	Indoors
3933	Upholsterers	Indoors
3941	Cabinetmakers	Indoors
3942	Wood Machinists and Other Wood Trades Workers	Indoors
3991	Boat Builders and Shipwrights	Outdoors
3992	Chemical, Gas, Petroleum and Power Generation Plant Operators	Indoors
3993	Gallery, Library and Museum Technicians	Indoors
3994	Jewellers	Indoors
3995	Performing Arts Technicians	Indoors
3996	Signwriters	Indoors
3999	Other Miscellaneous Technicians and Trades Workers	Indoors
4111	Ambulance Officers and Paramedics	Outdoors

Table C.1: Australian and New Zealand Standard Classification of Occupations units and their assigned indoors or outdoors status *(continued)*

Unit	Description	Location
4112	Dental Hygienists, Technicians and Therapists	Indoors
4113	Diversional Therapists	Indoors
4114	Enrolled and Mothercraft Nurses	Indoors
4115	Indigenous Health Workers	Indoors
4116	Massage Therapists	Indoors
4117	Welfare Support Workers	Indoors
4211	Child Carers	Indoors
4221	Education Aides	Outdoors
4231	Aged and Disabled Carers	Indoors
4232	Dental Assistants	Indoors
4233	Nursing Support and Personal Care Workers	Indoors
4234	Special Care Workers	Indoors
4311	Bar Attendants and Baristas	Indoors
4312	Cafe Workers	Indoors
4313	Gaming Workers	Indoors
4314	Hotel Service Managers	Indoors
4315	Waiters	Indoors
4319	Other Hospitality Workers	Indoors
4411	Defence Force Members - Other Ranks	Indoors
4412	Fire and Emergency Workers	Indoors
4413	Police	Outdoors
4421	Prison Officers	Indoors
4422	Security Officers and Guards	Indoors
4511	Beauty Therapists	Indoors
4512	Driving Instructors	Indoors
4513	Funeral Workers	Indoors
4514	Gallery, Museum and Tour Guides	Outdoors
4515	Personal Care Consultants	Indoors
4516	Tourism and Travel Advisers	Indoors
4517	Travel Attendants	Indoors
4518	Other Personal Service Workers	Indoors
4521	Fitness Instructors	Outdoors
4522	Outdoor Adventure Guides	Outdoors
4523	Sports Coaches, Instructors and Officials	Outdoors
4524	Sportspersons	Indoors
5111	Contract, Program and Project Administrators	Indoors
5121	Office Managers	Indoors
5122	Practice Managers	Indoors
5211	Personal Assistants	Indoors
5212	Secretaries	Indoors
5311	General Clerks	Indoors

Table C.1: Australian and New Zealand Standard Classification of Occupations units and their assigned indoors or outdoors status *(continued)*

Unit	Description	Location
5321	Keyboard Operators	Indoors
5411	Call or Contact Centre Workers	Indoors
5412	Information Officers	Indoors
5421	Receptionists	Indoors
5511	Accounting Clerks	Indoors
5512	Bookkeepers	Indoors
5513	Payroll Clerks	Indoors
5521	Bank Workers	Indoors
5522	Credit and Loans Officers	Indoors
5523	Insurance, Money Market and Statistical Clerks	Indoors
5611	Betting Clerks	Indoors
5612	Couriers and Postal Deliverers	Outdoors
5613	Filing and Registry Clerks	Indoors
5614	Mail Sorters	Indoors
5615	Survey Interviewers	Outdoors
5616	Switchboard Operators	Indoors
5619	Other Clerical and Office Support Workers	Indoors
5911	Purchasing and Supply Logistics Clerks	Indoors
5912	Transport and Despatch Clerks	Indoors
5991	Conveyancers and Legal Executives	Indoors
5992	Court and Legal Clerks	Indoors
5993	Debt Collectors	Outdoors
5994	Human Resource Clerks	Indoors
5995	Inspectors and Regulatory Officers	Indoors
5996	Insurance Investigators, Loss Adjusters and Risk Surveyors	Indoors
5997	Library Assistants	Indoors
5999	Other Miscellaneous Clerical and Administrative Workers	Indoors
6111	Auctioneers, and Stock and Station Agents	Indoors
6112	Insurance Agents	Indoors
6113	Sales Representatives	Indoors
6121	Real Estate Sales Agents	Indoors
6211	Sales Assistants (General)	Indoors
6212	ICT Sales Assistants	Indoors
6213	Motor Vehicle and Vehicle Parts Salespersons	Indoors
6214	Pharmacy Sales Assistants	Indoors
6215	Retail Supervisors	Indoors
6216	Service Station Attendants	Outdoors
6217	Street Vendors and Related Salespersons	Outdoors
6219	Other Sales Assistants and Salespersons	Indoors
6311	Checkout Operators and Office Cashiers	Indoors
6391	Models and Sales Demonstrators	Indoors

Table C.1: Australian and New Zealand Standard Classification of Occupations units and their assigned indoors or outdoors status *(continued)*

Unit	Description	Location
6392	Retail and Wool Buyers	Indoors
6393	Telemarketers	Indoors
6394	Ticket Salespersons	Indoors
6395	Visual Merchandisers	Indoors
6399	Other Sales Support Workers	Indoors
7111	Clay, Concrete, Glass and Stone Processing Machine Operators	Indoors
7112	Industrial Spraypainters	Indoors
7113	Paper and Wood Processing Machine Operators	Indoors
7114	Photographic Developers and Printers	Indoors
7115	Plastics and Rubber Production Machine Operators	Indoors
7116	Sewing Machinists	Indoors
7117	Textile and Footwear Production Machine Operators	Indoors
7119	Other Machine Operators	Indoors
7121	Crane, Hoist and Lift Operators	Indoors
7122	Drillers, Miners and Shot Firers	Indoors
7123	Engineering Production Workers	Indoors
7129	Other Stationary Plant Operators	Indoors
7211	Agricultural, Forestry and Horticultural Plant Operators	Indoors
7212	Earthmoving Plant Operators	Indoors
7213	Forklift Drivers	Indoors
7219	Other Mobile Plant Operators	Indoors
7311	Automobile Drivers	Indoors
7312	Bus and Coach Drivers	Indoors
7313	Train and Tram Drivers	Indoors
7321	Delivery Drivers	Indoors
7331	Truck Drivers	Indoors
7411	Storepersons	Indoors
8111	Car Detailers	Outdoors
8112	Commercial Cleaners	Indoors
8113	Domestic Cleaners	Indoors
8114	Housekeepers	Indoors
8115	Laundry Workers	Indoors
8116	Other Cleaners	Outdoors
8211	Building and Plumbing Labourers	Outdoors
8212	Concreters	Outdoors
8213	Fencers	Outdoors
8214	Insulation and Home Improvement Installers	Outdoors
8215	Paving and Surfacing Labourers	Outdoors
8216	Railway Track Workers	Outdoors
8217	Structural Steel Construction Workers	Outdoors
8219	Other Construction and Mining Labourers	Outdoors

Table C.1: Australian and New Zealand Standard Classification of Occupations units and their assigned indoors or outdoors status *(continued)*

Unit	Description	Location
8311	Food and Drink Factory Workers	Indoors
8312	Meat Boners and Slicers, and Slaughterers	Indoors
8313	Meat, Poultry and Seafood Process Workers	Indoors
8321	Packers	Indoors
8322	Product Assemblers	Indoors
8391	Metal Engineering Process Workers	Indoors
8392	Plastics and Rubber Factory Workers	Indoors
8393	Product Quality Controllers	Indoors
8394	Timber and Wood Process Workers	Indoors
8399	Other Factory Process Workers	Indoors
8411	Aquaculture Workers	Outdoors
8412	Crop Farm Workers	Indoors
8413	Forestry and Logging Workers	Outdoors
8414	Garden and Nursery Labourers	Outdoors
8415	Livestock Farm Workers	Indoors
8416	Mixed Crop and Livestock Farm Workers	Indoors
8419	Other Farm, Forestry and Garden Workers	Outdoors
8511	Fast Food Cooks	Indoors
8512	Food Trades Assistants	Indoors
8513	Kitchenhands	Indoors
8911	Freight and Furniture Handlers	Outdoors
8912	Shelf Fillers	Outdoors
8991	Caretakers	Outdoors
8992	Deck and Fishing Hands	Outdoors
8993	Handypersons	Outdoors
8994	Motor Vehicle Parts and Accessories Fitters	Outdoors
8995	Printing Assistants and Table Workers	Indoors
8996	Recycling and Rubbish Collectors	Outdoors
8997	Vending Machine Attendants	Indoors
8999	Other Miscellaneous Labourers	Outdoors

Classification of individual Australian and New Zealand Standard Classification of Occupations (ANZSCO) units as either indoors or outdoors based on a crosswalk with the Canadian National Occupation System.

Table C.2: Inclusion and exclusion criteria for workers' compensation claims data

Filter	Total	Adelaide	Brisbane	Darwin	Hobart	Perth	Melbourne	Sydney
Overall	4,142,872 (100.00)	403,273 (100.00)	658,988 (100.00)	45,547 (100.00)	113,984 (100.00)	523,635 (100.00)	735,146 (100.00)	1,662,299 (100.00)
Duplicate record	3,929 (0.09)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	3,929 (0.53)	0 (0.00)
Missing workplace postcode	169,193 (4.08)	59,141 (14.67)	8,525 (1.29)	12,555 (27.56)	11,937 (10.47)	16,358 (3.12)	6,642 (0.90)	54,035 (3.25)
Not in capital city	1,182,547 (28.54)	67,722 (16.79)	194,672 (29.54)	12,443 (27.32)	51,398 (45.09)	151,113 (28.86)	180,567 (24.56)	524,632 (31.56)
Cannot determine if in capital city	113,037 (2.73)	3,883 (0.96)	17,155 (2.60)	2,804 (6.16)	4,960 (4.35)	1,477 (0.28)	7,150 (0.97)	75,608 (4.55)
Claim submitted before date of OII	4 (<0.01)	1 (<0.01)	3 (<0.01)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Missing date of OII	1 (<0.01)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (<0.01)	0 (0.00)	0 (0.00)
Date of OII before July 05 (06 for Tasmania)	248,785 (6.01)	6,551 (1.62)	33,133 (5.03)	1,598 (3.51)	345 (0.30)	35,291 (6.74)	70,374 (9.57)	101,493 (6.11)
Date of OII after 30 June 18	1 (<0.01)	0 (0.00)	1 (<0.01)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Age at OII $<$ 15 years	780 (0.02)	114 (0.03)	89 (0.01)	22 (0.05)	13 (0.01)	160 (0.03)	138 (0.02)	244 (0.01)
Age at OII $>$ 75 years	1,950 (0.05)	122 (0.03)	495 (0.08)	12 (0.03)	14 (0.01)	149 (0.03)	271 (0.04)	887 (0.05)
Missing age at illness	243 (0.01)	7 (<0.01)	15 (<0.01)	1 (<0.01)	42 (0.04)	12 (<0.01)	1 (<0.01)	165 (0.01)
Not in labor force at time of OII	37 (<0.01)	8 (<0.01)	28 (<0.01)	1 (<0.01)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
No occupational data	100,763 (2.43)	22,205 (5.51)	6,273 (0.95)	14 (0.03)	162 (0.14)	0 (0.00)	71,209 (9.69)	900 (0.05)
Claims for analysis	2,321,602 (56.04)	243,519 (60.39)	398,599 (60.49)	16,097 (35.34)	45,113 (39.58)	319,074 (60.93)	394,865 (53.71)	904,335 (54.40)

Records included and excluded for analysis with justification and stratification by city. The inclusion/exclusion criteria are applied in the order listed from top to bottom. The top row states the number and percentage of records for all claims extracted, and the final row represents the claims that were analyzed. Results are presented as n (%): the number of claims removed and (in brackets) the percentage of overall claims per state. Claims were filtered in order from top the bottom as per the table. 'Cannot determine if metropolitan' refers to a workplace postcode that was either associated with both a metropolitan and regional location or was missing. OII: occupational injury or illness.

Table C.3: National demographics and claim statistics for workers' compensation claims data

Variable	Category	OIIs	Total costs (000s)	Cost per OII
Total		2321602	42,846,949	18,456
	Same financial year as claim submission		13,853,410	5,967
	1 financial year after claim submission		12,083,339	5,205
	2 financial years after claim submission		6,970,641	3,003
	3 financial years after claim submission		4,652,961	2,004
	4 financial years after claim submission		2,986,149	1,286
	5 financial years after claim submission		1,755,537	756
	6 financial years after claim submission		544,222	234
Financial year	2005	214676	3,061,341	14,260
	2006	217893	3,179,910	14,594
	2007	218686	3,531,964	16,151
	2008	201983	4,287,659	21,228
	2009	200441	4,254,803	21,227
	2010	200406	4,351,246	21,712
	2011	200951	4,139,809	20,601
	2012	164203	3,483,210	21,213
	2013	152453	3,189,442	20,921
	2014	145394	2,935,927	20,193
	2015	138160	2,588,376	18,735
	2016	138287	2,308,085	16,691
	2017	128069	1,535,178	11,987
Month	January	170740	3,195,475	18,715
	February	203831	3,685,659	18,082
	March	209996	3,843,687	18,304
	April	172272	3,261,564	18,933
	May	207048	3,768,095	18,199
	June	181642	3,365,098	18,526
	July	200673	3,743,836	18,656
	August	207358	3,877,780	18,701
	September	193722	3,601,084	18,589
	October	202808	3,783,119	18,654
	November	206891	3,722,966	17,995
	December	164621	2,998,584	18,215
Day of week	Monday	436594	7,993,989	18,310
	Tuesday	436562	7,743,780	17,738
	Wednesday	431206	7,644,465	17,728
	Thursday	412923	7,597,320	18,399
	Friday	361507	7,003,848	19,374
	Saturday	137443	2,821,277	20,527
	Sunday	105367	2,042,270	19,382
City	Adelaide	243519	3,405,026	13,983
	Brisbane	398599	9,103,122	22,838
	Darwin	16097	409,137	25,417
	Hobart	45113	711,092	15,762
	Melbourne	394865	7,184,026	18,194
	Perth	319074	6,092,054	19,093
	Sydney	904335	15,942,491	17,629
Sex	Female	842243	14,492,686	17,207
	Male	1479359	28,354,262	19,167
Age (years)	15-19	99074	583,071	5,885
	20-24	240961	2,147,472	8,912
	25-29	255301	3,224,756	12,631
	30-34	246045	4,130,864	16,789
	35-39	253342	5,261,388	20,768
	40-44	270919	6,006,585	22,171
	45-49	289091	6,484,202	22,430
	50-54	273746	6,314,516	23,067
	55-59	218013	5,005,828	22,961
	60-64	130912	2,826,054	21,587
	65-75	44198	862,215	19,508

Table C.3: National demographics and claim statistics for workers' compensation claims data *(continued)*

Variable	Category	OIIs	Total costs (000s)	Cost per OII
Indoors/outdoors	Indoors	1718601	31,145,625	18,123
	Outdoors	603001	11,701,323	19,405
Occupation	Clerical and administrative workers	140184	2,407,802	17,176
	Community and personal service workers	351481	6,230,370	17,726
	Laborers	525427	10,398,543	19,791
	Machinery operators and drivers	314527	7,032,284	22,358
	Managers	103944	2,170,570	20,882
	Professionals	293447	4,864,171	16,576
	Sales workers	149222	2,279,425	15,275
	Technicians and trades workers	443370	7,463,784	16,834
Industry	Accommodation and Food Services	109096	1,485,651	13,618
	Administrative and Support Services	93081	1,599,294	17,182
	Agriculture, Forestry and Fishing	16960	363,777	21,449
	Arts and Recreation Services	49628	611,841	12,329
	Construction	213683	5,616,200	26,283
	Education and Training	170743	2,404,717	14,084
	Electricity, Gas, Water and Waste Services	27400	506,422	18,483
	Financial and Insurance Services	28308	477,521	16,869
	Health Care and Social Assistance	279400	4,756,383	17,024
	Information Media and Telecommunications	16761	257,284	15,350
	Manufacturing	357205	6,700,078	18,757
	Mining	22143	916,175	41,375
	Other Services	70943	1,255,485	17,697
	Professional, Scientific and Technical Services	58742	1,021,834	17,395
	Public Administration and Safety	169232	3,445,759	20,361
	Rental, Hiring and Real Estate Services	22397	457,586	20,431
	Retail Trade	207905	3,187,616	15,332
	Transport, Postal and Warehousing	179716	3,818,637	21,248
	Wholesale Trade	115687	2,211,561	19,117
	Missing	112572	1,753,128	15,573
Type of OII	Injuries	1813203	29,229,223	16,120
	Diseases and conditions	508399	13,617,726	26,786
OII nature	Intracranial injuries	14888	446,353	29,981
	Fractures	139958	4,492,209	32,097
	Wounds, lacerations, amputations and internal organ damage	498248	4,130,181	8,289
	Burn	43681	290,487	6,650
	Injury to nerves and spinal cord	2276	218,759	96,116
	Traumatic joint/ligament and muscle/tendon injury	1003079	18,317,111	18,261
	Other injuries	111073	1,334,123	12,011
	Musculoskeletal and connective tissue diseases	271824	6,898,377	25,378
	Mental disorders	103566	4,514,021	43,586
	Digestive system diseases	29732	471,938	15,873
	Skin and subcutaneous tissue diseases	13479	91,010	6,752
	Nervous system and sense organ diseases	57678	1,008,684	17,488
	Respiratory system diseases	6019	139,009	23,095
	Circulatory system diseases	3314	133,042	40,145
	Infectious and parasitic diseases	4043	39,366	9,737
	Neoplasms (cancer)	1395	136,592	97,915
	Other diseases	3059	57,308	18,734
	Other claims	14290	128,379	8,984
OII mechanism	Falls, trips and slips of a person	442818	9,059,787	20,459
	Hitting objects with a part of the body	227541	1,593,169	7,002
	Being hit by moving objects	402883	5,322,650	13,211
	Sound and pressure	37609	572,795	15,230
	Body stressing	835258	17,285,265	20,695
	Heat, electricity and other environmental factors	46502	333,432	7,170
	Chemicals and other substances	41419	352,456	8,510
	Biological factors	11711	79,531	6,791
	Mental stress	76590	3,648,689	47,639
	Vehicle incidents and other	199271	4,599,176	23,080
OII agency	Machinery and (mainly) fixed plant	100659	1,993,852	19,808

Table C.3: National demographics and claim statistics for workers' compensation claims data *(continued)*

Variable	Category	OIIs	Total costs (000s)	Cost per OII
	Mobile plant and transport	197591	4,301,741	21,771
	Powered equipment, tools and appliances	98263	1,511,009	15,377
	Non-powered handtools, appliances and equipment	501149	7,860,811	15,686
	Chemicals and chemical products	26503	234,507	8,848
	Materials and substances	318560	4,739,081	14,877
	Environmental agencies	327492	6,238,810	19,050
	Animal, human and biological agencies	204640	3,929,320	19,201
	Other and unspecified agencies	546745	12,037,818	22,017

Descriptive statistics of all claims included for analysis. Costs are presented in Australian dollars; total costs are presented to the nearest thousand Australian dollars (000s). OII: occupational injury and illness.

Table C.4: Dispersion parameters for the number of occupational injuries and illnesses

Location	Dispersion parameter
Adelaide Indoors	1.290
Adelaide Outdoors	1.127
Brisbane Indoors	1.317
Brisbane Outdoors	1.260
Darwin Indoors	1.025
Darwin Outdoors	1.049
Hobart Indoors	1.075
Hobart Outdoors	1.015
Melbourne Indoors	1.395
Melbourne Outdoors	1.232
Perth Indoors	1.198
Perth Outdoors	1.117
Sydney Indoors	1.507
Sydney Outdoors	1.312

Dispersion parameters from the models analyzing the number of ocupational injuries and illnesses, fitted with a Poisson distribution.

Table C.5: Attributable fractions for the main analysis

Outcome	Location	Heat	Moderate heat	Extreme heat	Cold	Moderate cold	Extreme cold
OIIs	Total	1.66 (1.38 to 1.94)	1.40 (1.17 to 1.63)	0.26 (0.21 to 0.31)	-0.66 (-0.89 to -0.45)	-0.62 (-0.81 to -0.43)	-0.05 (-0.08 to -0.01)
	Indoors	1.82 (1.45 to 2.17)	1.53 (1.24 to 1.83)	0.28 (0.22 to 0.34)	-0.66 (-0.94 to -0.37)	-0.62 (-0.87 to -0.38)	-0.04 (-0.08 to 0.00)
	Outdoors	1.22 (0.86 to 1.56)	1.01 (0.74 to 1.28)	0.20 (0.13 to 0.27)	-0.68 (-0.91 to -0.46)	-0.61 (-0.80 to -0.44)	-0.07 (-0.11 to -0.02)
	Adelaide	1.16 (0.42 to 1.87)	0.99 (0.41 to 1.57)	0.17 (0.02 to 0.31)	-1.15 (-1.73 to -0.59)	-1.03 (-1.55 to -0.55)	-0.12 (-0.20 to -0.03)
	Brisbane	1.22 (0.53 to 1.91)	1.06 (0.44 to 1.65)	0.16 (0.05 to 0.26)	-0.87 (-1.12 to -0.63)	-0.77 (-0.98 to -0.57)	-0.10 (-0.15 to -0.04)
	Darwin	1.71 (-0.05 to 3.39)	1.56 (-0.06 to 3.09)	0.14 (0.00 to 0.28)	-1.16 (-1.54 to -0.77)	-1.02 (-1.42 to -0.65)	-0.14 (-0.20 to -0.08)
	Hobart	1.25 (0.56 to 1.96)	1.04 (0.49 to 1.57)	0.21 (0.04 to 0.36)	-0.78 (-1.36 to -0.21)	-0.71 (-1.20 to -0.24)	-0.07 (-0.18 to 0.02)
	Melbourne	1.74 (1.13 to 2.32)	1.44 (0.98 to 1.90)	0.30 (0.18 to 0.42)	-0.61 (-1.08 to -0.13)	-0.58 (-1.00 to -0.17)	-0.03 (-0.09 to 0.03)
	Perth	1.77 (1.05 to 2.50)	1.50 (0.89 to 2.11)	0.28 (0.14 to 0.40)	-0.81 (-1.25 to -0.38)	-0.75 (-1.13 to -0.38)	-0.06 (-0.13 to 0.01)
	Sydney	1.93 (1.43 to 2.41)	1.62 (1.21 to 2.03)	0.31 (0.22 to 0.40)	-0.40 (-0.88 to 0.05)	-0.40 (-0.80 to -0.02)	-0.01 (-0.08 to 0.06)
	Adelaide Indoors	1.10 (0.20 to 1.98)	0.95 (0.23 to 1.66)	0.15 (-0.04 to 0.32)	-1.27 (-2.01 to -0.56)	-1.13 (-1.77 to -0.53)	-0.13 (-0.24 to -0.03)
	Adelaide Outdoors	1.39 (0.46 to 2.33)	1.13 (0.38 to 1.86)	0.26 (0.02 to 0.48)	-0.76 (-1.42 to -0.08)	-0.70 (-1.26 to -0.12)	-0.06 (-0.18 to 0.04)
	Brisbane Indoors	1.29 (0.36 to 2.20)	1.14 (0.31 to 1.90)	0.16 (0.02 to 0.28)	-0.92 (-1.27 to -0.59)	-0.82 (-1.11 to -0.56)	-0.10 (-0.17 to -0.03)
	Brisbane Outdoors	1.06 (0.15 to 1.90)	0.89 (0.20 to 1.57)	0.18 (0.01 to 0.34)	-0.73 (-0.97 to -0.51)	-0.65 (-0.86 to -0.45)	-0.08 (-0.14 to -0.02)
	Darwin Indoors	1.59 (-0.74 to 3.86)	1.48 (-0.70 to 3.57)	0.11 (-0.07 to 0.28)	-1.18 (-1.70 to -0.65)	-1.03 (-1.56 to -0.52)	-0.15 (-0.23 to -0.08)
	Darwin Outdoors	2.00 (0.17 to 3.78)	1.78 (0.15 to 3.28)	0.23 (-0.01 to 0.44)	-1.10 (-1.46 to -0.77)	-1.01 (-1.33 to -0.69)	-0.10 (-0.21 to 0.02)
	Hobart Indoors	1.23 (0.32 to 2.16)	1.03 (0.32 to 1.71)	0.21 (-0.01 to 0.40)	-0.81 (-1.61 to -0.03)	-0.73 (-1.39 to -0.08)	-0.08 (-0.21 to 0.05)
	Hobart Outdoors	1.30 (0.28 to 2.25)	1.09 (0.31 to 1.81)	0.21 (0.01 to 0.40)	-0.73 (-1.38 to -0.10)	-0.66 (-1.19 to -0.17)	-0.07 (-0.20 to 0.06)
	Melbourne Indoors	1.88 (1.11 to 2.61)	1.55 (0.96 to 2.17)	0.33 (0.17 to 0.47)	-0.63 (-1.25 to -0.02)	-0.60 (-1.15 to -0.06)	-0.03 (-0.11 to 0.05)
	Melbourne Outdoors	1.34 (0.64 to 2.03)	1.10 (0.55 to 1.65)	0.24 (0.08 to 0.39)	-0.54 (-1.11 to 0.01)	-0.51 (-0.98 to -0.06)	-0.03 (-0.14 to 0.07)
	Perth Indoors	1.81 (0.88 to 2.76)	1.53 (0.73 to 2.30)	0.28 (0.11 to 0.44)	-0.86 (-1.47 to -0.30)	-0.80 (-1.30 to -0.30)	-0.06 (-0.16 to 0.02)
	Perth Outdoors	1.68 (0.76 to 2.55)	1.41 (0.66 to 2.17)	0.27 (0.10 to 0.43)	-0.65 (-1.06 to -0.24)	-0.61 (-0.94 to -0.28)	-0.04 (-0.12 to 0.05)
	Sydney Indoors	2.23 (1.61 to 2.84)	1.87 (1.36 to 2.39)	0.36 (0.24 to 0.46)	-0.31 (-0.91 to 0.27)	-0.33 (-0.83 to 0.16)	0.02 (-0.07 to 0.10)
	Sydney Outdoors	1.00 (0.38 to 1.61)	0.84 (0.33 to 1.32)	0.16 (0.02 to 0.30)	-0.70 (-1.18 to -0.23)	-0.61 (-1.00 to -0.24)	-0.08 (-0.18 to 0.02)
Costs	Total	1.53 (0.77 to 2.27)	1.22 (0.56 to 1.85)	0.31 (0.20 to 0.41)	1.33 (0.66 to 1.97)	1.09 (0.50 to 1.65)	0.23 (0.15 to 0.31)
	Indoors	1.63 (0.61 to 2.57)	1.31 (0.44 to 2.13)	0.32 (0.17 to 0.44)	1.50 (0.63 to 2.32)	1.26 (0.47 to 2.00)	0.25 (0.14 to 0.34)
	Outdoors	1.27 (0.42 to 2.06)	0.98 (0.27 to 1.67)	0.29 (0.15 to 0.42)	0.85 (0.13 to 1.52)	0.65 (0.02 to 1.23)	0.19 (0.10 to 0.28)
	Adelaide	1.11 (-0.79 to 2.91)	0.80 (-0.80 to 2.33)	0.31 (-0.01 to 0.59)	2.27 (0.55 to 3.94)	1.96 (0.45 to 3.46)	0.31 (0.13 to 0.48)
	Brisbane	2.07 (0.52 to 3.57)	1.74 (0.39 to 3.08)	0.33 (0.12 to 0.51)	0.35 (-0.80 to 1.51)	0.19 (-0.85 to 1.15)	0.16 (0.00 to 0.30)
	Darwin	2.70 (0.01 to 5.23)	2.47 (-0.04 to 4.88)	0.23 (0.03 to 0.41)	0.30 (-1.44 to 1.90)	0.06 (-1.41 to 1.46)	0.24 (-0.01 to 0.47)
	Hobart	1.31 (-0.18 to 2.73)	0.97 (-0.25 to 2.17)	0.34 (0.09 to 0.56)	1.49 (0.09 to 2.89)	1.24 (-0.03 to 2.44)	0.25 (0.08 to 0.40)
	Melbourne	1.11 (-0.58 to 2.71)	0.82 (-0.59 to 2.18)	0.28 (0.01 to 0.52)	1.71 (0.24 to 3.16)	1.49 (0.14 to 2.74)	0.23 (0.09 to 0.35)
	Perth	2.04 (0.17 to 3.74)	1.64 (0.03 to 3.09)	0.40 (0.11 to 0.64)	1.24 (-0.19 to 2.62)	1.01 (-0.28 to 2.28)	0.22 (0.05 to 0.38)
	Sydney	1.29 (-0.20 to 2.69)	1.00 (-0.26 to 2.23)	0.29 (0.07 to 0.48)	1.56 (0.21 to 2.92)	1.29 (0.07 to 2.45)	0.26 (0.09 to 0.42)
	Adelaide Indoors	0.98 (-1.36 to 3.20)	0.70 (-1.29 to 2.60)	0.28 (-0.12 to 0.62)	2.52 (0.40 to 4.61)	2.19 (0.30 to 4.02)	0.33 (0.11 to 0.54)
	Adelaide Outdoors	1.61 (-0.54 to 3.55)	1.19 (-0.62 to 2.84)	0.42 (0.03 to 0.75)	1.32 (-0.35 to 3.01)	1.10 (-0.52 to 2.53)	0.22 (0.02 to 0.40)
	Brisbane Indoors	2.39 (0.26 to 4.44)	2.05 (0.22 to 3.84)	0.34 (0.07 to 0.58)	0.36 (-1.24 to 1.93)	0.20 (-1.23 to 1.50)	0.16 (-0.05 to 0.36)

Table C.5: Attributable fractions for the main analysis *(continued)*

Outcome	Location	Heat	Moderate heat	Extreme heat	Cold	Moderate cold	Extreme cold
	Brisbane Outdoors	1.36 (-0.31 to 2.94)	1.07 (-0.36 to 2.39)	0.29 (0.00 to 0.53)	0.32 (-0.97 to 1.61)	0.18 (-1.00 to 1.28)	0.14 (-0.05 to 0.32)
	Darwin Indoors	2.78 (-0.87 to 6.16)	2.58 (-0.88 to 5.84)	0.20 (-0.05 to 0.43)	0.22 (-2.10 to 2.34)	-0.01 (-1.91 to 1.82)	0.23 (-0.10 to 0.53)
	Darwin Outdoors	2.49 (-0.22 to 5.02)	2.20 (-0.18 to 4.50)	0.29 (0.00 to 0.53)	0.48 (-1.62 to 2.38)	0.21 (-1.71 to 1.86)	0.27 (-0.02 to 0.55)
	Hobart Indoors	1.31 (-0.55 to 3.10)	0.97 (-0.59 to 2.51)	0.34 (0.01 to 0.62)	1.58 (-0.32 to 3.43)	1.33 (-0.36 to 2.90)	0.25 (0.03 to 0.46)
	Hobart Outdoors	1.30 (-0.83 to 3.28)	0.97 (-0.76 to 2.59)	0.33 (-0.03 to 0.64)	1.25 (-0.30 to 2.79)	1.01 (-0.37 to 2.36)	0.24 (0.03 to 0.44)
	Melbourne Indoors	1.22 (-0.98 to 3.29)	0.91 (-0.90 to 2.67)	0.30 (-0.06 to 0.61)	1.84 (-0.09 to 3.69)	1.62 (-0.13 to 3.24)	0.22 (0.05 to 0.39)
	Melbourne Outdoors	0.79 (-0.92 to 2.42)	0.56 (-0.83 to 1.95)	0.22 (-0.05 to 0.48)	1.34 (-0.26 to 2.83)	1.11 (-0.28 to 2.39)	0.23 (0.03 to 0.42)
	Perth Indoors	2.21 (-0.20 to 4.38)	1.78 (-0.30 to 3.65)	0.42 (0.05 to 0.73)	1.39 (-0.47 to 3.19)	1.15 (-0.52 to 2.77)	0.24 (0.02 to 0.44)
	Perth Outdoors	1.55 (-0.42 to 3.46)	1.24 (-0.51 to 2.85)	0.31 (0.00 to 0.59)	0.78 (-0.70 to 2.26)	0.61 (-0.71 to 1.90)	0.17 (-0.01 to 0.34)
	Sydney Indoors	1.31 (-0.69 to 3.18)	1.02 (-0.68 to 2.64)	0.28 (0.00 to 0.53)	1.81 (-0.01 to 3.58)	1.52 (-0.13 to 3.08)	0.29 (0.05 to 0.49)
	Sydney Outdoors	1.23 (-0.40 to 2.81)	0.94 (-0.42 to 2.27)	0.29 (0.03 to 0.53)	0.91 (-0.54 to 2.34)	0.71 (-0.52 to 1.88)	0.21 (0.01 to 0.40)

The proportion of occupational injuries and illnesses (OIIs) and associated costs attributable to heat and cold stress, with 95% empirical confidence intervals.

Table C.6: Sensitivity analyses for model parameters

	OIIs			Costs		
Analysis	AIC	Heat	Cold	AIC	Heat	Cold
Main model	374695.2	1.66 (1.38 to 1.94)	-0.66 (-0.89 to -0.45)	826354.9	1.53 (0.77 to 2.27)	1.33 (0.66 to 1.97)
Exposure-response knots						
33th and 67th	374732.5	1.46 (1.25 to 1.68)	-0.51 (-0.76 to -0.28)	826389.6	1.52 (0.84 to 2.15)	1.25 (0.53 to 1.92)
25th and 75th	374733.2	1.44 (1.22 to 1.66)	-0.55 (-0.79 to -0.31)	826392.0	1.50 (0.80 to 2.14)	1.26 (0.52 to 1.93)
10th and 90th	374732.7	1.42 (1.20 to 1.65)	-0.60 (-0.83 to -0.37)	826394.6	1.51 (0.88 to 2.11)	1.25 (0.47 to 1.99)
Lag-response period & knots						
6 days, 1 knot	374761.0	1.13 (0.96 to 1.30)	-0.85 (-0.99 to -0.72)	826367.2	0.55 (0.28 to 0.84)	-0.10 (-0.78 to 0.57)
13 days, 1 knot	374742.6	1.35 (1.15 to 1.56)	-0.68 (-0.89 to -0.47)	826358.1	1.13 (0.49 to 1.75)	0.90 (0.10 to 1.67)
13 days, 2 knots	374751.2	1.35 (1.16 to 1.56)	-0.69 (-0.90 to -0.48)	826384.7	1.12 (0.44 to 1.75)	0.90 (0.06 to 1.66)
20 days, 2 knots	374708.3	1.68 (1.41 to 1.96)	-0.67 (-0.90 to -0.47)	826368.7	1.54 (0.78 to 2.26)	1.34 (0.66 to 1.99)
27 days, 1 knot	374660.1	1.83 (1.52 to 2.12)	-0.58 (-0.94 to -0.24)	826371.7	1.69 (1.19 to 2.18)	1.65 (1.02 to 2.26)
27 days, 2 knots	374665.6	1.84 (1.54 to 2.15)	-0.58 (-0.94 to -0.24)	826374.2	1.71 (1.20 to 2.20)	1.63 (1.01 to 2.24)
27 days, 3 knots	374695.9	1.84 (1.54 to 2.14)	-0.60 (-0.96 to -0.25)	826401.9	1.71 (1.19 to 2.22)	1.64 (1.01 to 2.23)
Seasonality df/year						
2	375623.5	1.36 (1.17 to 1.54)	-0.97 (-1.21 to -0.74)	826318.0	1.78 (1.18 to 2.36)	0.88 (0.17 to 1.55)
3	375042.0	1.62 (1.33 to 1.93)	-0.82 (-0.99 to -0.66)	826317.4	1.69 (0.94 to 2.38)	0.99 (0.27 to 1.66)
5	374526.6	1.62 (1.38 to 1.86)	-0.46 (-0.76 to -0.19)	826405.0	1.36 (0.73 to 1.98)	1.89 (0.96 to 2.78)
6	374376.0	1.25 (1.05 to 1.46)	-0.53 (-0.81 to -0.28)	826481.7	0.93 (0.02 to 1.77)	2.37 (1.44 to 3.21)
7	374290.8	1.25 (1.10 to 1.41)	-0.67 (-0.91 to -0.43)	826502.8	1.33 (0.16 to 2.29)	2.23 (1.47 to 2.93)
8	374123.7	1.53 (1.24 to 1.82)	-0.80 (-1.04 to -0.56)	826569.3	1.19 (0.17 to 2.12)	2.54 (1.73 to 3.29)
GAM with 12 df/year, penalized	374224.5	1.55 (1.43 to 1.68)	-1.09 (-1.46 to -0.75)	826317.6	1.55 (1.01 to 2.07)	1.07 (0.46 to 1.63)

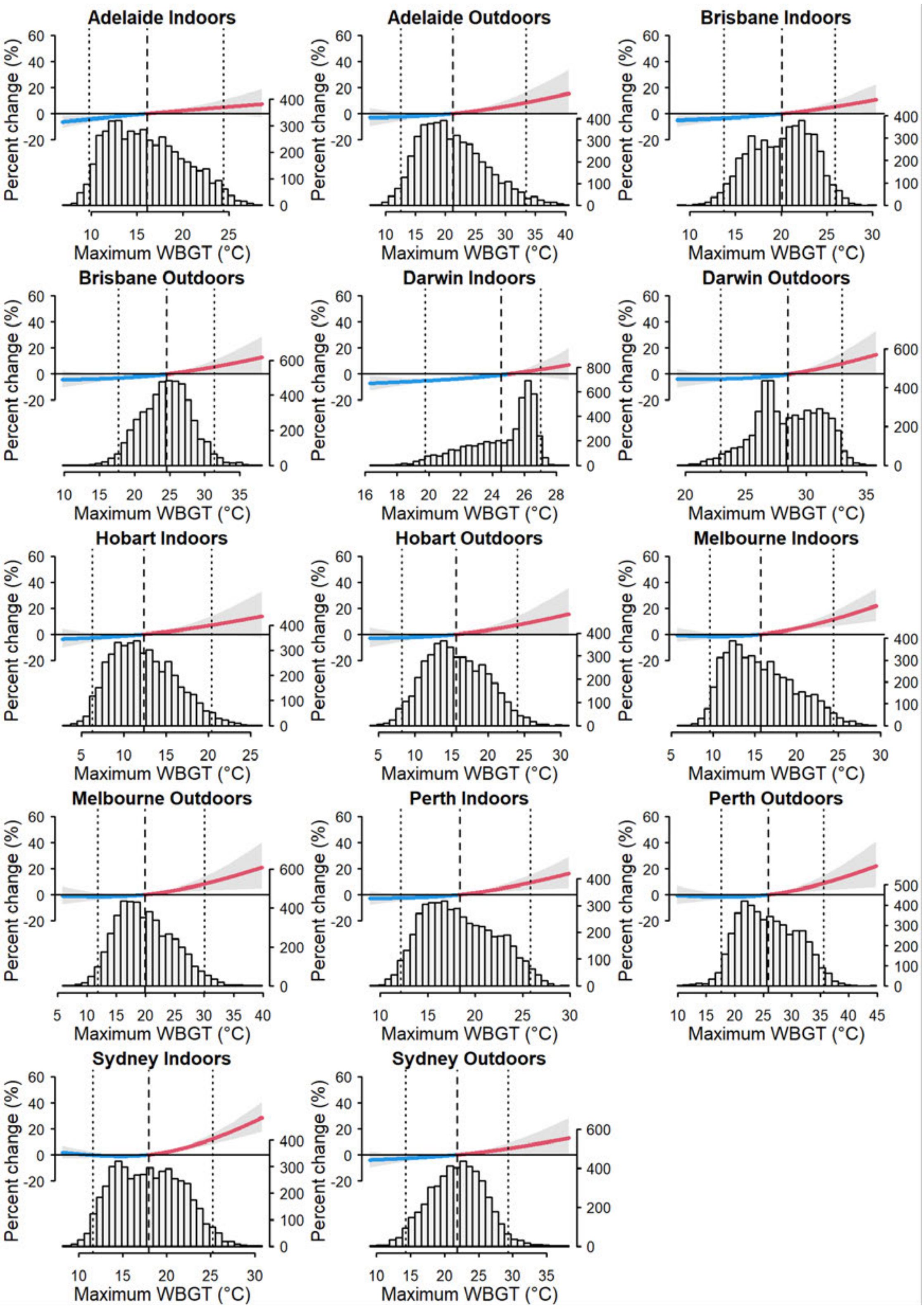
The Akaike information criterion (AIC) presented is identical to the sum of AIC for the individual models. Attributable fractions are presented with 95% empirical confidence intervals. Number of occupational injuries and illnesses (OIIs) were modeled with generalized linear models except for the penalized analysis, whereas all costs analyses were analyzed with generalized additive models (GAMs).

Table C.7: Sensitivity analyses based on indoor/outdoor classification and temperature metric

	OIIs		Costs		
Analysis	Heat	Cold	Heat	Extreme heat	Cold
Indoor/outdoor split by occupation					
Max WBGT (main model)	1.66 (1.38 to 1.94)	-0.66 (-0.89 to -0.45)	1.53 (0.77 to 2.27)	0.31 (0.20 to 0.41)	1.33 (0.66 to 1.97)
Costs up to Jun 2014	-	-	2.01 (0.72 to 3.19)	0.41 (0.24 to 0.56)	1.84 (0.48 to 3.09)
Average WBGT	1.80 (1.48 to 2.12)	-0.46 (-0.65 to -0.27)	1.19 (0.66 to 1.69)	0.21 (0.14 to 0.28)	1.08 (0.53 to 1.61)
Max indoor WBGT	1.78 (1.52 to 2.05)	-0.63 (-0.84 to -0.43)	1.14 (0.49 to 1.75)	0.25 (0.14 to 0.33)	1.58 (1.03 to 2.12)
Max outdoor WBGT	1.26 (1.04 to 1.48)	-0.40 (-0.62 to -0.18)	0.96 (0.53 to 1.36)	0.26 (0.19 to 0.33)	1.41 (0.74 to 2.08)
Max Steadman's apparent T	1.63 (1.39 to 1.87)	-0.56 (-0.82 to -0.31)	0.96 (0.24 to 1.62)	0.24 (0.11 to 0.36)	1.70 (1.10 to 2.28)
Average Steadman's apparent T	1.77 (1.47 to 2.06)	-0.42 (-0.65 to -0.21)	0.89 (0.03 to 1.70)	0.19 (0.07 to 0.29)	1.35 (0.69 to 1.99)
Indoor/outdoor split by industry					
Max WBGT	1.73 (1.46 to 2.01)	-0.65 (-0.92 to -0.39)	1.20 (0.71 to 1.67)	0.26 (0.19 to 0.33)	1.47 (0.88 to 2.03)
Max indoor WBGT	1.79 (1.51 to 2.09)	-0.67 (-0.92 to -0.44)	1.02 (0.54 to 1.48)	0.23 (0.16 to 0.29)	1.57 (0.98 to 2.13)
Max outdoor WBGT	1.28 (1.04 to 1.51)	-0.42 (-0.71 to -0.16)	0.91 (0.46 to 1.35)	0.25 (0.17 to 0.33)	1.44 (0.92 to 1.93)
No indoor/outdoor split					
Max indoor WBGT	1.77 (1.43 to 2.12)	-0.62 (-0.91 to -0.35)	1.08 (0.52 to 1.65)	0.23 (0.14 to 0.32)	1.41 (0.67 to 2.08)
Average indoor WBGT	1.78 (1.33 to 2.23)	-0.40 (-0.63 to -0.19)	1.02 (0.37 to 1.63)	0.19 (0.10 to 0.27)	1.17 (0.50 to 1.81)
Max outdoor WBGT	1.26 (0.98 to 1.53)	-0.39 (-0.67 to -0.12)	0.97 (0.43 to 1.49)	0.25 (0.15 to 0.35)	1.19 (0.57 to 1.81)
Average outdoor WBGT	1.71 (1.34 to 2.09)	-0.39 (-0.64 to -0.13)	0.97 (0.32 to 1.60)	0.20 (0.11 to 0.29)	1.27 (0.63 to 1.94)
Max heat index	1.38 (1.15 to 1.59)	-0.51 (-0.86 to -0.16)	0.87 (0.22 to 1.49)	0.24 (0.11 to 0.35)	1.36 (0.55 to 2.08)
Max humidex	1.66 (1.35 to 1.98)	-0.62 (-0.94 to -0.31)	0.99 (0.45 to 1.54)	0.24 (0.15 to 0.32)	1.46 (0.68 to 2.19)
Max T	1.12 (0.97 to 1.26)	-0.50 (-0.85 to -0.17)	0.64 (-0.10 to 1.33)	0.20 (0.03 to 0.35)	1.25 (0.46 to 2.05)
Average T	1.53 (1.28 to 1.77)	-0.46 (-0.84 to -0.09)	0.69 (0.10 to 1.25)	0.19 (0.10 to 0.27)	1.39 (0.66 to 2.11)
Max T adjusted for specific humidity	1.08 (0.93 to 1.24)	-0.44 (-0.78 to -0.12)	0.61 (-0.14 to 1.32)	0.20 (0.02 to 0.35)	1.32 (0.50 to 2.08)
Average T adjusted for specific humidity	1.36 (1.15 to 1.57)	-0.30 (-0.68 to 0.06)	0.45 (-0.14 to 1.01)	0.15 (0.06 to 0.24)	1.63 (0.91 to 2.34)
Max relative humidity	0.07 (-0.17 to 0.30)	0.09 (-0.36 to 0.53)	0.13 (-0.44 to 0.70)	0.07 (-0.06 to 0.18)	0.57 (-0.22 to 1.31)
Average relative humidity	-0.09 (-0.25 to 0.06)	-0.11 (-0.48 to 0.26)	-0.33 (-1.39 to 0.65)	-0.05 (-0.24 to 0.11)	0.20 (-0.40 to 0.75)

The sensitivity analysis of claims submitted before July 2014 had costs restricted to up to five financial years after the financial year of claim submission. For the temperature + specific humidity models, humidity was fitted linearly; fitting humidity as a natural cubic spline function with one internal knot at the 50th percentile instead produced near-identical estimates (not included). T: temperature.

C.3 Supplementary Figures



Adelaide Indoors

Adelaide Outdoors

Brisbane Indoors

Brisbane Outdoors

Darwin Indoors

Darwin Outdoors

Hobart Indoors

Hobart Outdoors

Melbourne Indoors

Melbourne Outdoors

Perth Indoors

Perth Outdoors

Sydney Indoors

Sydney Outdoors

Figure C.1: Overall cumulative exposure-response curves for occupational injuries and illnesses (OIIs) in Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth and Sydney indoor and outdoor workers. The curves with 95% confidence intervals represent percentage change against mean daily maximum wet bulb globe temperature (WBGT). The dashed lines represent the 2.5th percentile, mean and 97.5th percentiles.

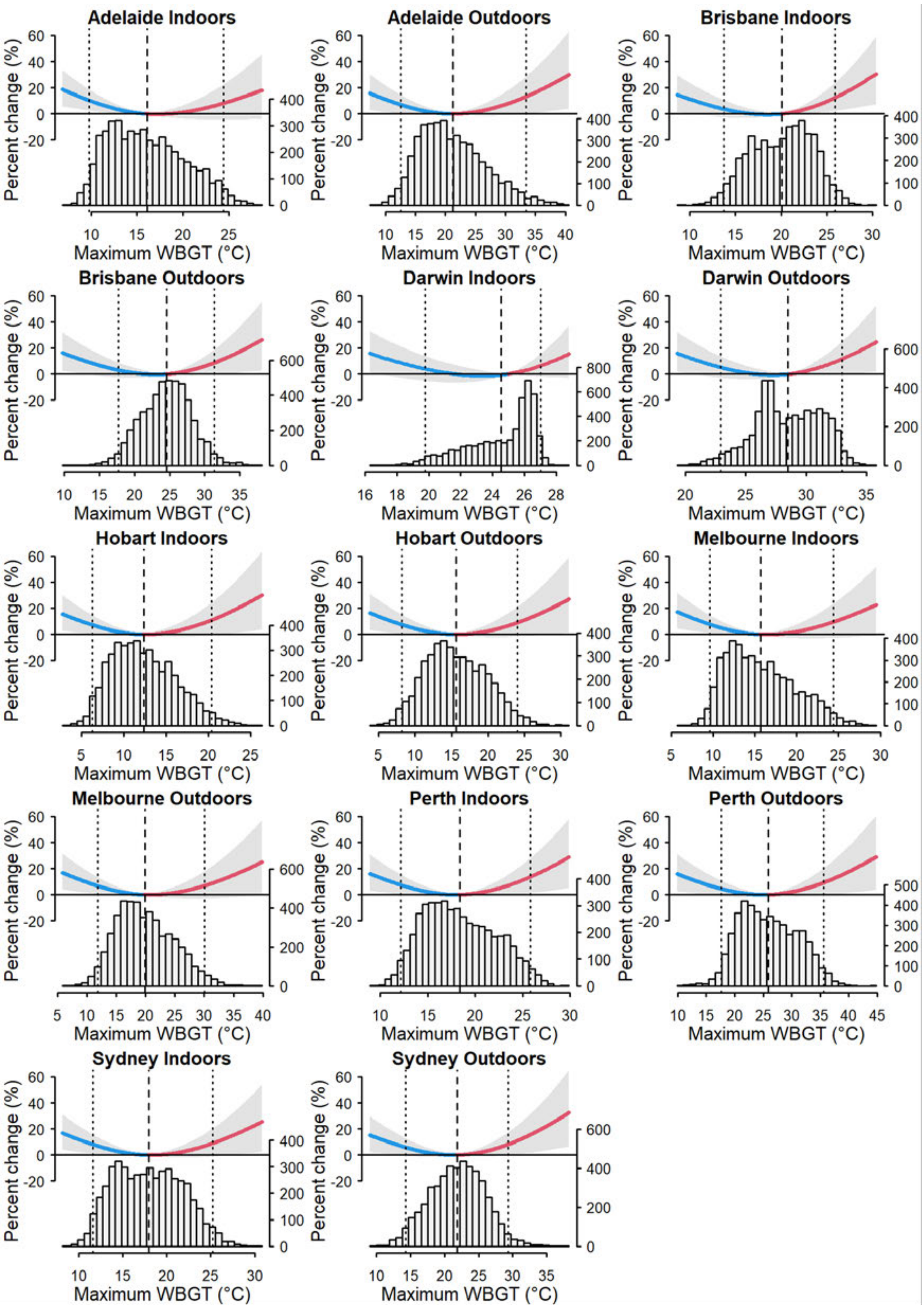


Figure C.2: Overall cumulative exposure-response curves for occupational injuries- and illnesses- (OIIs) associated costs in Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth and Sydney indoor and outdoor workers. The curves with 95% confidence intervals represent percentage change against mean daily maximum wet bulb globe temperature (WBGT). The dashed lines represent the 2.5th percentile, mean and 97.5th percentiles.

D

Chapter 5 Supplementary Material

D.1 Supplementary Methods

Excess Heat Factor

Daily mean temperature was calculated as the average of daily maximum and minimum temperatures within the same 9am-to-9am 24-hour period. DMT is averaged across the current and previous two days ($\mathrm{DMT_{3days}}$) to represent heat that has already occurred (188). EHF incorporates a significance index ($\mathrm{EHI_{sig}}$) and an acclimatization index ($\mathrm{EHI_{accl}}$). $\mathrm{EHI_{accl}}$ represents recent acclimatization over the 30 days prior to the three-day period. $\mathrm{EHI_{sig}}$ represents DMT against the 95th percentile for DMT ($\mathrm{DMT_{95}}$) across the entire time period covered by the BARRA dataaset (January 1990 to February 2019) (187), representing long-term climate adaptation over a near-30 year period. A 30-year reference period is commonly selected for long-term climate change and climate variability assessments (77). EHF was calculated as follows:

$DMT_{3days} = (T_d + T_{d-1} + T_{d-2})/3$ (°C)

$EHI_{sig} = DMT_{3days} - DMT_{95}$ (°C)

$EHI_{accl} = DMT_{3days} - (T_{d-3} + ... + T_{d-32})/30$ (°C)

$EHF = EHI_{sig} * max(1, EHI_{accl})$ [(°C)^2]

Humidity calculations

Vapour pressure (V) for the retrospective meteorological dataset was calculated using specific humidity and air pressure as per the Bureau of Meteorology guidelines (172). The calculation was derived from Wallace and Hobbs (229):
$V = \frac{PQ}{m+(1-m)H_S}$, where m = $\frac{18.01528}{28.9634}$, P = air pressure at 20m elevation (hPa) and H_S = specific humidity (kg/kg).

Saturation vapour pressure (hPa) and dew point temperature were estimated using Buck's 1996 equations including an enhancement factor to accommodate for calculations using moist air instead of pure water vapour (230):
$6.1121e^{T\frac{18.678-T/234.5}{257.14+T}}(1+10^{-4}(7.2+P(0.0320+5.9*10^{-6}T^2)))$, T > 0°C
$6.1115e^{T\frac{23.036-T/333.7}{279.82+T}}(1+10^{-4}(2.2+P(0.0383+6.4*10^{-6}T^2)))$, $T \leq 0$°C
T = air temperature (°C), P = air pressure (hPa), and e is a mathematical constant ≈ 2.718.

Relative humidity was defined as vapour pressure divided by saturation vapour pressure, capped at 100%. The projected meteorological dataset has relative humidity but not specific humidity or air pressure data. To calculate specific humidity, the aforementioned equations were applied in reverse assuming air pressure was identical to atmospheric pressure (1013.25 mbar).

Heat index

Heat index was calculated as (148,231):
$T \leq 40$°F: $HI = T$
$40 < T < 80$°F, $HI = 1.1T + 0.047H - 10.3$
$T \geq 80$°F, $HI = -42.379 + 2.04901523T + 10.14333127H - 0.22475541TH - 0.00683783T^2 - 0.05481717H^2 + 0.00122874T^2H + .00085282TH^2 - 0.00000199T^2H^2$. This formulation is updated if:
$80 \leq T < 112$°F and $H \leq 13$%; subtract from HI: $\frac{13-H}{4}\sqrt{\frac{17-|T-95|}{17}}$

$80 \leq$ T $<$ 87°F and H $>$ 85%; add to HI: $\frac{(H-85)(87-T)}{50}$

Statistical model equation

The statistical model equation used was:
$log[E(Y_t)] = cb(EHF_t) + DOW_t + PH_t + SH_t + D1_t + F_t + Sat : (PH_t + SH_t + D1_t) + Sun : (PH_t + SH_t + D1_t) + ncs(t) + offset(log(n)) + \alpha$

$E(Y_t)$ is the expected number of OIIs or costs on day *t*. *cb(EHF)* is the cross-basis natural cubic spline (ncs) function for EHF with one internal knot at the 50th percentile. Lag effects were modeled using a ncs over ten days with one knot at five days. *DOW* is the day of the week. *PH* is a binary variable indicating whether the day was a public holiday. *SH* designates each of the four school holidays periods, with no school holidays as the reference period (152). The number of hours worked varies seasonally with school holidays (153). *D1* is a binary variable indicating whether the day was the first of the month (excluding New Year's Day), which was associated with more claims relative to other days, likely because OIIs with an unknown day of onset were reported as occurring on the first day. *F* is a factor variable designating the following days or periods that were highly influential on model fit: (1) 23rd-30th December, (2) New Year's Eve, (3) New Year's Day, (4) 2nd-4th January and (5) city-specific days for Adelaide (24th-30th June 2008, which had notably less OIIs than expected), Brisbane (the city-specific holidays of the Royal Queensland Show and 2014 G20 Leaders' Summit), Melbourne (the day before Melbourne Cup) and Sydney (Australia Day, which includes a public celebration at the Sydney Opera House). Interaction terms ("*:*") were included with Saturday/Sunday and *PH*, *SH* and *D1*. *ncs(t)* is a ncs with 4 degrees of freedom (df) per year across the 13-year study period (12-year for Hobart), representing long-term trend. This was penalized for generalized additive models. n is the monthly workforce size, and α is a modeled intercept. Every Sunday is a public holiday in Adelaide (154). Thus for Adelaide, *PH* was always zero on a

Sunday and *Sun:PH* was excluded.

Indoor and outdoor classification

Workers were classified as indoors and outdoors by two separate methods for the stratified analyses. The first method was based on workplace industry. Industries of agriculture, forestry and fishing", "construction", "electricity, gas and water" and "mining" were denoted as outdoor industries; all other industries were indoors (39,54,138).

The second method involved classification using workers' occupations. Occupations, as defined by the Australian and New Zealand Standard Classification of Occupations (ANZSCO) (132), were matched with their corresponding occupations from the Canadian National Occupation System (NOC) (133,134). Both ANZSCO and NOC are derived from the International Standard Classification of Occupations (137). NOC occupations classified with an "L3 location" (having main duties with outdoor work for at least part of the working day), including occupations with multiple locations, were classified as outdoor. Occupations without this classification were analyzed as indoor workers (no outdoor work). Cross-matching was done for 6-digit ANZSCO occupations (the lowest level classification) which were then aggregated to 4-digit unit groups to match the SWA data. ANZSCO occupations associated with both indoor and outdoor NOC occupations were classified based on the more common classification, with indoors being selected in the event of a tie. The cross-matching of ANZSCO and NOC occupation used in this study was checked against two previous cross-matches used in previous Australian studies examining the relationship between temperature and OIIs (29,39,40,135,136) derived from older ANZSCO and NOC versions (39,134). The original cross-match was validated with a strong correlation between ANZSCO and NOC for outdoor work (134). This method is less likely to misclassify indoor/outdoor status. However, it is less commonly used compared to indoor/outdoor stratification by industry for assessing outcomes from occupational heat stress, because it is more difficult to obtain detailed occupational data, especially at the country-level (39,47).

D.2 Supplementary Tables

Table D.1: Number of heatwave days per city per financial year

City	HW days	f05	f06	f07	f08	f09	f10	f11	f12	f13	f14	f15	f16	f17	Mean
Adelaide	Any	13	14	20	8	17	8	9	17	16	9	20	7	19	13.6
Brisbane	Any	34	10	2	7	13	10	4	12	14	17	9	30	16	13.7
Darwin	Any	17	4	5	15	12	4	9	18	10	16	32	22	20	14.2
Hobart	Any	-	14	14	4	15	4	13	17	15	12	16	10	21	12.9
Melbourne	Any	11	13	16	6	18	7	12	17	13	6	10	11	22	12.5
Perth	Any	9	11	20	10	18	29	20	16	14	9	14	4	3	13.6
Sydney	Any	10	8	0	11	16	14	2	5	4	5	17	29	18	10.7
Adelaide	Severe	3	2	3	6	2	2	1	1	4	0	3	2	1	2.3
Brisbane	Severe	4	0	0	0	0	0	1	0	4	4	3	3	2	1.6
Darwin	Severe	1	0	0	7	0	0	0	3	1	6	0	2	2	1.7
Hobart	Severe	-	3	0	3	3	0	2	2	1	2	0	1	3	1.7
Melbourne	Severe	2	4	3	4	0	0	2	0	4	0	2	0	1	1.7
Perth	Severe	0	6	2	0	4	0	3	5	0	0	1	0	0	1.6
Sydney	Severe	1	1	0	3	2	5	0	1	2	0	3	5	3	2.0
Adelaide	Extreme	1	0	0	3	0	0	0	0	3	0	0	0	0	0.5
Brisbane	Extreme	0	0	0	0	0	0	0	0	2	0	0	0	0	0.2
Darwin	Extreme	0	0	0	5	0	0	0	2	0	0	0	0	0	0.5
Hobart	Extreme	-	1	0	1	0	0	2	0	0	0	0	0	1	0.4
Melbourne	Extreme	0	0	0	3	0	0	0	0	3	0	2	0	0	0.6
Perth	Extreme	0	3	0	0	2	0	0	2	0	0	0	0	0	0.5
Sydney	Extreme	0	0	0	0	1	1	0	0	0	0	3	1	0	0.5

The number of heatwave (HW) days during the study period in each of the seven cities for each financial [f]year during the warm season (October to March). The number of HW days is included for all (any), severe and extreme heatwave days. As Hobart was not analyzed during the 2005 financial year, the number of days in Hobart during this year are omitted.

Table D.2: Projected heatwave characteristics

					Non-adaptation				Adaptation			
Location	Period	RCP	GCM	Average DMT (SD)	DMT_{95}	HW days/years	EHF_{50p}	EHF_{85p}	DMT$_{95}$	HW days/years	EHF_{50p}	EHF_{85p}
Adelaide	2016-2045	4.5	ACCESS1-0	19.99 (4.93)	26.51	14	9.96	32.29	27.06	11.4	9.88	30.57
Adelaide	2016-2045	4.5	CESM1-CAM5	19.95 (4.91)	26.51	13.8	10.5	31.86	27.04	11.3	9.76	29.81
Adelaide	2016-2045	4.5	CNRM-CM5	19.95 (4.74)	26.51	12.4	9.96	33.12	26.88	10.6	10.25	31.57
Adelaide	2016-2045	4.5	CanESM2	20.36 (4.98)	26.51	16.6	10.46	34.46	27.5	11.6	9.86	32.98
Adelaide	2016-2045	4.5	GFDL-ESM2M	20.09 (4.85)	26.51	14	10.22	33.81	27.14	11.1	9.96	31.64
Adelaide	2016-2045	4.5	HadGEM2-CC	19.82 (4.85)	26.51	12.4	10.56	32.81	26.87	10.8	9.97	31.27
Adelaide	2016-2045	4.5	MIROC5	20.19 (4.79)	26.51	14.3	10.02	31.96	27.21	10.7	10.8	31.55
Adelaide	2016-2045	4.5	NorESM1-M	19.91 (4.80)	26.51	12.8	10.1	31.16	26.96	10.7	10.31	30.14
Adelaide	2016-2045	8.5	ACCESS1-0	20.38 (4.94)	26.51	16.1	10.45	34.61	27.49	11.1	10.09	31.69
Adelaide	2016-2045	8.5	CESM1-CAM5	20.14 (4.96)	26.51	14.9	10.74	34.49	27.29	11.2	10.31	30.51
Adelaide	2016-2045	8.5	CNRM-CM5	20.14 (4.77)	26.51	13.7	11.02	34.51	27.12	10.8	10.35	30.77
Adelaide	2016-2045	8.5	CanESM2	20.62 (4.93)	26.51	17.5	10.96	35.34	27.73	11.3	9.87	30.69
Adelaide	2016-2045	8.5	GFDL-ESM2M	19.83 (4.78)	26.51	12.3	9.6	31.72	26.78	11	10.25	30.34
Adelaide	2016-2045	8.5	HadGEM2-CC	20.13 (4.77)	26.51	13.5	10.89	32.82	27.08	10.5	11.24	31.57
Adelaide	2016-2045	8.5	MIROC5	20.01 (4.83)	26.51	13.3	10.41	33.67	26.99	11.2	10.16	31.19
Adelaide	2016-2045	8.5	NorESM1-M	20.10 (4.86)	26.51	14.1	10.2	32.12	27.21	10.8	10.35	29.8
Adelaide	2036-2065	4.5	ACCESS1-0	20.59 (4.83)	26.51	16.6	10.73	33.24	27.6	11.1	9.81	30.7
Adelaide	2036-2065	4.5	CESM1-CAM5	20.22 (4.82)	26.51	14.5	10.24	33.5	27.21	11.2	9.91	29.43
Adelaide	2036-2065	4.5	CNRM-CM5	20.44 (4.74)	26.51	14.8	10.17	34.91	27.37	10.6	10.75	31.9
Adelaide	2036-2065	4.5	CanESM2	20.70 (4.94)	26.51	18.2	10.28	35.9	27.91	10.9	10.19	29.74
Adelaide	2036-2065	4.5	GFDL-ESM2M	20.01 (4.80)	26.51	13.4	10.13	31.34	26.99	11.1	9.99	29.93
Adelaide	2036-2065	4.5	HadGEM2-CC	21.05 (4.79)	26.51	18.6	10.9	34.05	28.01	10.7	10.5	31.69
Adelaide	2036-2065	4.5	MIROC5	20.13 (4.88)	26.51	14.5	10.68	31.78	27.22	11	10.06	30.24
Adelaide	2036-2065	4.5	NorESM1-M	20.15 (4.85)	26.51	14.5	10.33	32.18	27.23	11	10.43	30.44
Adelaide	2036-2065	8.5	ACCESS1-0	20.84 (4.88)	26.51	18.7	10.44	33.9	27.9	11.2	10.11	29.74
Adelaide	2036-2065	8.5	CESM1-CAM5	20.58 (4.84)	26.51	16.6	10.34	33.04	27.61	10.7	10.07	30.5
Adelaide	2036-2065	8.5	CNRM-CM5	21.08 (4.90)	26.51	20.1	9.82	35.7	28.22	10.6	10.81	31.41
Adelaide	2036-2065	8.5	CanESM2	21.57 (4.96)	26.51	23.8	10.45	35.67	28.68	11.3	9.91	31.19
Adelaide	2036-2065	8.5	GFDL-ESM2M	20.41 (4.74)	26.51	15	10.57	34.72	27.32	11.1	10.03	31.3
Adelaide	2036-2065	8.5	HadGEM2-CC	21.32 (4.83)	26.51	20.9	10.29	34.61	28.3	10.7	11.08	31.57
Adelaide	2036-2065	8.5	MIROC5	20.49 (4.86)	26.51	16.4	10.11	34.7	27.53	11.2	10.2	30.04
Adelaide	2036-2065	8.5	NorESM1-M	20.58 (4.81)	26.51	16.6	10.13	34.3	27.6	11	10.22	29.54
Brisbane	2016-2045	4.5	ACCESS1-0	24.52 (2.61)	27.28	19.5	1.55	5.67	27.66	14	1.41	5.39
Brisbane	2016-2045	4.5	CESM1-CAM5	24.11 (2.48)	27.28	12.1	1.47	5.25	27.18	13.5	1.43	5.02
Brisbane	2016-2045	4.5	CNRM-CM5	24.02 (2.58)	27.28	13.1	1.43	5.44	27.2	14.1	1.36	5.44
Brisbane	2016-2045	4.5	CanESM2	24.67 (2.37)	27.28	18.5	1.38	5.34	27.58	13.6	1.45	4.94
Brisbane	2016-2045	4.5	GFDL-ESM2M	24.10 (2.45)	27.28	12.1	1.54	5.33	27.15	13.8	1.42	5.43
Brisbane	2016-2045	4.5	HadGEM2-CC	24.53 (2.39)	27.28	16.9	1.44	5.14	27.5	13.1	1.53	5.25
Brisbane	2016-2045	4.5	MIROC5	24.16 (2.53)	27.28	13.4	1.47	5.49	27.26	13.6	1.42	5.52
Brisbane	2016-2045	4.5	NorESM1-M	24.23 (2.54)	27.28	15.2	1.52	5.46	27.35	14.2	1.46	5.31

Table D.2: Projected heatwave characteristics *(continued)*

					Non-adaptation				Adaptation			
Location	Period	RCP	GCM	Average DMT (SD)	DMT_{95}	HW days/years	EHF_{50p}	EHF_{85p}	DMT_{95}	HW days/years	EHF_{50p}	EHF_{85p}
Brisbane	2016-2045	8.5	ACCESS1-0	24.35 (2.42)	27.28	14.1	1.48	5.13	27.34	13.3	1.47	5.13
Brisbane	2016-2045	8.5	CESM1-CAM5	24.67 (2.43)	27.28	18.9	1.42	5.37	27.68	13.2	1.45	5.08
Brisbane	2016-2045	8.5	CNRM-CM5	24.35 (2.58)	27.28	17.8	1.4	5.64	27.53	14	1.43	5.66
Brisbane	2016-2045	8.5	CanESM2	24.92 (2.49)	27.28	26	1.24	5.49	27.97	13.9	1.41	5.04
Brisbane	2016-2045	8.5	GFDL-ESM2M	24.37 (2.47)	27.28	15.9	1.36	5.46	27.43	13.7	1.4	5.56
Brisbane	2016-2045	8.5	HadGEM2-CC	24.71 (2.50)	27.28	21.5	1.36	5.66	27.77	13.7	1.48	5.4
Brisbane	2016-2045	8.5	MIROC5	24.66 (2.56)	27.28	22	1.32	5.77	27.79	13.9	1.44	5.46
Brisbane	2016-2045	8.5	NorESM1-M	24.32 (2.52)	27.28	15.6	1.51	5.46	27.4	13.6	1.51	5.11
Brisbane	2036-2065	4.5	ACCESS1-0	24.79 (2.40)	27.28	20.7	1.33	5.36	27.76	13.1	1.39	4.94
Brisbane	2036-2065	4.5	CESM1-CAM5	24.83 (2.46)	27.28	23.6	1.24	5.6	27.89	13.5	1.46	5.44
Brisbane	2036-2065	4.5	CNRM-CM5	24.50 (2.47)	27.28	18.1	1.35	5.58	27.57	14	1.49	5.26
Brisbane	2036-2065	4.5	CanESM2	25.26 (2.56)	27.28	34.8	1.32	5.58	28.39	13.9	1.53	5.31
Brisbane	2036-2065	4.5	GFDL-ESM2M	24.53 (2.47)	27.28	18.3	1.42	5.77	27.57	13.9	1.44	5.76
Brisbane	2036-2065	4.5	HadGEM2-CC	24.87 (2.34)	27.28	21.2	1.44	5.61	27.8	13.4	1.49	5.23
Brisbane	2036-2065	4.5	MIROC5	24.86 (2.48)	27.28	24.9	1.23	5.53	27.92	13.5	1.47	5.44
Brisbane	2036-2065	4.5	NorESM1-M	24.66 (2.55)	27.28	22.3	1.33	5.57	27.8	13.4	1.61	5.29
Brisbane	2036-2065	8.5	ACCESS1-0	25.32 (2.56)	27.28	36.9	1.29	5.18	28.47	13.5	1.55	5.12
Brisbane	2036-2065	8.5	CESM1-CAM5	25.54 (2.50)	27.28	39.6	1.36	5.37	28.61	13.3	1.49	5.4
Brisbane	2036-2065	8.5	CNRM-CM5	25.20 (2.55)	27.28	33.8	1.33	5.7	28.38	14	1.47	5.58
Brisbane	2036-2065	8.5	CanESM2	26.03 (2.50)	27.28	54.7	1.39	5.67	29.08	13.9	1.53	5.23
Brisbane	2036-2065	8.5	GFDL-ESM2M	25.01 (2.41)	27.28	26.5	1.23	5.35	28.02	13.5	1.39	5.42
Brisbane	2036-2065	8.5	HadGEM2-CC	25.37 (2.39)	27.28	34	1.31	5.34	28.35	13.8	1.55	5.25
Brisbane	2036-2065	8.5	MIROC5	25.18 (2.53)	27.28	32.7	1.32	5.85	28.27	14	1.53	5.74
Brisbane	2036-2065	8.5	NorESM1-M	24.79 (2.48)	27.28	23.2	1.31	5.58	27.85	13.5	1.53	5.23
Darwin	2016-2045	4.5	ACCESS1-0	30.06 (1.23)	30.02	98.2	0.78	1.63	31.62	10.4	0.34	1.02
Darwin	2016-2045	4.5	CESM1-CAM5	29.93 (1.26)	30.02	88.8	0.75	1.6	31.51	11.3	0.35	1.02
Darwin	2016-2045	4.5	CNRM-CM5	29.72 (1.28)	30.02	75.8	0.68	1.5	31.31	11.1	0.37	0.98
Darwin	2016-2045	4.5	CanESM2	30.18 (1.32)	30.02	103.8	0.93	1.88	31.89	10.4	0.37	0.92
Darwin	2016-2045	4.5	GFDL-ESM2M	29.75 (1.25)	30.02	78.4	0.64	1.43	31.38	9.4	0.38	1
Darwin	2016-2045	4.5	HadGEM2-CC	29.94 (1.37)	30.02	89.7	0.89	1.83	31.68	12	0.35	0.96
Darwin	2016-2045	4.5	MIROC5	29.82 (1.23)	30.02	82.2	0.66	1.43	31.36	11	0.35	0.92
Darwin	2016-2045	4.5	NorESM1-M	29.84 (1.31)	30.02	84.2	0.76	1.6	31.51	10.6	0.36	0.92
Darwin	2016-2045	8.5	ACCESS1-0	30.06 (1.26)	30.02	98.3	0.79	1.66	31.69	9.7	0.33	0.99
Darwin	2016-2045	8.5	CESM1-CAM5	30.04 (1.31)	30.02	95.2	0.85	1.78	31.71	10.8	0.37	0.97
Darwin	2016-2045	8.5	CNRM-CM5	29.83 (1.28)	30.02	83.7	0.72	1.58	31.42	10.7	0.35	0.98
Darwin	2016-2045	8.5	CanESM2	30.47 (1.27)	30.02	121.9	1.02	2	32.09	10.6	0.35	0.95
Darwin	2016-2045	8.5	GFDL-ESM2M	29.94 (1.21)	30.02	91.1	0.69	1.51	31.48	9.7	0.34	0.92
Darwin	2016-2045	8.5	HadGEM2-CC	30.28 (1.25)	30.02	112.1	0.9	1.82	31.84	11.2	0.32	0.93
Darwin	2016-2045	8.5	MIROC5	29.91 (1.28)	30.02	87.8	0.77	1.6	31.51	11.7	0.34	0.99
Darwin	2016-2045	8.5	NorESM1-M	29.98 (1.28)	30.02	91.6	0.81	1.67	31.59	11	0.36	0.97

Table D.2: Projected heatwave characteristics *(continued)*

					Non-adaptation				Adaptation			
Location	Period	RCP	GCM	Average DMT (SD)	DMT_{95}	HW days/years	EHF_{50p}	EHF_{85p}	DMT_{95}	HW days/years	EHF_{50p}	EHF_{85p}
Darwin	2036-2065	4.5	ACCESS1-0	30.37 (1.25)	30.02	119.2	0.94	1.88	31.94	10	0.34	0.93
Darwin	2036-2065	4.5	CESM1-CAM5	30.47 (1.29)	30.02	121.4	1.03	2.11	32.14	11.5	0.37	1.02
Darwin	2036-2065	4.5	CNRM-CM5	30.09 (1.29)	30.02	100.2	0.85	1.81	31.72	10.3	0.37	0.95
Darwin	2036-2065	4.5	CanESM2	30.66 (1.32)	30.02	131.1	1.17	2.26	32.35	11.1	0.36	0.96
Darwin	2036-2065	4.5	GFDL-ESM2M	30.15 (1.35)	30.02	101.9	0.96	1.87	31.89	10.7	0.33	0.95
Darwin	2036-2065	4.5	HadGEM2-CC	30.44 (1.35)	30.02	118.5	1.11	2.13	32.15	11.7	0.34	0.96
Darwin	2036-2065	4.5	MIROC5	30.18 (1.28)	30.02	104.1	0.89	1.8	31.8	11.5	0.35	1.01
Darwin	2036-2065	4.5	NorESM1-M	30.10 (1.29)	30.02	99.7	0.87	1.76	31.72	11.3	0.36	0.96
Darwin	2036-2065	8.5	ACCESS1-0	31.08 (1.23)	30.02	153.1	1.37	2.43	32.67	9.7	0.34	1.02
Darwin	2036-2065	8.5	CESM1-CAM5	30.89 (1.30)	30.02	142.6	1.29	2.44	32.59	10.4	0.36	1.04
Darwin	2036-2065	8.5	CNRM-CM5	30.41 (1.27)	30.02	120.5	0.98	1.95	32	10.8	0.37	0.96
Darwin	2036-2065	8.5	CanESM2	31.19 (1.30)	30.02	153.2	1.51	2.75	32.85	11.1	0.37	0.96
Darwin	2036-2065	8.5	GFDL-ESM2M	30.58 (1.29)	30.02	127.6	1.1	2.1	32.22	11	0.35	1.01
Darwin	2036-2065	8.5	HadGEM2-CC	30.94 (1.33)	30.02	143.3	1.37	2.52	32.6	11.6	0.34	1
Darwin	2036-2065	8.5	MIROC5	30.53 (1.30)	30.02	123.4	1.09	2.11	32.17	11.7	0.34	0.95
Darwin	2036-2065	8.5	NorESM1-M	30.31 (1.29)	30.02	112.5	0.95	1.92	31.96	10.8	0.35	0.91
Hobart	2016-2045	4.5	ACCESS1-0	14.89 (3.56)	18.79	17.8	3.82	15.88	19.68	10.2	4.58	15.38
Hobart	2016-2045	4.5	CESM1-CAM5	15.04 (3.54)	18.79	18.9	3.86	15.12	19.78	10.2	4.82	14.83
Hobart	2016-2045	4.5	CNRM-CM5	14.86 (3.43)	18.79	15.7	4.37	15.77	19.52	10	4.68	14.36
Hobart	2016-2045	4.5	CanESM2	15.12 (3.58)	18.79	20.1	3.96	16.74	19.91	10.5	4.88	15.42
Hobart	2016-2045	4.5	GFDL-ESM2M	15.09 (3.53)	18.79	19.2	3.79	15.02	19.85	10	4.59	15.04
Hobart	2016-2045	4.5	HadGEM2-CC	14.77 (3.47)	18.79	15.3	4.18	15.42	19.41	10.1	4.65	14.39
Hobart	2016-2045	4.5	MIROC5	15.01 (3.49)	18.79	17.9	4.26	15.52	19.67	10.6	4.48	15.37
Hobart	2016-2045	4.5	NorESM1-M	14.87 (3.43)	18.79	16	4.12	15.43	19.51	10.1	4.38	14.91
Hobart	2016-2045	8.5	ACCESS1-0	15.32 (3.58)	18.79	22.8	3.62	15.39	20.09	10.3	4.66	15.5
Hobart	2016-2045	8.5	CESM1-CAM5	15.36 (3.63)	18.79	23.5	3.91	15.89	20.18	10.6	4.65	15.19
Hobart	2016-2045	8.5	CNRM-CM5	14.81 (3.43)	18.79	15.2	3.68	15.35	19.46	9.9	4.6	15.74
Hobart	2016-2045	8.5	CanESM2	15.48 (3.61)	18.79	24.7	3.94	16.1	20.31	10.4	4.87	15.48
Hobart	2016-2045	8.5	GFDL-ESM2M	14.90 (3.48)	18.79	16.6	4.11	15.13	19.63	9.7	4.79	14.83
Hobart	2016-2045	8.5	HadGEM2-CC	15.36 (3.44)	18.79	21.1	3.47	14.23	20	10	4.8	13.89
Hobart	2016-2045	8.5	MIROC5	14.80 (3.53)	18.79	16.3	4.6	15.43	19.49	10.6	4.7	15.48
Hobart	2016-2045	8.5	NorESM1-M	14.97 (3.48)	18.79	17.3	4.06	15.73	19.67	10	4.49	14.76
Hobart	2036-2065	4.5	ACCESS1-0	15.90 (3.56)	18.79	30	3.46	15.18	20.68	10.3	4.65	15.43
Hobart	2036-2065	4.5	CESM1-CAM5	15.44 (3.49)	18.79	23	3.54	15.29	20.13	10.1	4.74	14.61
Hobart	2036-2065	4.5	CNRM-CM5	15.14 (3.49)	18.79	19.7	3.39	15.38	19.84	10.1	4.59	15.31
Hobart	2036-2065	4.5	CanESM2	15.58 (3.55)	18.79	25.5	3.64	15.42	20.32	10.4	4.6	14.99
Hobart	2036-2065	4.5	GFDL-ESM2M	15.09 (3.50)	18.79	18.9	3.76	15.35	19.81	9.9	4.57	15.11
Hobart	2036-2065	4.5	HadGEM2-CC	16.43 (3.56)	18.79	36.8	3.78	14.81	21.15	10.2	4.79	14.96
Hobart	2036-2065	4.5	MIROC5	14.99 (3.54)	18.79	18.5	4.12	15.32	19.68	10.8	4.77	15.45
Hobart	2036-2065	4.5	NorESM1-M	15.00 (3.49)	18.79	18.2	3.8	16.06	19.72	10.4	4.77	15.37

Table D.2: Projected heatwave characteristics *(continued)*

					Non-adaptation				Adaptation			
Location	Period	RCP	GCM	Average DMT (SD)	DMT_{95}	HW days/years	EHF_{50p}	EHF_{85p}	DMT$_{95}$	HW days/years	EHF_{50p}	EHF_{85p}
Hobart	2036-2065	8.5	ACCESS1-0	16.04 (3.55)	18.79	31.7	3.47	15.19	20.8	10.2	4.6	15.31
Hobart	2036-2065	8.5	CESM1-CAM5	15.96 (3.53)	18.79	30.1	3.65	14.92	20.69	10.2	4.63	15.02
Hobart	2036-2065	8.5	CNRM-CM5	15.41 (3.47)	18.79	21.9	3.52	14.38	20.07	10.1	4.75	14.99
Hobart	2036-2065	8.5	CanESM2	15.86 (3.58)	18.79	29.8	3.53	15.39	20.68	10.3	4.82	15.49
Hobart	2036-2065	8.5	GFDL-ESM2M	15.33 (3.51)	18.79	21.7	3.71	15.06	20.02	10.1	4.81	14.71
Hobart	2036-2065	8.5	HadGEM2-CC	16.48 (3.59)	18.79	38.2	3.78	14.7	21.25	10.5	4.58	14.94
Hobart	2036-2065	8.5	MIROC5	15.33 (3.50)	18.79	21.6	3.92	15.61	19.99	10.5	4.64	15.49
Hobart	2036-2065	8.5	NorESM1-M	15.79 (3.49)	18.79	26.9	3.6	15.41	20.5	10	4.4	14.81
Melbourne	2016-2045	4.5	ACCESS1-0	18.66 (4.49)	25.23	9.2	8.34	23.26	25.09	9.9	7.94	23.66
Melbourne	2016-2045	4.5	CESM1-CAM5	18.70 (4.49)	25.23	9.4	7.86	22.72	25.07	10.2	7.94	22.29
Melbourne	2016-2045	4.5	CNRM-CM5	18.83 (4.37)	25.23	9.3	7.83	23.22	25.07	10.1	7.51	23.27
Melbourne	2016-2045	4.5	CanESM2	19.17 (4.56)	25.23	12.7	7.42	26.33	25.6	10.7	7.52	24.7
Melbourne	2016-2045	4.5	GFDL-ESM2M	19.10 (4.51)	25.23	11.2	7.29	23.3	25.45	10.3	7.55	22.72
Melbourne	2016-2045	4.5	HadGEM2-CC	18.68 (4.40)	25.23	8.5	7.93	21.7	24.93	10	7.31	22.27
Melbourne	2016-2045	4.5	MIROC5	19.14 (4.39)	25.23	11	8.02	23.2	25.37	10.4	7.56	22.35
Melbourne	2016-2045	4.5	NorESM1-M	18.77 (4.37)	25.23	9	8.08	21.74	25	10.2	8.06	22.43
Melbourne	2016-2045	8.5	ACCESS1-0	19.05 (4.49)	25.23	10.9	8	23.63	25.48	9.8	7.41	23.61
Melbourne	2016-2045	8.5	CESM1-CAM5	19.23 (4.60)	25.23	13.2	6.73	24.31	25.67	10.3	8.05	23.44
Melbourne	2016-2045	8.5	CNRM-CM5	18.87 (4.36)	25.23	9.3	8.36	23.3	25.07	10.2	7.83	23.32
Melbourne	2016-2045	8.5	CanESM2	19.48 (4.57)	25.23	14.2	6.89	25.8	25.96	10.1	8.14	23.7
Melbourne	2016-2045	8.5	GFDL-ESM2M	18.72 (4.42)	25.23	9.1	7.39	22.73	25.09	9.7	7.77	23.38
Melbourne	2016-2045	8.5	HadGEM2-CC	19.08 (4.33)	25.23	10.1	7.12	23.28	25.29	9.7	7.29	22.89
Melbourne	2016-2045	8.5	MIROC5	18.84 (4.47)	25.23	10	7.74	22.75	25.16	10.2	7.92	22.95
Melbourne	2016-2045	8.5	NorESM1-M	18.95 (4.44)	25.23	10.3	7.89	22.03	25.27	10.1	7.8	21.77
Melbourne	2036-2065	4.5	ACCESS1-0	19.51 (4.42)	25.23	13.1	7.67	22.5	25.85	10	7.78	21.99
Melbourne	2036-2065	4.5	CESM1-CAM5	19.29 (4.45)	25.23	12.1	7.5	22.61	25.68	9.8	8.4	22.18
Melbourne	2036-2065	4.5	CNRM-CM5	19.15 (4.35)	25.23	10.7	7.09	23.91	25.36	9.9	7.54	23.67
Melbourne	2036-2065	4.5	CanESM2	19.54 (4.60)	25.23	14.7	7.32	25.01	26.02	10.2	7.75	22.16
Melbourne	2036-2065	4.5	GFDL-ESM2M	19.16 (4.44)	25.23	11	8.11	23.07	25.53	9.9	8	23.33
Melbourne	2036-2065	4.5	HadGEM2-CC	20.05 (4.39)	25.23	15.9	6.88	24.8	26.26	10.2	7.35	22.73
Melbourne	2036-2065	4.5	MIROC5	19.04 (4.52)	25.23	11.3	7.93	23.57	25.41	10.5	7.47	22.44
Melbourne	2036-2065	4.5	NorESM1-M	18.96 (4.47)	25.23	10.4	8.18	23.23	25.32	10.2	7.86	22.82
Melbourne	2036-2065	8.5	ACCESS1-0	19.79 (4.49)	25.23	15.3	7.24	24.31	26.17	10.2	7.8	24.01
Melbourne	2036-2065	8.5	CESM1-CAM5	19.85 (4.42)	25.23	14.9	7.32	23.58	26.2	9.9	7.58	21.52
Melbourne	2036-2065	8.5	CNRM-CM5	19.82 (4.49)	25.23	14.9	7.8	24.53	26.16	10	7.47	22.64
Melbourne	2036-2065	8.5	CanESM2	20.44 (4.60)	25.23	20.4	7.34	26.97	26.92	10.5	7.74	24.93
Melbourne	2036-2065	8.5	GFDL-ESM2M	19.48 (4.40)	25.23	12.4	7.57	22.93	25.75	10	7.34	22.54
Melbourne	2036-2065	8.5	HadGEM2-CC	20.27 (4.46)	25.23	17.5	7.91	25.07	26.64	9.7	7.08	22.78
Melbourne	2036-2065	8.5	MIROC5	19.35 (4.44)	25.23	12.2	7.63	23.32	25.67	10.1	7.93	22.4
Melbourne	2036-2065	8.5	NorESM1-M	19.57 (4.37)	25.23	13.1	6.87	23.38	25.8	10.2	7.88	22.41

Table D.2: Projected heatwave characteristics *(continued)*

					Non-adaptation				Adaptation			
Location	Period	RCP	GCM	Average DMT (SD)	DMT_{95}	HW days/years	EHF_{50p}	EHF_{85p}	DMT$_{95}$	HW days/years	EHF_{50p}	EHF_{85p}
Perth	2016-2045	4.5	ACCESS1-0	22.68 (4.24)	27.97	15.9	5.51	18.87	28.35	13.3	5.09	18.22
Perth	2016-2045	4.5	CESM1-CAM5	22.67 (4.33)	27.97	16.3	5.55	19.3	28.43	12.9	5.23	19.53
Perth	2016-2045	4.5	CNRM-CM5	22.46 (4.33)	27.97	14.7	5.37	17.92	28.16	13	5.27	18.04
Perth	2016-2045	4.5	CanESM2	22.89 (4.39)	27.97	18.1	5.95	19.23	28.69	12.9	5.34	20.25
Perth	2016-2045	4.5	GFDL-ESM2M	22.61 (4.24)	27.97	15	5.15	18.99	28.33	12.1	5.28	18.93
Perth	2016-2045	4.5	HadGEM2-CC	22.75 (4.59)	27.97	19.2	5.83	19.49	28.8	13.7	5.08	19.14
Perth	2016-2045	4.5	MIROC5	22.60 (4.39)	27.97	16.1	5.84	20.5	28.39	13.2	5.37	20.16
Perth	2016-2045	4.5	NorESM1-M	22.41 (4.41)	27.97	15.4	5.38	18.91	28.31	13.1	4.74	18.68
Perth	2016-2045	8.5	ACCESS1-0	22.99 (4.33)	27.97	18.8	5.82	19.26	28.75	13.2	5.14	19.11
Perth	2016-2045	8.5	CESM1-CAM5	22.84 (4.28)	27.97	17.1	5.61	18.89	28.53	13.1	5.02	18.81
Perth	2016-2045	8.5	CNRM-CM5	22.48 (4.35)	27.97	15.1	5.33	19.31	28.25	12.9	5.49	19.75
Perth	2016-2045	8.5	CanESM2	22.98 (4.29)	27.97	18.1	5.96	19	28.7	12.5	5.4	19.88
Perth	2016-2045	8.5	GFDL-ESM2M	22.31 (4.12)	27.97	12.2	5	17.84	27.87	13	5.09	17.6
Perth	2016-2045	8.5	HadGEM2-CC	23.18 (4.37)	27.97	20.6	6.18	19.27	28.98	13.5	5.2	19.52
Perth	2016-2045	8.5	MIROC5	22.57 (4.28)	27.97	15	5.25	18.55	28.23	13	5.5	18.93
Perth	2016-2045	8.5	NorESM1-M	22.54 (4.35)	27.97	15.8	5.51	19.18	28.35	13.1	4.82	18.65
Perth	2036-2065	4.5	ACCESS1-0	23.35 (4.29)	27.97	20.9	6.13	19.33	29.05	13.3	4.95	18.63
Perth	2036-2065	4.5	CESM1-CAM5	23.16 (4.37)	27.97	20.5	5.77	19.18	28.98	13.2	4.93	18.61
Perth	2036-2065	4.5	CNRM-CM5	23.17 (4.36)	27.97	19.9	6.08	19.47	28.95	12.6	5.27	19.76
Perth	2036-2065	4.5	CanESM2	23.31 (4.32)	27.97	21.6	5.73	19.19	29.03	12.9	5.47	20.35
Perth	2036-2065	4.5	GFDL-ESM2M	22.63 (4.15)	27.97	14.4	5.36	17.63	28.2	12.8	5.67	17.53
Perth	2036-2065	4.5	HadGEM2-CC	23.31 (4.40)	27.97	21.9	6.23	19.46	29.17	13.2	4.85	18.87
Perth	2036-2065	4.5	MIROC5	22.92 (4.29)	27.97	17.7	5.74	19.05	28.58	13	5.54	19.25
Perth	2036-2065	4.5	NorESM1-M	22.69 (4.48)	27.97	17.6	5.85	19.16	28.56	13.2	5.33	20.13
Perth	2036-2065	8.5	ACCESS1-0	23.62 (4.25)	27.97	24	6.14	18.42	29.28	13.2	5.24	18.26
Perth	2036-2065	8.5	CESM1-CAM5	23.74 (4.28)	27.97	25	5.93	18.81	29.46	12.6	5.23	19.32
Perth	2036-2065	8.5	CNRM-CM5	23.45 (4.50)	27.97	24.9	6.03	19.56	29.38	13	5.47	20.26
Perth	2036-2065	8.5	CanESM2	23.78 (4.39)	27.97	27	6.21	18.92	29.61	13	5.29	19.36
Perth	2036-2065	8.5	GFDL-ESM2M	23.20 (4.14)	27.97	18.8	5.52	18.27	28.76	13	5.22	18.33
Perth	2036-2065	8.5	HadGEM2-CC	24.02 (4.49)	27.97	30.5	5.88	18.94	29.9	13	5.26	19.07
Perth	2036-2065	8.5	MIROC5	23.12 (4.34)	27.97	19.4	6.17	19.44	28.88	13	5.27	19.01
Perth	2036-2065	8.5	NorESM1-M	23.17 (4.30)	27.97	19.6	5.88	19.95	28.93	13	4.75	18.71
Sydney	2016-2045	4.5	ACCESS1-0	21.77 (3.48)	26.24	11.3	2.63	9.31	26.25	11.2	2.67	9.36
Sydney	2016-2045	4.5	CESM1-CAM5	21.56 (3.38)	26.24	8.3	2.8	9.15	25.96	10.4	2.49	9.44
Sydney	2016-2045	4.5	CNRM-CM5	21.63 (3.42)	26.24	9.4	2.7	9.84	26.09	10.7	2.46	9.11
Sydney	2016-2045	4.5	CanESM2	22.05 (3.26)	26.24	11.2	2.59	9.55	26.34	10.3	2.64	9.86
Sydney	2016-2045	4.5	GFDL-ESM2M	21.70 (3.37)	26.24	9.6	2.63	9.29	26.09	10.7	2.59	9.46
Sydney	2016-2045	4.5	HadGEM2-CC	21.95 (3.38)	26.24	11.6	2.47	9.24	26.39	10.4	2.52	9.12
Sydney	2016-2045	4.5	MIROC5	21.93 (3.27)	26.24	9.8	2.74	9.55	26.21	10.1	2.75	9.63
Sydney	2016-2045	4.5	NorESM1-M	21.73 (3.31)	26.24	9.6	2.43	9.31	26.07	10.8	2.65	9.69

Table D.2: Projected heatwave characteristics *(continued)*

					Non-adaptation				Adaptation			
Location	Period	RCP	GCM	Average DMT (SD)	DMT_{95}	HW days/years	EHF_{50p}	EHF_{85p}	DMT$_{95}$	HW days/years	EHF_{50p}	EHF_{85p}
Sydney	2016-2045	8.5	ACCESS1-0	21.83 (3.27)	26.24	9.4	2.86	9.79	26.14	10.2	2.74	9.61
Sydney	2016-2045	8.5	CESM1-CAM5	21.92 (3.40)	26.24	11.5	2.57	9.82	26.32	10.7	2.54	9.66
Sydney	2016-2045	8.5	CNRM-CM5	21.95 (3.43)	26.24	12.3	2.49	9.21	26.47	10.6	2.6	9.27
Sydney	2016-2045	8.5	CanESM2	22.40 (3.34)	26.24	15.5	2.72	9.61	26.78	10.5	2.57	9.68
Sydney	2016-2045	8.5	GFDL-ESM2M	21.69 (3.36)	26.24	10	2.64	9.49	26.1	10.9	2.69	10.06
Sydney	2016-2045	8.5	HadGEM2-CC	22.18 (3.32)	26.24	12.8	2.7	9.49	26.5	10.2	2.76	9.96
Sydney	2016-2045	8.5	MIROC5	22.01 (3.33)	26.24	11.3	2.56	9.64	26.36	10.5	2.58	9.11
Sydney	2016-2045	8.5	NorESM1-M	21.77 (3.29)	26.24	9	2.89	9.47	26.07	10.6	2.48	9.66
Sydney	2036-2065	4.5	ACCESS1-0	22.34 (3.20)	26.24	12.8	2.78	9.75	26.54	10.2	2.94	9.97
Sydney	2036-2065	4.5	CESM1-CAM5	22.02 (3.35)	26.24	12.1	2.58	9.49	26.39	10.6	2.49	9.62
Sydney	2036-2065	4.5	CNRM-CM5	22.09 (3.30)	26.24	11.8	2.44	9.53	26.42	10.3	2.63	9.39
Sydney	2036-2065	4.5	CanESM2	22.79 (3.43)	26.24	21	2.7	9.99	27.28	10.8	2.56	9.51
Sydney	2036-2065	4.5	GFDL-ESM2M	22.00 (3.30)	26.24	11.7	2.82	9.95	26.38	10.5	2.92	9.79
Sydney	2036-2065	4.5	HadGEM2-CC	22.71 (3.26)	26.24	17.8	2.51	9.59	27.03	10	2.43	9.16
Sydney	2036-2065	4.5	MIROC5	22.37 (3.31)	26.24	14.2	2.48	9.83	26.68	10.3	2.54	9.25
Sydney	2036-2065	4.5	NorESM1-M	22.17 (3.39)	26.24	13.6	2.63	10.19	26.56	11.1	2.69	9.47
Sydney	2036-2065	8.5	ACCESS1-0	22.93 (3.37)	26.24	22	2.74	10.22	27.33	11	2.7	9.6
Sydney	2036-2065	8.5	CESM1-CAM5	22.62 (3.37)	26.24	17.7	2.64	9.57	27.03	10.5	2.51	9.6
Sydney	2036-2065	8.5	CNRM-CM5	22.96 (3.43)	26.24	22.9	2.82	10.11	27.4	10.6	2.59	9.05
Sydney	2036-2065	8.5	CanESM2	23.65 (3.30)	26.24	31.3	2.59	10.49	28.03	10.2	2.48	9.41
Sydney	2036-2065	8.5	GFDL-ESM2M	22.76 (3.33)	26.24	19.2	2.66	9.6	27.15	10.6	2.4	9.48
Sydney	2036-2065	8.5	HadGEM2-CC	23.03 (3.28)	26.24	21.1	2.69	9.58	27.31	10.1	2.7	9.26
Sydney	2036-2065	8.5	MIROC5	22.66 (3.29)	26.24	17	2.66	9.65	26.99	10.4	2.39	9.38
Sydney	2036-2065	8.5	NorESM1-M	22.44 (3.24)	26.24	14.1	2.8	10.33	26.69	11	2.42	9.74

Projected average daily mean temperature and heatwave (HW) characteristics per city, GCM (general circulation model), RCP (representative concentration pathway), and period. EHF_{50p} and EHF_{85p} represent the 50th and 85th percentiles of all positive EHF values, respectively. Both heatwave non-adaptation and adaptation scenarios are considered. For non-adaptation scenarios, the heatwave thresholds are identical to the baseline thresholds.

Table D.3: Inclusion and exclusion criteria for workers' compensation claims data

Filter	Total	Adelaide	Brisbane	Darwin	Hobart	Perth	Melbourne	Sydney
Overall	4,142,872 (100.00)	403,273 (100.00)	658,988 (100.00)	45,547 (100.00)	113,984 (100.00)	523,635 (100.00)	735,146 (100.00)	1,662,299 (100.00)
Duplicate record	3,929 (0.09)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	3,929 (0.53)	0 (0.00)
Missing workplace postcode	169,193 (4.08)	59,141 (14.67)	8,525 (1.29)	12,555 (27.56)	11,937 (10.47)	16,358 (3.12)	6,642 (0.90)	54,035 (3.25)
Not in capital city	1,182,547 (28.54)	67,722 (16.79)	194,672 (29.54)	12,443 (27.32)	51,398 (45.09)	151,113 (28.86)	180,567 (24.56)	524,632 (31.56)
Cannot determine if in capital city	113,037 (2.73)	3,883 (0.96)	17,155 (2.60)	2,804 (6.16)	4,960 (4.35)	1,477 (0.28)	7,150 (0.97)	75,608 (4.55)
Claim submitted before date of OII	4 (<0.01)	1 (<0.01)	3 (<0.01)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Missing date of OII	1 (<0.01)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (<0.01)	0 (0.00)	0 (0.00)
Date of OII before July 05 (06 for Tasmania)	248,785 (6.01)	6,551 (1.62)	33,133 (5.03)	1,598 (3.51)	345 (0.30)	35,291 (6.74)	70,374 (9.57)	101,493 (6.11)
Date of OII after 30 June 18	1 (<0.01)	0 (0.00)	1 (<0.01)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
Age at OII $<$ 15 years	780 (0.02)	114 (0.03)	89 (0.01)	22 (0.05)	13 (0.01)	160 (0.03)	138 (0.02)	244 (0.01)
Age at OII $>$ 75 years	1,950 (0.05)	122 (0.03)	495 (0.08)	12 (0.03)	14 (0.01)	149 (0.03)	271 (0.04)	887 (0.05)
Missing age at OII	243 (0.01)	7 (<0.01)	15 (<0.01)	1 (<0.01)	42 (0.04)	12 (<0.01)	1 (<0.01)	165 (0.01)
Claims for analysis	2,422,402 (58.47)	265,732 (65.89)	404,900 (61.44)	16,112 (35.37)	45,275 (39.72)	319,074 (60.93)	466,074 (63.40)	905,235 (54.46)

Records included and excluded for analysis with justification and stratification by city. The inclusion/exclusion criteria are applied in the order listed from top to bottom. The top row states the number and percentage of records for all claims extracted, and the final row represents the claims that were analyzed. Results are presented as n (%): the number of claims removed and (in brackets) the percentage of overall claims per state. Claims were filtered in order from top the bottom as per the table. 'Cannot determine if metropolitan' refers to a workplace postcode that was either associated with both a metropolitan and regional location or was missing. OII: occupational injury or illness.

Table D.4: National costs and their components across all claims included for analysis

Payment category	Component	Total 000s (%)	Mean	Median	IQR
Total		22,142,218 (100.00)	18.333	1.588	0.397 - 8.869
Compensation		13,223,197 (59.72)	10.949	0.301	0.000 - 3.027
	Weekly benefits (income support)	7,804,445 (35.25)	6.462	0.240	0.000 - 2.479
	Death benefit lump sum	316,438 (1.43)	0.262	0.000	0.000 - 0.000
	Total statutory lump sum*	1,999,105 (9.03)	1.655	0.000	0.000 - 0.000
	Common law lump sum	3,104,352 (14.02)	2.570	0.000	0.000 - 0.000
Goods & services		6,597,031 (29.79)	5.462	0.691	0.190 - 3.742
	Medical services	3,243,120 (14.65)	2.686	0.414	0.123 - 1.731
	Hospital services	1,118,765 (5.05)	0.926	0.000	0.000 - 0.000
	Allied health services	961,303 (4.34)	0.796	0.000	0.000 - 0.617
	Vocational rehabilitation services	978,416 (4.42)	0.810	0.000	0.000 - 0.000
	Other	298,592 (1.35)	0.247	0.000	0.000 - 0.025
Non-compensation		2,326,507 (10.51)	1.926	0.000	0.000 - 0.253
	Legal	1,024,706 (4.63)	0.848	0.000	0.000 - 0.000
	Other	1,301,988 (5.88)	1.078	0.000	0.000 - 0.207

Descriptive summaries of all claim payments for analysis presented to the nearest thousand Australian dollars (000s). A median of 0 indicates that most claims were not associated with this category of payment. *Total statutory lump sums are settlements of weekly benefits and non-economic payments. Non-economic payments included, but are not limited to, payments for permanent injuries, pain and suffering, severe injury payments and gratuitous care. IQR: interquartile range.

Table D.5: National demographics and claim statistics for workers' compensation claims data

Variable	Category	OIIs	Total costs (000s)	Cost per OII
Total		1,208,004	22,142,218	18,330
	Same financial year as claim submission		7,282,978	6,029
	1 financial year after claim submission		6,045,215	5,004
	2 financial years after claim submission		3,664,386	3,033
	3 financial years after claim submission		2,419,309	2,003
	4 financial years after claim submission		1,565,981	1,296
	5 financial years after claim submission		894,908	741
	6 financial years after claim submission		269,030	223
Financial year	2005	108,030	1,516,340	14,036
	2006	109,329	1,594,164	14,581
	2007	108,027	1,704,192	15,776
	2008	100,463	2,125,747	21,160
	2009	100,319	2,133,993	21,272
	2010	102,029	2,105,993	20,641
	2011	102,940	2,102,131	20,421
	2012	89,062	1,929,046	21,660
	2013	82,932	1,745,347	21,046
	2014	79,047	1,612,923	20,405
	2015	76,071	1,436,704	18,886
	2016	75,930	1,254,466	16,521
	2017	73,825	881,174	11,936
Month	January	178,388	3,336,487	18,704
	February	212,801	3,861,326	18,145
	March	218,574	3,998,182	18,292
	October	211,131	3,931,922	18,623
	November	215,253	3,876,634	18,010
	December	171,857	3,137,667	18,257
Category	Monday	227,289	4,157,196	18,290
	Tuesday	224,856	3,967,240	17,643
	Wednesday	224,233	3,909,877	17,437
	Thursday	215,176	3,930,998	18,269
	Friday	187,807	3,610,617	19,225
	Saturday	72,621	1,480,172	20,382
	Sunday	56,022	1,086,118	19,387
City	Adelaide	133,208	1,771,362	13,298
	Brisbane	202,542	4,552,728	22,478
	Darwin	8,083	202,154	25,010
	Hobart	22,208	337,420	15,194
	Melbourne	228,452	4,322,269	18,920
	Perth	161,468	3,050,046	18,889
	Sydney	452,043	7,906,238	17,490
Sex	Female	436,073	7,441,720	17,065
	Male	771,931	14,700,498	19,044
Age (years)	15-19	51,669	295,046	5,710
	20-24	126,010	1,099,074	8,722
	25-29	132,987	1,652,160	12,423
	30-34	128,448	2,161,249	16,826
	35-39	131,363	2,741,859	20,872
	40-44	140,351	3,059,883	21,802
	45-49	149,232	3,305,926	22,153
	50-54	142,088	3,292,528	23,172
	55-59	113,931	2,606,212	22,875
	60-64	68,564	1,477,379	21,547
	65-75	23,361	450,902	19,302
Indoors/outdoors	Indoors	857,613	15,419,660	17,980
	Outdoors	301,274	5,809,830	19,284
	Missing	49,117	912,728	18,583
Occupation	Clerical and administrative workers	69,615	1,208,310	17,357
	Community and personal service workers	185,173	3,313,303	17,893
	Laborers	264,673	5,183,360	19,584
	Machinery operators and drivers	166,288	3,743,783	22,514
	Managers	55,277	1,180,236	21,351
	Professionals	146,128	2,403,091	16,445
	Sales workers	81,955	1,238,193	15,108
	Technicians and trades workers	224,815	3,753,794	16,697
	Missing	14,080	118,147	8,391
Industry	Accommodation and Food Services	57,769	781,257	13,524

Table D.5: National demographics and claim statistics for workers' compensation claims data *(continued)*

Variable	Category	OIIs	Total costs (000s)	Cost per OII
	Administrative and Support Services	48,164	810,594	16,830
	Agriculture, Forestry and Fishing	8,703	193,910	22,281
	Arts and Recreation Services	26,167	329,441	12,590
	Construction	110,087	2,880,659	26,167
	Education and Training	84,374	1,186,506	14,062
	Electricity, Gas, Water and Waste Services	14,091	252,943	17,951
	Financial and Insurance Services	14,991	257,876	17,202
	Health Care and Social Assistance	146,144	2,445,848	16,736
	Information Media and Telecommunications	8,688	134,795	15,515
	Manufacturing	184,678	3,494,924	18,924
	Mining	11,283	456,316	40,443
	Other Services	37,003	647,139	17,489
	Professional, Scientific and Technical Services	30,262	533,062	17,615
	Public Administration and Safety	88,190	1,784,647	20,236
	Rental, Hiring and Real Estate Services	11,951	235,873	19,737
	Retail Trade	108,737	1,665,409	15,316
	Transport, Postal and Warehousing	94,632	2,009,067	21,230
	Wholesale Trade	61,507	1,178,805	19,165
	Missing	60,583	863,145	14,247
Type of OII	Injuries	928,276	14,805,213	15,949
	Illnesses (diseases and conditions)	279,728	7,337,005	26,229
OII nature	Intracranial injuries	7,673	226,000	29,454
	Fractures	71,543	2,288,675	31,990
	Wounds, lacerations, amputations and internal organ damage	259,151	2,117,905	8,172
	Burn	23,480	159,192	6,780
	Injury to nerves and spinal cord	1,150	120,879	105,112
	Traumatic joint/ligament and muscle/tendon injury	504,802	9,194,848	18,215
	Other injuries	60,477	697,714	11,537
	Musculoskeletal and connective tissue diseases	146,318	3,728,515	25,482
	Mental disorders	55,756	2,399,902	43,043
	Digestive system diseases	15,536	247,295	15,918
	Skin and subcutaneous tissue diseases	7,261	48,441	6,671
	Nervous system and sense organ diseases	29,641	514,035	17,342
	Respiratory system diseases	3,135	76,034	24,253
	Circulatory system diseases	1,782	70,386	39,498
	Infectious and parasitic diseases	2,063	19,446	9,426
	Neoplasms (cancer)	796	74,973	94,187
	Other diseases	1,647	26,536	16,112
	Other claims	15,793	131,442	8,323
OII mechanism	Falls, trips and slips of a person	225,677	4,630,179	20,517
	Hitting objects with a part of the body	117,648	810,649	6,890
	Being hit by moving objects	208,958	2,732,038	13,075
	Sound and pressure	19,606	300,066	15,305
	Body stressing	428,653	8,882,352	20,722
	Heat, electricity and other environmental factors	25,368	189,768	7,481
	Chemicals and other substances	23,210	203,626	8,773
	Biological factors	5,999	40,404	6,735
	Mental stress	39,219	1,867,558	47,619
	Vehicle incidents and other	113,666	2,485,577	21,867
OII agency	Machinery and (mainly) fixed plant	50,545	989,994	19,586
	Mobile plant and transport	98,031	2,117,228	21,598
	Powered equipment, tools and appliances	48,681	740,879	15,219
	Non-powered handtools, appliances and equipment	251,036	3,910,328	15,577
	Chemicals and chemical products	13,812	121,563	8,801
	Materials and substances	160,669	2,353,782	14,650
	Environmental agencies	162,279	3,092,594	19,057
	Animal, human and biological agencies	103,450	1,950,698	18,856
	Other and unspecified agencies	319,501	6,865,151	21,487

Descriptive statistics of all claims included for analysis. Costs are presented in Australian dollars; total costs are presented to the nearest thousand Australian dollars (000s). OII: occupational injury and illness.

Table D.6: Fractions of occupational injuries/illnesses attributable to heatwaves

Setting	Heatwaves	Low-intensity heatwaves	Severe heatwaves	Extreme heatwaves
Total, baseline	0.129 (0.107 – 0.165)	0.065 (0.054 – 0.082)	0.041 (0.033 – 0.053)	0.023 (0.019 – 0.030)
- 2030, RCP4.5	0.137 (0.084 – 0.195)	0.072 (0.041 – 0.103)	0.044 (0.027 – 0.063)	0.022 (0.012 – 0.035)
- 2030, RCP8.5	0.151 (0.091 – 0.222)	0.077 (0.045 – 0.114)	0.048 (0.029 – 0.071)	0.025 (0.014 – 0.042)
- 2050, RCP4.5	0.176 (0.104 – 0.265)	0.088 (0.048 – 0.134)	0.056 (0.034 – 0.083)	0.032 (0.018 – 0.055)
- 2050, RCP8.5	0.228 (0.125 – 0.370)	0.109 (0.053 – 0.180)	0.071 (0.042 – 0.110)	0.048 (0.025 – 0.087)
Adelaide, baseline	0.147 (0.094 – 0.217)	0.084 (0.049 – 0.130)	0.045 (0.031 – 0.065)	0.018 (0.012 – 0.026)
- 2030, RCP4.5	0.173 (0.095 – 0.253)	0.106 (0.050 – 0.162)	0.054 (0.032 – 0.077)	0.012 (0.006 – 0.028)
- 2030, RCP8.5	0.181 (0.097 – 0.273)	0.109 (0.049 – 0.170)	0.057 (0.032 – 0.090)	0.015 (0.007 – 0.025)
- 2050, RCP4.5	0.196 (0.102 – 0.306)	0.116 (0.051 – 0.186)	0.065 (0.036 – 0.105)	0.015 (0.007 – 0.026)
- 2050, RCP8.5	0.226 (0.109 – 0.363)	0.127 (0.049 – 0.211)	0.078 (0.040 – 0.130)	0.021 (0.012 – 0.034)
Brisbane, baseline	0.131 (0.072 – 0.202)	0.066 (0.038 – 0.103)	0.037 (0.019 – 0.056)	0.028 (0.015 – 0.044)
- 2030, RCP4.5	0.128 (0.074 – 0.208)	0.054 (0.031 – 0.087)	0.040 (0.022 – 0.071)	0.034 (0.018 – 0.054)
- 2030, RCP8.5	0.152 (0.088 – 0.229)	0.062 (0.035 – 0.096)	0.050 (0.028 – 0.076)	0.040 (0.021 – 0.061)
- 2050, RCP4.5	0.176 (0.103 – 0.282)	0.071 (0.037 – 0.116)	0.057 (0.033 – 0.086)	0.049 (0.027 – 0.086)
- 2050, RCP8.5	0.253 (0.126 – 0.462)	0.101 (0.041 – 0.191)	0.073 (0.038 – 0.129)	0.079 (0.039 – 0.147)
Darwin, baseline	0.072 (0.038 – 0.115)	0.041 (0.022 – 0.063)	0.013 (0.007 – 0.021)	0.018 (0.010 – 0.029)
- 2030, RCP4.5	1.246 (0.728 – 1.825)	0.133 (0.072 – 0.197)	0.328 (0.197 – 0.469)	0.785 (0.413 – 1.275)
- 2030, RCP8.5	1.400 (0.823 – 2.179)	0.130 (0.067 – 0.194)	0.339 (0.200 – 0.487)	0.931 (0.504 – 1.594)
- 2050, RCP4.5	1.644 (0.954 – 2.496)	0.109 (0.043 – 0.173)	0.313 (0.152 – 0.467)	1.223 (0.687 – 1.973)
- 2050, RCP8.5	2.049 (1.052 – 3.404)	0.085 (0.014 – 0.157)	0.292 (0.081 – 0.484)	1.671 (0.856 – 2.880)
Hobart, baseline	0.153 (0.102 – 0.222)	0.075 (0.050 – 0.109)	0.043 (0.029 – 0.063)	0.035 (0.021 – 0.052)
- 2030, RCP4.5	0.162 (0.074 – 0.253)	0.072 (0.022 – 0.124)	0.054 (0.025 – 0.085)	0.036 (0.022 – 0.050)
- 2030, RCP8.5	0.178 (0.079 – 0.301)	0.080 (0.023 – 0.147)	0.058 (0.026 – 0.101)	0.040 (0.024 – 0.061)
- 2050, RCP4.5	0.208 (0.083 – 0.407)	0.092 (0.021 – 0.198)	0.069 (0.029 – 0.121)	0.048 (0.025 – 0.093)
- 2050, RCP8.5	0.233 (0.085 – 0.417)	0.103 (0.018 – 0.204)	0.076 (0.029 – 0.130)	0.054 (0.029 – 0.088)
Melbourne, baseline	0.089 (0.048 – 0.141)	0.047 (0.020 – 0.081)	0.027 (0.015 – 0.042)	0.015 (0.010 – 0.022)
- 2030, RCP4.5	0.092 (0.045 – 0.147)	0.051 (0.020 – 0.084)	0.028 (0.014 – 0.053)	0.013 (0.008 – 0.020)
- 2030, RCP8.5	0.099 (0.047 – 0.161)	0.053 (0.020 – 0.088)	0.032 (0.016 – 0.057)	0.014 (0.009 – 0.021)
- 2050, RCP4.5	0.113 (0.051 – 0.191)	0.061 (0.021 – 0.106)	0.037 (0.018 – 0.066)	0.016 (0.009 – 0.023)
- 2050, RCP8.5	0.137 (0.056 – 0.235)	0.071 (0.021 – 0.124)	0.046 (0.020 – 0.084)	0.020 (0.011 – 0.035)
Perth, baseline	0.183 (0.116 – 0.270)	0.085 (0.056 – 0.123)	0.043 (0.026 – 0.064)	0.055 (0.032 – 0.084)
- 2030, RCP4.5	0.210 (0.128 – 0.299)	0.100 (0.061 – 0.143)	0.079 (0.046 – 0.113)	0.031 (0.016 – 0.051)
- 2030, RCP8.5	0.213 (0.121 – 0.319)	0.103 (0.060 – 0.157)	0.080 (0.042 – 0.118)	0.030 (0.015 – 0.050)
- 2050, RCP4.5	0.247 (0.142 – 0.353)	0.119 (0.067 – 0.175)	0.090 (0.049 – 0.127)	0.039 (0.020 – 0.058)
- 2050, RCP8.5	0.287 (0.166 – 0.427)	0.135 (0.072 – 0.207)	0.100 (0.060 – 0.144)	0.052 (0.024 – 0.089)
Sydney, baseline	0.123 (0.072 – 0.188)	0.060 (0.037 – 0.089)	0.048 (0.027 – 0.074)	0.015 (0.008 – 0.024)
- 2030, RCP4.5	0.107 (0.063 – 0.158)	0.068 (0.041 – 0.101)	0.033 (0.018 – 0.051)	0.006 (0.002 – 0.014)
- 2030, RCP8.5	0.123 (0.072 – 0.188)	0.077 (0.047 – 0.116)	0.036 (0.020 – 0.058)	0.009 (0.002 – 0.023)
- 2050, RCP4.5	0.149 (0.087 – 0.229)	0.090 (0.053 – 0.135)	0.047 (0.026 – 0.070)	0.012 (0.004 – 0.035)
- 2050, RCP8.5	0.211 (0.118 – 0.358)	0.119 (0.065 – 0.201)	0.067 (0.039 – 0.103)	0.024 (0.008 – 0.064)

Attributable fractions of occupational injuries/illnesses attributable to heatwaves across the study period and projected to 2030 and 2050 with 95% empirical confidence intervals. Costs are presented per AU$1000 dollars. Projected results do not assume climate adaptation. RCP: representative concentration pathway.

Table D.7: Fractions of heatwave-attributable costs secondary to occupational injuries/illnesses

Setting	Heatwaves	Low-intensity heatwaves	Severe heatwaves	Extreme heatwaves
Total, baseline	0.252 (0.182 – 0.345)	0.124 (0.081 – 0.176)	0.078 (0.057 – 0.106)	0.050 (0.038 – 0.066)
- 2030, RCP4.5	0.153 (-0.062 – 0.345)	0.061 (-0.090 – 0.195)	0.057 (0.002 – 0.108)	0.036 (0.015 – 0.057)
- 2030, RCP8.5	0.150 (-0.118 – 0.392)	0.055 (-0.124 – 0.213)	0.057 (-0.014 – 0.122)	0.038 (0.011 – 0.069)
- 2050, RCP4.5	0.127 (-0.270 – 0.461)	0.033 (-0.217 – 0.244)	0.054 (-0.049 – 0.142)	0.040 (-0.012 – 0.087)
- 2050, RCP8.5	0.044 (-0.662 – 0.598)	-0.031 (-0.441 – 0.290)	0.037 (-0.137 – 0.177)	0.038 (-0.094 – 0.143)
Adelaide, baseline	0.174 (-0.102 – 0.456)	0.090 (-0.107 – 0.292)	0.058 (-0.009 – 0.126)	0.026 (0.011 – 0.043)
- 2030, RCP4.5	0.200 (-0.210 – 0.578)	0.115 (-0.210 – 0.412)	0.067 (-0.022 – 0.149)	0.017 (0.005 – 0.041)
- 2030, RCP8.5	0.207 (-0.236 – 0.636)	0.116 (-0.226 – 0.442)	0.070 (-0.029 – 0.175)	0.020 (0.007 – 0.038)
- 2050, RCP4.5	0.223 (-0.275 – 0.702)	0.123 (-0.261 – 0.484)	0.079 (-0.036 – 0.201)	0.020 (0.007 – 0.038)
- 2050, RCP8.5	0.252 (-0.382 – 0.853)	0.131 (-0.334 – 0.562)	0.093 (-0.068 – 0.261)	0.028 (0.010 – 0.052)
Brisbane, baseline	0.281 (0.115 – 0.466)	0.137 (0.062 – 0.229)	0.073 (0.030 – 0.122)	0.070 (0.027 – 0.115)
- 2030, RCP4.5	0.041 (-0.187 – 0.217)	-0.026 (-0.175 – 0.086)	0.014 (-0.058 – 0.073)	0.053 (0.022 – 0.089)
- 2030, RCP8.5	-0.002 (-0.341 – 0.238)	-0.055 (-0.264 – 0.098)	0.000 (-0.111 – 0.079)	0.053 (0.017 – 0.085)
- 2050, RCP4.5	-0.081 (-0.596 – 0.268)	-0.104 (-0.399 – 0.113)	-0.025 (-0.187 – 0.087)	0.048 (-0.019 – 0.088)
- 2050, RCP8.5	-0.330 (-1.455 – 0.387)	-0.255 (-0.884 – 0.161)	-0.098 (-0.431 – 0.111)	0.023 (-0.152 – 0.128)
Darwin, baseline	0.131 (-0.001 – 0.271)	0.078 (0.001 – 0.162)	0.018 (0.000 – 0.036)	0.035 (0.000 – 0.071)
- 2030, RCP4.5	1.111 (-1.463 – 3.271)	0.052 (-0.417 – 0.467)	0.209 (-0.758 – 0.984)	0.850 (-0.338 – 1.982)
- 2030, RCP8.5	1.032 (-2.785 – 4.211)	0.021 (-0.542 – 0.529)	0.143 (-1.122 – 1.181)	0.868 (-1.173 – 2.658)
- 2050, RCP4.5	0.689 (-5.722 – 5.796)	-0.040 (-0.697 – 0.564)	-0.015 (-1.654 – 1.365)	0.743 (-3.510 – 4.044)
- 2050, RCP8.5	-0.263 (-13.709 – 9.686)	-0.093 (-0.814 – 0.567)	-0.236 (-2.637 – 1.729)	0.067 (-10.438 – 7.575)
Hobart, baseline	0.167 (-0.042 – 0.390)	0.046 (-0.136 – 0.219)	0.047 (0.002 – 0.094)	0.075 (0.026 – 0.123)
- 2030, RCP4.5	-0.075 (-0.895 – 0.619)	-0.080 (-0.557 – 0.340)	-0.019 (-0.290 – 0.198)	0.025 (-0.052 – 0.086)
- 2030, RCP8.5	-0.093 (-1.059 – 0.729)	-0.095 (-0.657 – 0.401)	-0.023 (-0.333 – 0.228)	0.025 (-0.073 – 0.105)
- 2050, RCP4.5	-0.151 (-1.513 – 0.907)	-0.132 (-0.911 – 0.495)	-0.041 (-0.459 – 0.276)	0.022 (-0.146 – 0.149)
- 2050, RCP8.5	-0.207 (-1.781 – 1.036)	-0.166 (-1.042 – 0.563)	-0.058 (-0.554 – 0.314)	0.017 (-0.188 – 0.166)
Melbourne, baseline	0.300 (0.070 – 0.551)	0.199 (0.024 – 0.386)	0.053 (0.012 – 0.097)	0.047 (0.023 – 0.075)
- 2030, RCP4.5	0.320 (0.067 – 0.592)	0.209 (0.030 – 0.388)	0.088 (0.021 – 0.196)	0.023 (0.010 – 0.040)
- 2030, RCP8.5	0.351 (0.072 – 0.664)	0.223 (0.033 – 0.421)	0.102 (0.025 – 0.215)	0.025 (0.012 – 0.044)
- 2050, RCP4.5	0.418 (0.077 – 0.823)	0.264 (0.033 – 0.523)	0.122 (0.027 – 0.260)	0.031 (0.013 – 0.053)
- 2050, RCP8.5	0.530 (0.086 – 1.047)	0.325 (0.035 – 0.627)	0.162 (0.032 – 0.348)	0.042 (0.017 – 0.094)
Perth, baseline	0.252 (0.103 – 0.416)	0.115 (0.046 – 0.197)	0.061 (0.022 – 0.104)	0.076 (0.017 – 0.139)
- 2030, RCP4.5	0.261 (0.060 – 0.463)	0.116 (-0.022 – 0.252)	0.100 (0.036 – 0.165)	0.044 (0.014 – 0.079)
- 2030, RCP8.5	0.262 (0.053 – 0.505)	0.117 (-0.032 – 0.283)	0.101 (0.035 – 0.175)	0.043 (0.013 – 0.076)
- 2050, RCP4.5	0.295 (0.010 – 0.593)	0.130 (-0.077 – 0.340)	0.111 (0.029 – 0.194)	0.054 (0.019 – 0.090)
- 2050, RCP8.5	0.329 (-0.067 – 0.740)	0.140 (-0.142 – 0.421)	0.119 (0.011 – 0.230)	0.070 (0.024 – 0.129)
Sydney, baseline	0.233 (0.116 – 0.366)	0.090 (0.042 – 0.148)	0.110 (0.058 – 0.169)	0.034 (0.018 – 0.050)
- 2030, RCP4.5	0.061 (-0.076 – 0.174)	0.003 (-0.113 – 0.092)	0.046 (0.010 – 0.084)	0.013 (0.005 – 0.027)
- 2030, RCP8.5	0.060 (-0.167 – 0.205)	-0.005 (-0.186 – 0.102)	0.046 (-0.011 – 0.095)	0.019 (0.006 – 0.037)
- 2050, RCP4.5	-0.001 (-0.361 – 0.201)	-0.062 (-0.349 – 0.098)	0.040 (-0.044 – 0.094)	0.021 (0.008 – 0.046)
- 2050, RCP8.5	-0.144 (-0.819 – 0.201)	-0.191 (-0.713 – 0.083)	0.014 (-0.145 – 0.091)	0.034 (0.012 – 0.068)

Attributable fractions of heatwave-attributable costs secondary to occupational injuries/illnesses across the study period and projected to 2030 and 2050 with 95% empirical confidence intervals. Costs are presented per AU$1000 dollars. Projected results do not assume climate adaptation. RCP: representative concentration pathway.

Table D.8: Projected fractions of occupational injuries/illnesses attributable to heatwaves with climate adaptation

Location	Time	Heatwaves	Low-intensity heatwaves	Severe heatwaves	Extreme heatwaves
Total	2030, RCP4.5	0.121 (0.076 – 0.165)	0.068 (0.040 – 0.094)	0.038 (0.024 – 0.053)	0.015 (0.008 – 0.021)
	2030, RCP8.5	0.122 (0.077 – 0.167)	0.068 (0.042 – 0.096)	0.039 (0.024 – 0.054)	0.015 (0.009 – 0.022)
	2050, RCP4.5	0.122 (0.077 – 0.166)	0.068 (0.041 – 0.095)	0.040 (0.025 – 0.055)	0.014 (0.008 – 0.021)
	2050, RCP8.5	0.122 (0.078 – 0.167)	0.069 (0.042 – 0.095)	0.039 (0.024 – 0.054)	0.015 (0.008 – 0.021)
Adelaide	2030, RCP4.5	0.141 (0.083 – 0.196)	0.092 (0.048 – 0.134)	0.039 (0.024 – 0.055)	0.009 (0.005 – 0.014)
	2030, RCP8.5	0.141 (0.084 – 0.198)	0.091 (0.048 – 0.133)	0.041 (0.025 – 0.057)	0.010 (0.005 – 0.015)
	2050, RCP4.5	0.141 (0.084 – 0.198)	0.091 (0.049 – 0.134)	0.041 (0.026 – 0.056)	0.009 (0.005 – 0.012)
	2050, RCP8.5	0.141 (0.084 – 0.197)	0.092 (0.049 – 0.134)	0.040 (0.025 – 0.056)	0.009 (0.005 – 0.014)
Brisbane	2030, RCP4.5	0.118 (0.073 – 0.164)	0.051 (0.031 – 0.072)	0.036 (0.022 – 0.052)	0.031 (0.018 – 0.044)
	2030, RCP8.5	0.118 (0.074 – 0.162)	0.052 (0.032 – 0.072)	0.036 (0.022 – 0.051)	0.031 (0.018 – 0.044)
	2050, RCP4.5	0.118 (0.074 – 0.162)	0.051 (0.031 – 0.071)	0.037 (0.022 – 0.053)	0.030 (0.017 – 0.043)
	2050, RCP8.5	0.120 (0.075 – 0.166)	0.051 (0.031 – 0.072)	0.037 (0.023 – 0.054)	0.031 (0.018 – 0.044)
Darwin	2030, RCP4.5	0.140 (0.066 – 0.214)	0.044 (0.021 – 0.070)	0.050 (0.022 – 0.079)	0.046 (0.021 – 0.072)
	2030, RCP8.5	0.138 (0.066 – 0.212)	0.043 (0.021 – 0.066)	0.049 (0.024 – 0.075)	0.045 (0.020 – 0.074)
	2050, RCP4.5	0.143 (0.068 – 0.215)	0.043 (0.021 – 0.066)	0.053 (0.025 – 0.081)	0.046 (0.021 – 0.071)
	2050, RCP8.5	0.137 (0.066 – 0.208)	0.042 (0.021 – 0.063)	0.050 (0.024 – 0.079)	0.045 (0.020 – 0.072)
Hobart	2030, RCP4.5	0.106 (0.059 – 0.152)	0.053 (0.024 – 0.082)	0.029 (0.016 – 0.041)	0.024 (0.015 – 0.033)
	2030, RCP8.5	0.107 (0.061 – 0.153)	0.053 (0.024 – 0.082)	0.030 (0.017 – 0.044)	0.024 (0.015 – 0.033)
	2050, RCP4.5	0.108 (0.061 – 0.155)	0.054 (0.024 – 0.083)	0.031 (0.017 – 0.045)	0.024 (0.015 – 0.033)
	2050, RCP8.5	0.106 (0.060 – 0.151)	0.053 (0.024 – 0.081)	0.029 (0.017 – 0.042)	0.024 (0.015 – 0.033)
Melbourne	2030, RCP4.5	0.093 (0.046 – 0.139)	0.051 (0.020 – 0.083)	0.029 (0.016 – 0.043)	0.013 (0.008 – 0.018)
	2030, RCP8.5	0.093 (0.047 – 0.138)	0.051 (0.020 – 0.082)	0.028 (0.016 – 0.041)	0.013 (0.008 – 0.018)
	2050, RCP4.5	0.093 (0.047 – 0.139)	0.051 (0.020 – 0.083)	0.028 (0.015 – 0.041)	0.014 (0.008 – 0.019)
	2050, RCP8.5	0.093 (0.047 – 0.137)	0.051 (0.021 – 0.081)	0.028 (0.015 – 0.043)	0.014 (0.008 – 0.019)
Perth	2030, RCP4.5	0.174 (0.107 – 0.241)	0.084 (0.052 – 0.115)	0.068 (0.039 – 0.100)	0.022 (0.012 – 0.033)
	2030, RCP8.5	0.174 (0.108 – 0.238)	0.085 (0.054 – 0.116)	0.067 (0.040 – 0.096)	0.021 (0.011 – 0.031)
	2050, RCP4.5	0.176 (0.109 – 0.243)	0.086 (0.054 – 0.117)	0.071 (0.041 – 0.103)	0.020 (0.011 – 0.030)
	2050, RCP8.5	0.174 (0.107 – 0.246)	0.084 (0.053 – 0.117)	0.068 (0.040 – 0.101)	0.022 (0.012 – 0.033)
Sydney	2030, RCP4.5	0.111 (0.069 – 0.156)	0.071 (0.043 – 0.102)	0.034 (0.019 – 0.052)	0.006 (0.002 – 0.014)
	2030, RCP8.5	0.115 (0.071 – 0.165)	0.073 (0.044 – 0.105)	0.034 (0.019 – 0.053)	0.007 (0.003 – 0.014)
	2050, RCP4.5	0.115 (0.071 – 0.163)	0.073 (0.044 – 0.103)	0.036 (0.020 – 0.054)	0.006 (0.002 – 0.013)
	2050, RCP8.5	0.115 (0.071 – 0.159)	0.074 (0.046 – 0.103)	0.035 (0.020 – 0.051)	0.006 (0.002 – 0.012)

Attributable fractions of occupational injuries/illnesses attributable to heatwaves projected to 2030 and 2050 with 95% empirical confidence intervals, assuming climate adaptation. RCP: representative concentration pathway.

Table D.9: Projected fractions of heatwave-attributable costs secondary to occupational injuries/illnesses with climate adaptation

Location	Time	Heatwaves	Low-intensity heatwaves	Severe heatwaves	Extreme heatwaves
Total	2030, RCP4.5	0.141 (-0.020 – 0.286)	0.060 (-0.064 – 0.173)	0.055 (0.016 – 0.090)	0.026 (0.013 – 0.038)
	2030, RCP8.5	0.148 (-0.006 – 0.291)	0.065 (-0.053 – 0.176)	0.056 (0.018 – 0.091)	0.027 (0.013 – 0.040)
	2050, RCP4.5	0.146 (-0.005 – 0.288)	0.063 (-0.053 – 0.174)	0.057 (0.020 – 0.091)	0.026 (0.012 – 0.039)
	2050, RCP8.5	0.150 (0.003 – 0.288)	0.066 (-0.047 – 0.172)	0.058 (0.021 – 0.092)	0.027 (0.013 – 0.040)
Adelaide	2030, RCP4.5	0.168 (-0.113 – 0.424)	0.104 (-0.130 – 0.321)	0.051 (0.001 – 0.096)	0.013 (0.004 – 0.021)
	2030, RCP8.5	0.168 (-0.111 – 0.428)	0.102 (-0.130 – 0.320)	0.052 (0.001 – 0.101)	0.014 (0.004 – 0.022)
	2050, RCP4.5	0.169 (-0.108 – 0.427)	0.104 (-0.128 – 0.321)	0.053 (0.002 – 0.099)	0.012 (0.004 – 0.020)
	2050, RCP8.5	0.170 (-0.104 – 0.421)	0.105 (-0.124 – 0.318)	0.051 (0.003 – 0.096)	0.013 (0.004 – 0.022)
Brisbane	2030, RCP4.5	0.053 (-0.112 – 0.201)	-0.016 (-0.127 – 0.081)	0.017 (-0.033 – 0.064)	0.052 (0.023 – 0.079)
	2030, RCP8.5	0.061 (-0.093 – 0.193)	-0.011 (-0.113 – 0.081)	0.019 (-0.027 – 0.060)	0.052 (0.023 – 0.078)
	2050, RCP4.5	0.052 (-0.094 – 0.189)	-0.016 (-0.116 – 0.080)	0.017 (-0.028 – 0.060)	0.051 (0.023 – 0.075)
	2050, RCP8.5	0.058 (-0.104 – 0.197)	-0.013 (-0.121 – 0.081)	0.019 (-0.033 – 0.062)	0.052 (0.024 – 0.078)
Darwin	2030, RCP4.5	0.255 (-0.024 – 0.515)	0.082 (-0.001 – 0.167)	0.091 (-0.008 – 0.194)	0.082 (-0.015 – 0.168)
	2030, RCP8.5	0.254 (-0.028 – 0.511)	0.081 (-0.003 – 0.162)	0.091 (-0.010 – 0.185)	0.082 (-0.016 – 0.169)
	2050, RCP4.5	0.262 (-0.029 – 0.524)	0.079 (-0.002 – 0.160)	0.099 (-0.010 – 0.200)	0.084 (-0.017 – 0.169)
	2050, RCP8.5	0.249 (-0.019 – 0.501)	0.076 (0.001 – 0.152)	0.092 (-0.006 – 0.194)	0.081 (-0.013 – 0.166)
Hobart	2030, RCP4.5	0.000 (-0.393 – 0.346)	-0.028 (-0.294 – 0.212)	0.006 (-0.096 – 0.091)	0.023 (-0.007 – 0.049)
	2030, RCP8.5	0.006 (-0.374 – 0.346)	-0.025 (-0.283 – 0.211)	0.007 (-0.093 – 0.094)	0.024 (-0.005 – 0.049)
	2050, RCP4.5	0.004 (-0.384 – 0.353)	-0.027 (-0.287 – 0.215)	0.007 (-0.097 – 0.098)	0.024 (-0.007 – 0.048)
	2050, RCP8.5	0.003 (-0.374 – 0.344)	-0.027 (-0.283 – 0.208)	0.006 (-0.093 – 0.092)	0.024 (-0.005 – 0.049)
Melbourne	2030, RCP4.5	0.324 (0.068 – 0.558)	0.211 (0.030 – 0.381)	0.091 (0.023 – 0.154)	0.022 (0.011 – 0.033)
	2030, RCP8.5	0.320 (0.070 – 0.554)	0.210 (0.032 – 0.379)	0.089 (0.024 – 0.149)	0.022 (0.011 – 0.032)
	2050, RCP4.5	0.319 (0.069 – 0.552)	0.208 (0.032 – 0.378)	0.087 (0.023 – 0.146)	0.023 (0.012 – 0.035)
	2050, RCP8.5	0.313 (0.071 – 0.537)	0.203 (0.032 – 0.366)	0.087 (0.023 – 0.150)	0.023 (0.011 – 0.036)
Perth	2030, RCP4.5	0.225 (0.080 – 0.361)	0.103 (0.015 – 0.187)	0.089 (0.034 – 0.146)	0.033 (0.008 – 0.055)
	2030, RCP8.5	0.223 (0.081 – 0.359)	0.103 (0.015 – 0.190)	0.088 (0.035 – 0.142)	0.031 (0.008 – 0.052)
	2050, RCP4.5	0.228 (0.085 – 0.364)	0.105 (0.018 – 0.189)	0.093 (0.036 – 0.153)	0.030 (0.007 – 0.050)
	2050, RCP8.5	0.226 (0.081 – 0.369)	0.103 (0.015 – 0.188)	0.090 (0.035 – 0.151)	0.032 (0.009 – 0.055)
Sydney	2030, RCP4.5	0.057 (-0.078 – 0.175)	-0.002 (-0.112 – 0.092)	0.046 (0.011 – 0.086)	0.014 (0.006 – 0.028)
	2030, RCP8.5	0.075 (-0.051 – 0.208)	0.009 (-0.090 – 0.105)	0.050 (0.015 – 0.095)	0.016 (0.006 – 0.028)
	2050, RCP4.5	0.073 (-0.048 – 0.194)	0.008 (-0.089 – 0.099)	0.051 (0.017 – 0.091)	0.014 (0.006 – 0.027)
	2050, RCP8.5	0.086 (-0.023 – 0.187)	0.017 (-0.070 – 0.098)	0.054 (0.023 – 0.084)	0.014 (0.006 – 0.026)

Attributable fractions of heatwave-attributable costs secondary to occupational injuries/illnesses projected to 2030 and 2050 with 95% empirical confidence intervals, assuming climate adaptation. Costs are presented per AU$1000 dollars. RCP: representative concentration pathway.

Table D.10: Sensitivity analyses for model parameters

	Number of OIIs		Costs	
	AIC	Heatwave-AF	AIC	Heatwave-AF
Main model	111921	0.129 (0.107 to 0.165)	231724	0.252 (0.182 to 0.345)
Claims submitted before July 2014*	-	-	-	0.165 (0.080 to 0.266)
Humidity and EHF variants				
Relative humidity	111913	0.114 (0.089 to 0.149)	231727	0.229 (0.155 to 0.329)
Specific humidity	111921	0.129 (0.107 to 0.164)	231724	0.252 (0.184 to 0.342)
Excess heat index factor	111936	0.138 (0.115 to 0.177)	231726	0.258 (0.184 to 0.355)
Excess heat factor (forward)	111929	0.095 (0.055 to 0.141)	231726	0.248 (0.149 to 0.366)
Excess heat index factor (forward)	111946	0.104 (0.069 to 0.147)	231716	0.274 (0.169 to 0.396)
Exposure-response knots				
33th and 67th	111953	0.134 (0.101 to 0.180)	231741	0.289 (0.216 to 0.385)
25th and 75th	111953	0.133 (0.098 to 0.182)	231742	0.284 (0.210 to 0.376)
10th and 90th	111954	0.133 (0.097 to 0.181)	231742	0.277 (0.206 to 0.373)
10th, 75th and 90th	111995	0.134 (0.106 to 0.175)	231757	0.224 (0.143 to 0.321)
25th, 50th and 75th	111995	0.134 (0.108 to 0.173)	231758	0.265 (0.178 to 0.368)
10th, 50th and 90th	111997	0.133 (0.106 to 0.174)	231760	0.256 (0.172 to 0.360)
Lag-response relationship				
6 days, 1 knot	111922	0.091 (0.063 to 0.124)	231735	0.195 (0.115 to 0.283)
8 days, 1 knot	111920	0.099 (0.074 to 0.133)	231733	0.219 (0.136 to 0.315)
8 days, 2 knots	111941	0.099 (0.074 to 0.133)	231749	0.215 (0.129 to 0.310)
10 days, 2 knots	111934	0.131 (0.109 to 0.166)	231744	0.257 (0.191 to 0.350)
12 days, 1 knot	111924	0.136 (0.105 to 0.187)	231725	0.269 (0.200 to 0.373)
12 days, 2 knots	111948	0.137 (0.104 to 0.189)	231747	0.271 (0.204 to 0.369)
14 days, 1 knot	111930	0.126 (0.087 to 0.183)	231728	0.299 (0.235 to 0.405)
14 days, 2 knots	111958	0.125 (0.086 to 0.183)	231738	0.294 (0.230 to 0.402)
Seasonality df per year				
2	112603	0.191 (0.139 to 0.261)	231724	0.251 (0.184 to 0.344)
3	112636	0.139 (0.102 to 0.189)	231724	0.252 (0.183 to 0.344)
5	112225	0.141 (0.118 to 0.178)	231724	0.252 (0.185 to 0.345)
6	112011	0.117 (0.089 to 0.157)	231725	0.252 (0.184 to 0.345)

National heatwave-attributable fractions (AF, %) for the number of occupational injuries and illnesses (OIIs) and associated costs with 95% empirical confidence intervals, with sensitivity analyses. The Akaike information criterion (AIC) presented is identical to the sum of AIC for the individual models. Seasonality degrees of freedom (df) were penalized for the cost (generalized additive) models but not for the number of OIIs (generalized linear) models. *The sensitivity analysis of claims submitted before July 2014 had costs restricted to up to five financial years after the financial year of claim submission.

Table D.11: Projected number of occupational injuries/illnesses attributable to heatwaves per year under different population scenarios

Location	Period	RCP	Pop growth	Heatwaves	Severe heatwaves	Extreme heatwaves
Total	2030	4.5	High	168.32 (102.52 – 238.50)	53.87 (32.57 – 77.53)	26.64 (14.86 – 42.25)
			Low	156.40 (95.26 – 221.61)	50.05 (30.27 – 72.04)	24.76 (13.81 – 39.26)
			None	127.72 (77.79 – 180.97)	40.87 (24.72 – 58.83)	20.22 (11.27 – 32.06)
		8.5	High	185.12 (111.45 – 272.04)	59.15 (35.36 – 87.45)	31.16 (16.92 – 51.05)
			Low	172.01 (103.56 – 252.77)	54.96 (32.86 – 81.26)	28.96 (15.73 – 47.44)
			None	140.46 (84.57 – 206.42)	44.88 (26.83 – 66.36)	23.65 (12.84 – 38.74)
	2050	4.5	High	298.97 (176.54 – 449.88)	95.73 (57.31 – 141.45)	53.79 (30.16 – 93.52)
			Low	245.11 (144.74 – 368.84)	78.49 (46.98 – 115.97)	44.10 (24.73 – 76.68)
			None	163.76 (96.70 – 246.42)	52.44 (31.39 – 77.48)	29.46 (16.52 – 51.23)
		8.5	High	387.15 (211.49 – 627.61)	120.68 (70.42 – 185.92)	80.81 (41.69 – 146.83)
			Low	317.41 (173.39 – 514.56)	98.95 (57.73 – 152.43)	66.26 (34.18 – 120.38)
			None	212.07 (115.84 – 343.78)	66.11 (38.57 – 101.84)	44.27 (22.84 – 80.43)
Adelaide	2030	4.5	High	20.15 (11.08 – 29.55)	6.29 (3.78 – 8.97)	1.44 (0.69 – 3.32)
			Low	19.33 (10.63 – 28.35)	6.04 (3.63 – 8.61)	1.38 (0.66 – 3.19)
			None	17.65 (9.70 – 25.87)	5.51 (3.31 – 7.86)	1.26 (0.61 – 2.91)
		8.5	High	21.11 (11.36 – 31.95)	6.66 (3.73 – 10.49)	1.73 (0.79 – 2.92)
			Low	20.25 (10.90 – 30.65)	6.39 (3.58 – 10.07)	1.66 (0.76 – 2.80)
			None	18.48 (9.95 – 27.97)	5.83 (3.27 – 9.19)	1.51 (0.69 – 2.55)
	2050	4.5	High	27.40 (14.27 – 42.75)	9.03 (4.99 – 14.66)	2.09 (1.04 – 3.59)
			Low	24.00 (12.50 – 37.45)	7.91 (4.37 – 12.84)	1.83 (0.91 – 3.14)
			None	20.04 (10.44 – 31.28)	6.61 (3.65 – 10.73)	1.53 (0.76 – 2.63)
		8.5	High	31.58 (15.28 – 50.81)	10.84 (5.65 – 18.20)	2.98 (1.63 – 4.82)
			Low	27.66 (13.39 – 44.51)	9.49 (4.95 – 15.94)	2.61 (1.43 – 4.22)
			None	23.10 (11.18 – 37.17)	7.93 (4.14 – 13.32)	2.18 (1.19 – 3.53)
Brisbane	2030	4.5	High	26.78 (15.39 – 43.54)	8.32 (4.56 – 14.77)	7.11 (3.81 – 11.26)
			Low	24.59 (14.13 – 39.97)	7.64 (4.19 – 13.57)	6.53 (3.49 – 10.34)
			None	19.91 (11.44 – 32.36)	6.18 (3.39 – 10.98)	5.28 (2.83 – 8.37)
		8.5	High	31.75 (18.45 – 47.93)	10.44 (5.82 – 15.99)	8.30 (4.42 – 12.87)
			Low	29.15 (16.94 – 44.01)	9.58 (5.35 – 14.68)	7.62 (4.06 – 11.81)
			None	23.60 (13.72 – 35.63)	7.76 (4.33 – 11.89)	6.17 (3.29 – 9.56)
	2050	4.5	High	52.36 (30.61 – 84.02)	16.91 (9.90 – 25.55)	14.47 (8.04 – 25.61)
			Low	41.68 (24.37 – 66.88)	13.46 (7.88 – 20.34)	11.52 (6.40 – 20.39)
			None	27.38 (16.01 – 43.93)	8.84 (5.18 – 13.36)	7.57 (4.20 – 13.39)
		8.5	High	75.15 (37.59 – 137.50)	21.65 (11.35 – 38.51)	23.55 (11.74 – 43.76)
			Low	59.83 (29.92 – 109.45)	17.24 (9.03 – 30.65)	18.75 (9.35 – 34.83)
			None	39.29 (19.65 – 71.89)	11.32 (5.93 – 20.13)	12.31 (6.14 – 22.88)
Darwin	2030	4.5	High	9.41 (5.50 – 13.79)	2.48 (1.49 – 3.54)	5.93 (3.12 – 9.63)
			Low	10.26 (5.99 – 15.02)	2.70 (1.62 – 3.86)	6.46 (3.40 – 10.49)
			None	7.73 (4.52 – 11.32)	2.04 (1.22 – 2.91)	4.87 (2.56 – 7.91)
		8.5	High	10.58 (6.22 – 16.46)	2.56 (1.51 – 3.68)	7.03 (3.80 – 12.04)
			Low	11.52 (6.78 – 17.93)	2.79 (1.65 – 4.01)	7.66 (4.14 – 13.12)
			None	8.69 (5.11 – 13.52)	2.11 (1.24 – 3.02)	5.78 (3.12 – 9.89)
	2050	4.5	High	16.48 (9.56 – 25.01)	3.13 (1.52 – 4.68)	12.26 (6.89 – 19.78)
			Low	19.68 (11.42 – 29.87)	3.74 (1.82 – 5.59)	14.64 (8.23 – 23.62)
			None	10.20 (5.92 – 15.48)	1.94 (0.94 – 2.90)	7.59 (4.26 – 12.24)
		8.5	High	20.53 (10.54 – 34.11)	2.93 (0.81 – 4.86)	16.75 (8.57 – 28.87)
			Low	24.52 (12.59 – 40.74)	3.50 (0.97 – 5.80)	20.01 (10.24 – 34.48)
			None	12.71 (6.52 – 21.12)	1.81 (0.50 – 3.01)	10.37 (5.31 – 17.87)
Hobart	2030	4.5	High	3.61 (1.66 – 5.65)	1.20 (0.56 – 1.90)	0.80 (0.50 – 1.11)
			Low	3.27 (1.51 – 5.11)	1.08 (0.51 – 1.72)	0.72 (0.45 – 1.00)
			None	2.99 (1.37 – 4.67)	0.99 (0.47 – 1.57)	0.66 (0.41 – 0.92)
		8.5	High	3.99 (1.77 – 6.73)	1.31 (0.59 – 2.25)	0.90 (0.53 – 1.36)
			Low	3.61 (1.61 – 6.09)	1.18 (0.54 – 2.04)	0.81 (0.48 – 1.23)
			None	3.29 (1.47 – 5.56)	1.08 (0.49 – 1.86)	0.74 (0.44 – 1.12)
	2050	4.5	High	5.86 (2.32 – 11.44)	1.94 (0.83 – 3.41)	1.34 (0.71 – 2.62)
			Low	4.37 (1.73 – 8.52)	1.44 (0.62 – 2.54)	1.00 (0.53 – 1.96)
			None	3.85 (1.52 – 7.51)	1.27 (0.54 – 2.24)	0.88 (0.47 – 1.72)
		8.5	High	6.56 (2.38 – 11.72)	2.13 (0.83 – 3.66)	1.53 (0.80 – 2.46)
			Low	4.89 (1.77 – 8.74)	1.58 (0.62 – 2.73)	1.14 (0.60 – 1.83)
			None	4.31 (1.56 – 7.70)	1.40 (0.54 – 2.40)	1.01 (0.53 – 1.62)
Melbourne	2030	4.5	High	22.57 (10.95 – 35.85)	6.89 (3.35 – 13.05)	3.23 (1.91 – 4.91)
			Low	20.48 (9.93 – 32.53)	6.25 (3.04 – 11.84)	2.93 (1.73 – 4.46)
			None	16.21 (7.86 – 25.76)	4.95 (2.41 – 9.37)	2.32 (1.37 – 3.53)
		8.5	High	24.18 (11.49 – 39.27)	7.75 (3.80 – 14.04)	3.47 (2.10 – 5.10)

Table D.11: Projected number of occupational injuries/illnesses attributable to heatwaves per year under different population scenarios *(continued)*

Location	Period	RCP	Pop growth	Heatwaves	Severe heatwaves	Extreme heatwaves
			Low	21.94 (10.42 – 35.63)	7.04 (3.45 – 12.74)	3.15 (1.91 – 4.62)
			None	17.37 (8.25 – 28.21)	5.57 (2.73 – 10.08)	2.49 (1.51 – 3.66)
	2050	4.5	High	39.96 (18.08 – 67.27)	12.91 (6.24 – 23.26)	5.69 (3.27 – 8.28)
			Low	31.12 (14.08 – 52.38)	10.05 (4.86 – 18.11)	4.43 (2.55 – 6.44)
			None	19.89 (9.00 – 33.49)	6.43 (3.10 – 11.58)	2.83 (1.63 – 4.12)
		8.5	High	48.15 (19.76 – 82.90)	16.17 (7.14 – 29.75)	7.02 (3.97 – 12.17)
			Low	37.50 (15.39 – 64.55)	12.59 (5.56 – 23.17)	5.47 (3.09 – 9.48)
			None	23.97 (9.84 – 41.27)	8.05 (3.56 – 14.81)	3.49 (1.98 – 6.06)
Perth	2030	4.5	High	32.76 (19.88 – 46.55)	12.27 (7.21 – 17.62)	4.84 (2.53 – 7.89)
			Low	31.83 (19.32 – 45.23)	11.92 (7.01 – 17.12)	4.70 (2.45 – 7.67)
			None	26.06 (15.82 – 37.04)	9.76 (5.74 – 14.02)	3.85 (2.01 – 6.28)
		8.5	High	33.27 (18.85 – 49.66)	12.49 (6.61 – 18.45)	4.71 (2.35 – 7.76)
			Low	32.32 (18.32 – 48.25)	12.14 (6.42 – 17.93)	4.57 (2.28 – 7.54)
			None	26.47 (15.00 – 39.51)	9.94 (5.26 – 14.68)	3.75 (1.87 – 6.17)
	2050	4.5	High	52.86 (30.46 – 75.65)	19.18 (10.52 – 27.27)	8.31 (4.27 – 12.52)
			Low	48.11 (27.72 – 68.85)	17.45 (9.57 – 24.82)	7.57 (3.88 – 11.39)
			None	30.63 (17.65 – 43.83)	11.11 (6.09 – 15.80)	4.82 (2.47 – 7.25)
		8.5	High	61.37 (35.54 – 91.33)	21.38 (12.87 – 30.90)	11.07 (5.17 – 19.10)
			Low	55.85 (32.34 – 83.12)	19.46 (11.71 – 28.12)	10.08 (4.71 – 17.38)
			None	35.56 (20.59 – 52.91)	12.39 (7.46 – 17.90)	6.41 (3.00 – 11.06)
Sydney	2030	4.5	High	48.78 (28.70 – 71.91)	15.02 (8.11 – 23.43)	2.59 (0.93 – 6.44)
			Low	45.50 (26.77 – 67.08)	14.01 (7.56 – 21.86)	2.41 (0.87 – 6.01)
			None	37.18 (21.87 – 54.81)	11.45 (6.18 – 17.86)	1.97 (0.71 – 4.91)
		8.5	High	55.85 (32.95 – 85.43)	16.52 (8.92 – 26.54)	4.21 (1.05 – 10.39)
			Low	52.09 (30.74 – 79.69)	15.41 (8.32 – 24.76)	3.92 (0.98 – 9.70)
			None	42.56 (25.11 – 65.11)	12.59 (6.80 – 20.23)	3.21 (0.80 – 7.92)
	2050	4.5	High	92.61 (53.75 – 142.36)	29.06 (16.43 – 43.26)	7.61 (2.44 – 21.88)
			Low	76.77 (44.56 – 118.02)	24.09 (13.62 – 35.86)	6.31 (2.02 – 18.14)
			None	51.76 (30.05 – 79.57)	16.24 (9.19 – 24.18)	4.25 (1.37 – 12.23)
		8.5	High	130.81 (73.02 – 222.39)	41.53 (24.10 – 63.70)	15.19 (5.14 – 39.52)
			Low	108.45 (60.53 – 184.36)	34.43 (19.98 – 52.81)	12.60 (4.26 – 32.76)
			None	73.12 (40.81 – 124.30)	23.21 (13.47 – 35.61)	8.49 (2.87 – 22.09)

The number of annual occupational injuries/illnesses attributable to heatwaves across to 2016-45 and 2036-65 centered at 2030 and 2050 with 95% empirical confidence intervals under the high, low and no population (pop) growth scenarios. Climate adaptation is not assumed.

Table D.12: Projected heatwave-attributable costs secondary to occupational injuries/illnesses attributable per year under different population scenarios

Location	Period	RCP	Pop growth	Heatwaves	Severe heatwaves	Extreme heatwaves
Total	2030	4.5	High	3,440.5 (-1,383.6 – 7,731.1)	1,280.2 (52.2 – 2,434.0)	797.5 (329.2 – 1,287.6)
			Low	3,196.9 (-1,285.6 – 7,183.7)	1,189.5 (48.5 – 2,261.7)	741.0 (305.9 – 1,196.4)
			None	2,610.6 (-1,049.9 – 5,866.2)	971.4 (39.6 – 1,846.9)	605.1 (249.8 – 977.0)
		8.5	High	3,363.9 (-2,646.9 – 8,788.5)	1,277.8 (-303.1 – 2,730.1)	862.3 (254.6 – 1,542.5)
			Low	3,125.7 (-2,459.5 – 8,166.2)	1,187.3 (-281.7 – 2,536.8)	801.2 (236.5 – 1,433.3)
			None	2,552.4 (-2,008.4 – 6,668.6)	969.5 (-230.0 – 2,071.6)	654.3 (193.1 – 1,170.4)
	2050	4.5	High	3,936.2 (-8,402.7 – 14,318.5)	1,672.2 (-1,535.5 – 4,400.5)	1,233.9 (-385.5 – 2,701.1)
			Low	3,227.2 (-6,889.1 – 11,739.3)	1,371.0 (-1,258.9 – 3,607.8)	1,011.6 (-316.1 – 2,214.6)
			None	2,156.1 (-4,602.7 – 7,843.1)	916.0 (-841.1 – 2,410.4)	675.9 (-211.2 – 1,479.6)
		8.5	High	1,359.2 (-20,564.6 – 18,583.3)	1,155.0 (-4,268.8 – 5,500.9)	1,168.3 (-2,936.3 – 4,436.4)
			Low	1,114.3 (-16,860.3 – 15,235.9)	947.0 (-3,499.8 – 4,510.0)	957.9 (-2,407.4 – 3,637.3)
			None	744.5 (-11,264.5 – 10,179.2)	632.7 (-2,338.3 – 3,013.2)	640.0 (-1,608.4 – 2,430.1)
Adelaide	2030	4.5	High	309.9 (-326.7 – 898.3)	104.8 (-34.3 – 231.4)	26.3 (8.4 – 63.1)
			Low	297.3 (-313.4 – 861.8)	100.5 (-32.9 – 221.9)	25.2 (8.0 – 60.5)
			None	271.4 (-286.1 – 786.5)	91.7 (-30.0 – 202.6)	23.0 (7.3 – 55.2)
		8.5	High	321.8 (-366.9 – 988.4)	109.3 (-44.7 – 271.1)	31.6 (10.2 – 59.1)
			Low	308.7 (-352.0 – 948.1)	104.8 (-42.9 – 260.1)	30.3 (9.8 – 56.7)
			None	281.7 (-321.3 – 865.4)	95.7 (-39.2 – 237.4)	27.6 (8.9 – 51.7)
	2050	4.5	High	414.4 (-512.0 – 1,305.3)	147.3 (-66.9 – 373.4)	37.7 (13.3 – 70.8)
			Low	363.1 (-448.5 – 1,143.5)	129.0 (-58.6 – 327.1)	33.0 (11.7 – 62.0)
			None	303.2 (-374.6 – 955.0)	107.8 (-49.0 – 273.2)	27.5 (9.7 – 51.8)
		8.5	High	467.6 (-710.8 – 1,585.8)	172.2 (-126.9 – 484.3)	52.5 (18.3 – 96.1)
			Low	409.6 (-622.7 – 1,389.2)	150.8 (-111.2 – 424.2)	46.0 (16.1 – 84.2)
			None	342.1 (-520.1 – 1,160.3)	126.0 (-92.9 – 354.3)	38.4 (13.4 – 70.3)
Brisbane	2030	4.5	High	192.0 (-877.5 – 1,019.1)	64.1 (-273.2 – 343.0)	249.7 (105.5 – 419.4)
			Low	176.3 (-805.7 – 935.7)	58.8 (-250.8 – 315.0)	229.3 (96.8 – 385.1)
			None	142.8 (-652.3 – 757.5)	47.6 (-203.1 – 255.0)	185.6 (78.4 – 311.8)
		8.5	High	-10.0 (-1,603.0 – 1,121.8)	1.7 (-522.3 – 370.6)	249.1 (80.8 – 398.1)
			Low	-9.2 (-1,471.9 – 1,030.1)	1.5 (-479.5 – 340.3)	228.7 (74.2 – 365.5)
			None	-7.4 (-1,191.5 – 833.9)	1.2 (-388.2 – 275.5)	185.2 (60.0 – 295.9)
	2050	4.5	High	-541.9 (-3,985.8 – 1,793.6)	-167.4 (-1,253.5 – 583.9)	321.5 (-124.0 – 586.5)
			Low	-431.4 (-3,172.8 – 1,427.8)	-133.2 (-997.8 – 464.8)	255.9 (-98.7 – 466.9)
			None	-283.3 (-2,084.0 – 937.8)	-87.5 (-655.4 – 305.3)	168.1 (-64.8 – 306.7)
		8.5	High	-2,204.7 (-9,733.0 – 2,585.7)	-652.7 (-2,881.3 – 743.9)	152.4 (-1,015.5 – 856.8)
			Low	-1,755.0 (-7,747.8 – 2,058.3)	-519.6 (-2,293.6 – 592.2)	121.3 (-808.4 – 682.1)
			None	-1,152.7 (-5,088.9 – 1,351.9)	-341.3 (-1,506.5 – 389.0)	79.7 (-530.9 – 448.0)
Darwin	2030	4.5	High	210.0 (-276.3 – 617.8)	39.5 (-143.2 – 185.9)	160.7 (-63.8 – 374.5)
			Low	228.8 (-301.0 – 673.2)	43.0 (-156.0 – 202.5)	175.0 (-69.6 – 408.0)
			None	172.4 (-226.9 – 507.5)	32.4 (-117.6 – 152.7)	131.9 (-52.4 – 307.6)
		8.5	High	195.0 (-526.0 – 795.4)	27.0 (-212.0 – 223.2)	164.0 (-221.6 – 502.2)
			Low	212.5 (-573.1 – 866.6)	29.5 (-231.0 – 243.1)	178.7 (-241.5 – 547.2)
			None	160.2 (-432.0 – 653.3)	22.2 (-174.1 – 183.3)	134.7 (-182.0 – 412.5)
	2050	4.5	High	172.6 (-1,434.1 – 1,452.8)	-3.7 (-414.6 – 342.2)	186.3 (-879.9 – 1,013.7)
			Low	206.1 (-1,712.9 – 1,735.2)	-4.4 (-495.2 – 408.7)	222.5 (-1,050.9 – 1,210.7)
			None	106.8 (-887.8 – 899.3)	-2.3 (-256.6 – 211.8)	115.3 (-544.7 – 627.5)
		8.5	High	-65.8 (-3,436.1 – 2,427.8)	-59.2 (-660.8 – 433.3)	16.8 (-2,616.1 – 1,898.7)
			Low	-78.6 (-4,103.9 – 2,899.6)	-70.7 (-789.3 – 517.5)	20.1 (-3,124.6 – 2,267.7)
			None	-40.8 (-2,127.0 – 1,502.9)	-36.7 (-409.1 – 268.2)	10.4 (-1,619.5 – 1,175.3)
Hobart	2030	4.5	High	-25.4 (-304.2 – 210.4)	-6.6 (-98.7 – 67.4)	8.5 (-17.8 – 29.2)
			Low	-23.0 (-275.4 – 190.5)	-6.0 (-89.3 – 61.0)	7.7 (-16.1 – 26.4)
			None	-21.0 (-251.4 – 173.9)	-5.4 (-81.5 – 55.7)	7.0 (-14.7 – 24.1)
		8.5	High	-31.6 (-359.9 – 247.8)	-7.9 (-113.0 – 77.3)	8.6 (-24.7 – 35.6)
			Low	-28.6 (-325.9 – 224.4)	-7.1 (-102.4 – 70.0)	7.8 (-22.4 – 32.2)
			None	-26.1 (-297.5 – 204.8)	-6.5 (-93.4 – 63.9)	7.1 (-20.4 – 29.4)
	2050	4.5	High	-64.5 (-646.9 – 388.0)	-17.4 (-196.4 – 117.8)	9.2 (-62.6 – 63.7)
			Low	-48.1 (-482.2 – 289.2)	-13.0 (-146.4 – 87.8)	6.9 (-46.6 – 47.5)
			None	-42.4 (-424.9 – 254.8)	-11.4 (-129.0 – 77.4)	6.1 (-41.1 – 41.8)
		8.5	High	-88.5 (-761.3 – 443.1)	-24.8 (-237.0 – 134.1)	7.3 (-80.2 – 71.0)
			Low	-66.0 (-567.4 – 330.3)	-18.5 (-176.7 – 99.9)	5.4 (-59.8 – 52.9)
			None	-58.1 (-500.1 – 291.1)	-16.3 (-155.7 – 88.1)	4.8 (-52.7 – 46.6)
Melbourne	2030	4.5	High	1,479.3 (310.8 – 2,738.4)	408.9 (98.3 – 907.1)	106.0 (48.3 – 185.7)
			Low	1,342.2 (282.0 – 2,484.6)	371.0 (89.2 – 823.1)	96.1 (43.8 – 168.5)
			None	1,062.6 (223.3 – 1,967.0)	293.7 (70.6 – 651.6)	76.1 (34.7 – 133.4)
		8.5	High	1,622.3 (333.5 – 3,070.6)	471.7 (113.8 – 994.9)	117.8 (54.7 – 205.1)
			Low	1,472.0 (302.6 – 2,786.0)	428.0 (103.2 – 902.7)	106.9 (49.7 – 186.1)
			None	1,165.4 (239.6 – 2,205.7)	338.9 (81.7 – 714.7)	84.7 (39.3 – 147.3)
	2050	4.5	High	2,785.3 (511.4 – 5,488.0)	815.6 (178.4 – 1,735.1)	207.0 (87.8 – 352.2)
			Low	2,168.8 (398.2 – 4,273.3)	635.1 (138.9 – 1,351.0)	161.2 (68.4 – 274.2)
			None	1,386.6 (254.6 – 2,732.0)	406.0 (88.8 – 863.7)	103.1 (43.7 – 175.3)
		8.5	High	3,535.4 (573.9 – 6,984.1)	1,083.7 (210.2 – 2,323.5)	281.4 (110.8 – 629.8)
			Low	2,752.9 (446.9 – 5,438.3)	843.8 (163.7 – 1,809.2)	219.1 (86.3 – 490.4)
			None	1,760.0 (285.7 – 3,476.7)	539.5 (104.6 – 1,156.7)	140.1 (55.2 – 313.5)

Table D.12: Projected heatwave-attributable costs secondary to occupational injuries/illnesses attributable per year under different population scenarios *(continued)*

Location	Period	RCP	Pop growth	Heatwaves	Severe heatwaves	Extreme heatwaves
Perth	2030	4.5	High	767.4 (176.4 – 1,361.8)	294.4 (106.3 – 485.0)	130.9 (40.6 – 231.6)
			Low	745.7 (171.4 – 1,323.1)	286.0 (103.3 – 471.3)	127.2 (39.5 – 225.0)
			None	610.6 (140.4 – 1,083.5)	234.2 (84.6 – 385.9)	104.1 (32.3 – 184.2)
		8.5	High	770.4 (154.7 – 1,487.6)	297.7 (103.9 – 514.9)	127.0 (38.1 – 224.4)
			Low	748.5 (150.3 – 1,445.4)	289.3 (101.0 – 500.3)	123.4 (37.0 – 218.0)
			None	613.0 (123.1 – 1,183.6)	236.9 (82.7 – 409.7)	101.0 (30.3 – 178.6)
	2050	4.5	High	1,191.5 (38.8 – 2,394.7)	446.9 (118.7 – 785.2)	219.5 (76.0 – 362.0)
			Low	1,084.5 (35.3 – 2,179.5)	406.8 (108.0 – 714.7)	199.7 (69.2 – 329.5)
			None	690.4 (22.5 – 1,387.5)	259.0 (68.8 – 455.0)	127.2 (44.0 – 209.7)
		8.5	High	1,329.1 (-271.2 – 2,988.9)	482.3 (45.3 – 927.7)	281.1 (96.8 – 520.2)
			Low	1,209.7 (-246.8 – 2,720.3)	439.0 (41.2 – 844.3)	255.8 (88.1 – 473.4)
			None	770.1 (-157.1 – 1,731.8)	279.5 (26.3 – 537.5)	162.9 (56.1 – 301.4)
Sydney	2030	4.5	High	487.8 (-607.2 – 1,385.0)	363.5 (80.6 – 666.9)	101.4 (42.7 – 217.9)
			Low	455.0 (-566.4 – 1,292.0)	339.1 (75.2 – 622.1)	94.6 (39.8 – 203.3)
			None	371.8 (-462.8 – 1,055.7)	277.1 (61.5 – 508.3)	77.3 (32.5 – 166.1)
		8.5	High	479.9 (-1,330.7 – 1,634.9)	368.9 (-89.5 – 755.2)	149.5 (47.3 – 291.1)
			Low	447.7 (-1,241.3 – 1,525.0)	344.2 (-83.5 – 704.4)	139.5 (44.1 – 271.5)
			None	365.8 (-1,014.2 – 1,246.1)	281.2 (-68.2 – 575.6)	114.0 (36.1 – 221.9)
	2050	4.5	High	-9.2 (-3,924.4 – 2,187.2)	437.4 (-474.4 – 1,023.6)	230.1 (89.8 – 497.1)
			Low	-7.6 (-3,253.4 – 1,813.2)	362.6 (-393.3 – 848.6)	190.7 (74.5 – 412.1)
			None	-5.2 (-2,193.6 – 1,222.5)	244.5 (-265.2 – 572.1)	128.6 (50.2 – 277.8)
		8.5	High	-1,567.3 (-8,894.1 – 2,181.5)	146.8 (-1,577.9 – 982.9)	364.4 (133.1 – 735.0)
			Low	-1,299.3 (-7,373.4 – 1,808.5)	121.7 (-1,308.1 – 814.9)	302.1 (110.3 – 609.3)
			None	-876.0 (-4,971.4 – 1,219.3)	82.0 (-882.0 – 549.4)	203.7 (74.4 – 410.8)

Annual costs secondary to occupational injuries/illnesses attributable to heatwaves across to 2016-45 and 2036-65 centered at 2030 and 2050 with 95% empirical confidence intervals under the high, low and no population (pop) growth scenarios. Adaptation is not assumed.

D.3 Supplementary Figures

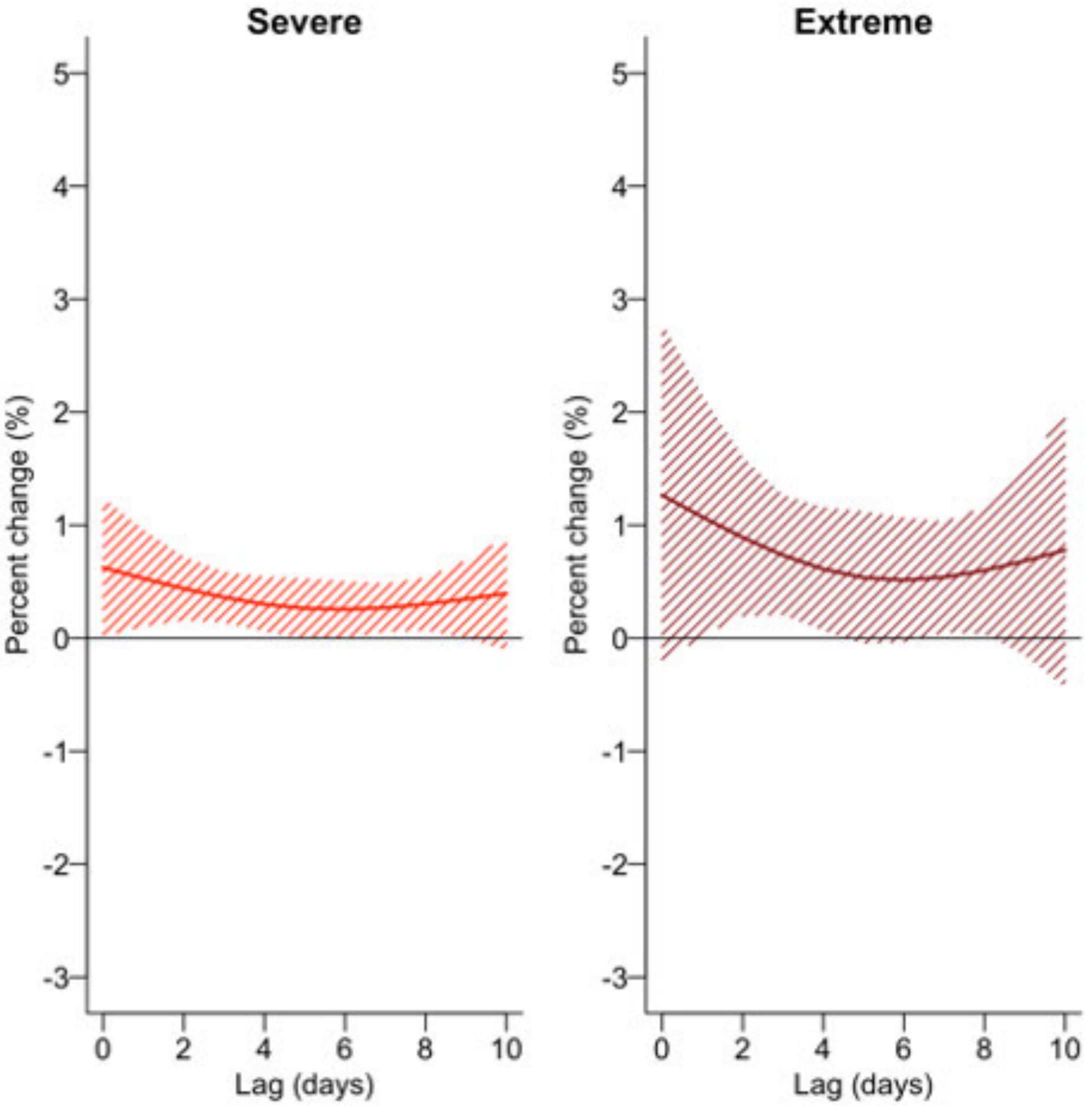


Figure D.1: Overall cumulative lag-response relationships pooled nationally at the thresholds for severe and extreme heatwave thresholds. The curves with 95% confidence intervals represent percentage change in occupational injuries and illnesses against Excess Heat Factor.

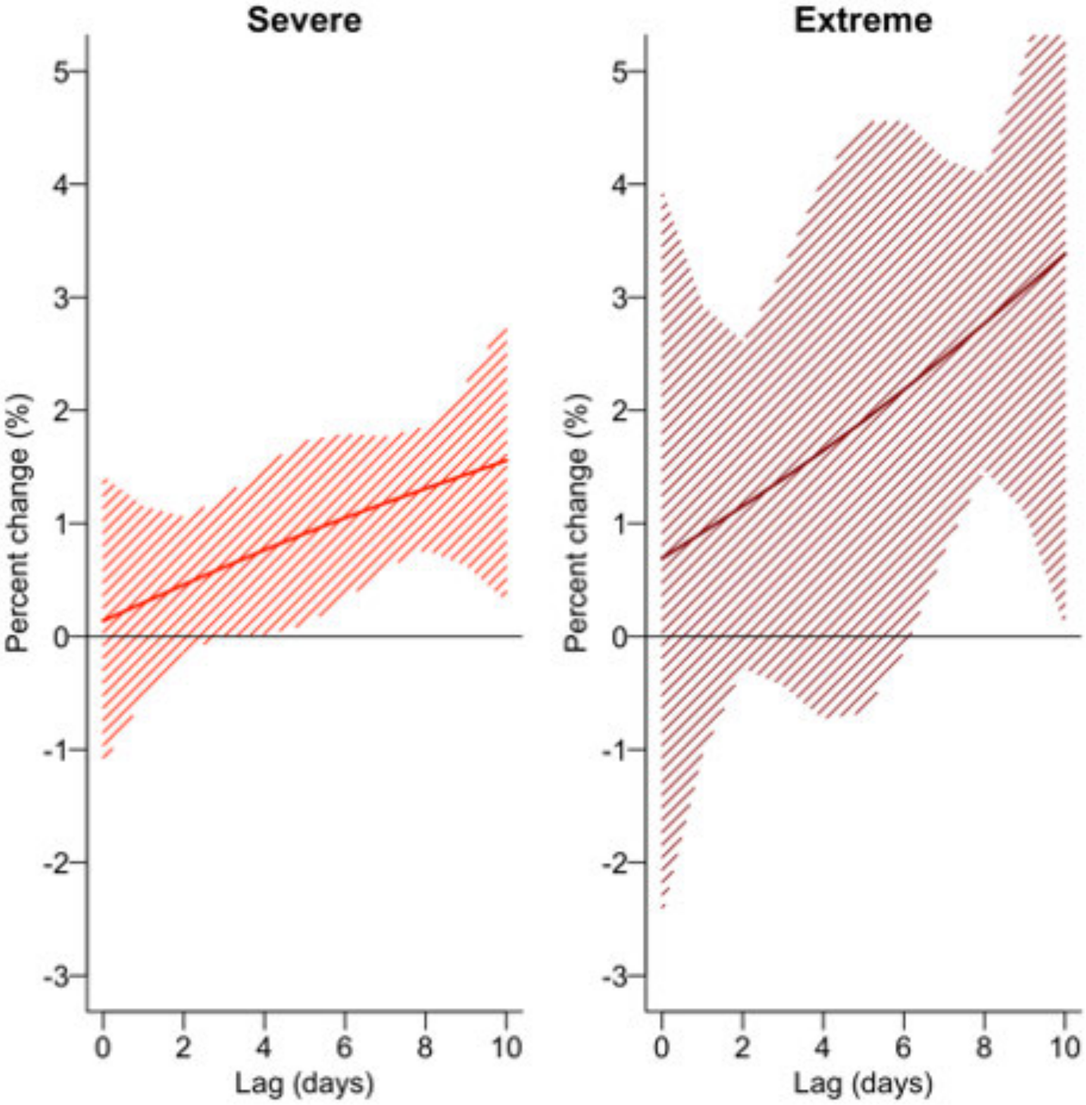


Figure D.2: Overall cumulative lag-response relationships pooled nationally at the thresholds for severe and extreme heatwave thresholds. The curves with 95% confidence intervals represent percentage change in costs against Excess Heat Factor.

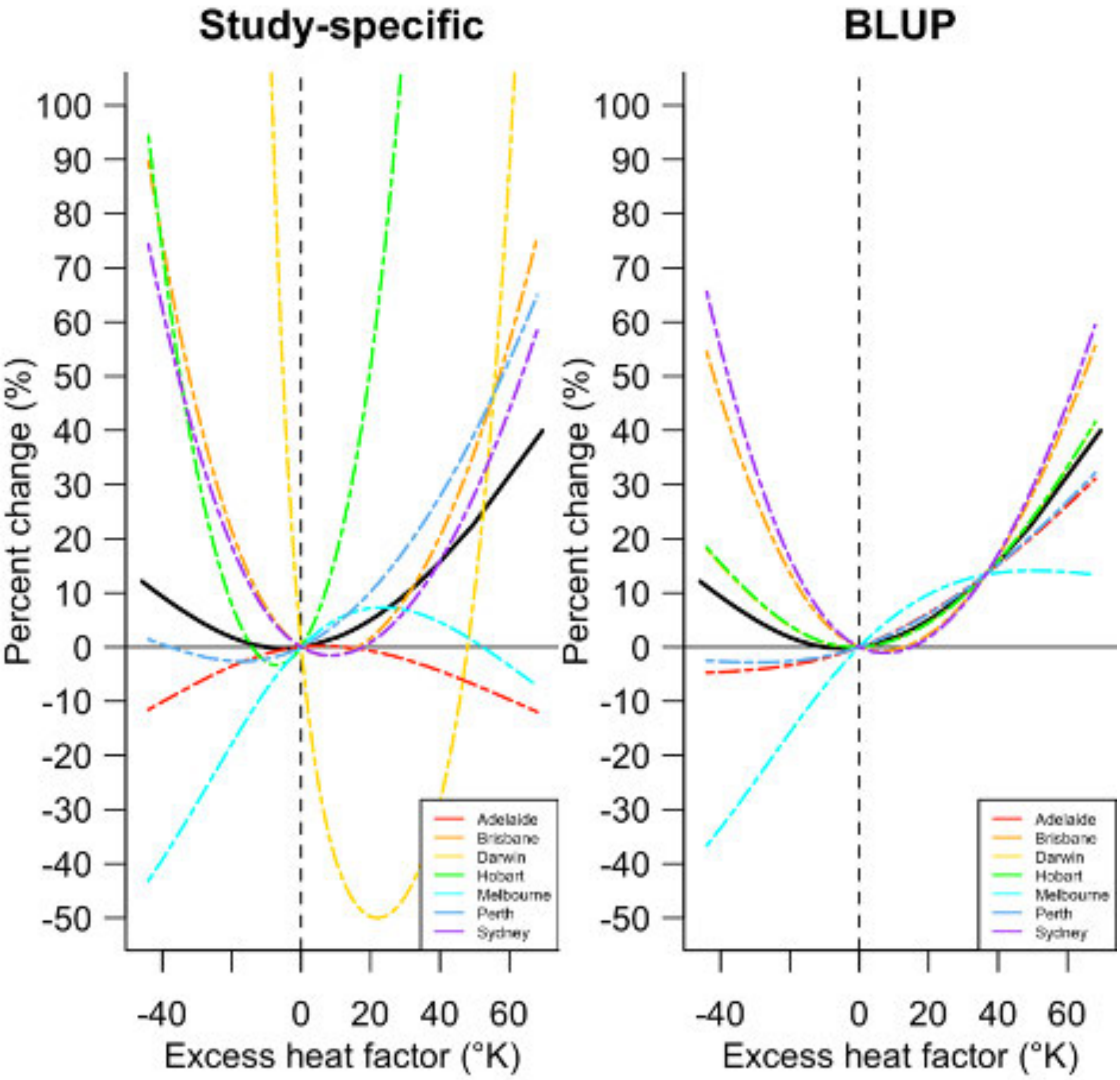


Figure D.3: Overall cumulative exposure-response relationships for occupational injury- and illness-associated costs in Adelaide, Brisbane, Darwin, Hobart, Melbourne, Perth and Sydney against Excess Heat Factor. The national pooled relationship is represented with the black, non-dashed curve. BLUP: best linear unbiased predictor.

References

1. Lyngs U. oxforddown: An Oxford University Thesis Template for R Markdown [Internet]. GitHub; 2019. Available from: `https://github.com/ulyngs/oxforddown`
2. Xie Y. bookdown: Authoring Books and Technical Documents with R Markdown [Internet]. 2022. Available from: `https://bookdown.org/yihui/bookdown/`
3. Ebi KL, Capon A, Berry P, Broderick C, De Dear R, Havenith G, et al. Hot weather and heat extremes: health risks. The Lancet [Internet]. 2021;398(10301):698 708. Available from: `https://dx.doi.org/10.1016/s0140-6736(21)01208-3`
4. Intergovernmental Panel on Climate Change. Climate Change 2021: The Physical Science Basis [Internet]. 2021. Available from: `https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf`
5. Australian Government Bureau of Meteorology. Climate change trends and extremes [Internet]. Canberra, Australia; 2022. (Australian climate variability & change - Time series graphs). Available from: `http://www.bom.gov.au/climate/change/index.shtml#tabs=Tracker&tracker=timeseries&tQ=graph%3Dtmean%26area%3Daus%26season%3D0706%26ave_yr%3D5`
6. Australian Government Bureau of Meteorology. Annual climate statement 2021 [Internet]. Canberra, Australia; 2022. (Analysis of Australia's temperature, rainfall, water, oceans, significant weather and influences during 2021). Available from: `http://www.bom.gov.au/climate/current/annual/aus/#tabs=Global`
7. Commonwealth Scientific and Industrial Research Organisation and Australian Government Bureau of Meteorology. Climate change in Australia Information for Australia's Natural Resource Management Regions [Internet]. Australia; 2015. Available from: `https://www.climatechangeinaustralia.gov.au/en/publications-library/technical-report/`
8. Song X, Wang S, Hu Y, Yue M, Zhang T, Liu Y, et al. Impact of ambient temperature on morbidity and mortality: An overview of reviews. Science of The Total Environment [Internet]. 2017;586:241 54. Available from: `https://doi.org/10.1016/j.scitotenv.2017.01.212`

9. Bobb JF, Obermeyer Z, Wang Y, Dominici F. Cause-specific risk of hospital admission related to extreme heat in older adults. JAMA [Internet]. 2014;312(24):2659 67. Available from: https://doi.org/10.1001/jama.2014.15715

10. Green H, Bailey J, Schwarz L, Vanos J, Ebi K, Benmarhnia T. Impact of heat on mortality and morbidity in low and middle income countries: A review of the epidemiological evidence and considerations for future research. Environmental Research [Internet]. 2019;171:80 91. Available from: https://dx.doi.org/10.1016/j.envres.2019.01.010

11. Li M, Gu S, Bi P, Yang J, Liu Q. Heat waves and morbidity: current knowledge and further direction-a comprehensive literature review. International Journal of Environmental Research and Public Health [Internet]. 2015;12(5):5256 83. Available from: https://doi.org/10.3390/ijerph120505256

12. Murray B. Hydration and physical performance. Journal of the American College of Nutrition [Internet]. 2007;26(sup5):542S 548S. Available from: https://dx.doi.org/10.1080/07315724.2007.10719656

13. Varghese BM, Hansen A, Bi P, Pisaniello D. Are workers at risk of occupational injuries due to heat exposure? A comprehensive literature review. Safety Science [Internet]. 2018;110:380 92. Available from: https://dx.doi.org/10.1016/j.ssci.2018.04.027

14. Borg MA, Bi P. The impact of climate change on kidney health. Nature Reviews Nephrology [Internet]. 2021;17(5):294 5. Available from: https://dx.doi.org/10.1038/s41581-020-00365-4

15. Périard JD, Eijsvogels TMH, Daanen HAM. Exercise under heat stress: thermoregulation, hydration, performance implications, and mitigation strategies. Physiological Reviews [Internet]. 2021;101(4):1873 979. Available from: https://doi.org/10.1152/physrev.00038.2020

16. Parsons K. Human thermal environments. 3rd ed. London: CRC Press; 2014. (The effects of hot, moderate, and cold environments on human health, comfort and performance).

17. Liu J, Varghese BM, Hansen A, Xiang J, Zhang Y, Dear K, et al. Is there an association between hot weather and poor mental health outcomes? A systematic review and meta-analysis. Environment International [Internet]. 2021;153:106533. Available from: https://dx.doi.org/10.1016/j.envint.2021.106533

18. Kenny GP, Wilson TE, Flouris AD, Fujii N. Heat exhaustion. Handb Clin Neurol [Internet]. 2018;157:505 29. Available from: https://doi.org/10.1016/B978-0-444-64074-1.00031-8

19. Levy B, Roelofs C. Impacts of Climate Change on Workers' Health and Safety [Internet]. Oxford University Press; 2019. Available from: https://doi.org/10.1093/acrefore/9780190632366.013.39

20. Coates L, Haynes K, O'Brien J, McAneney J, Oliveira FD de. Exploring 167 years of vulnerability: An examination of extreme heat events in Australia 1844 2010. Environmental Science & Policy [Internet]. 2014;42:33 44. Available from: https://www.sciencedirect.com/science/article/pii/S1462901114000999

21. Lundgren K, Kuklane K, Gao C, Holmer I. Effects of heat stress on working populations when facing climate change. Industrial Health [Internet]. 2013;51(1):3 15. Available from: https://doi.org/10.2486/indhealth.2012-0089

22. Australian Government Bureau of Meteorology. About Air Temperature Data [Internet]. Australia: BoM; 2011. Available from: http://www.bom.gov.au/climate/cdo/about/about-airtemp-data.shtml

23. Kjellstrom T, Briggs D, Freyberg C, Lemke B, Otto M, Hyatt O. Heat, human performance, and occupational health: a key issue for the Assessment of global climate change impacts. Annual Review of Public Health [Internet]. 2016;37(1):97 112. Available from: https://dx.doi.org/10.1146/annurev-publhealth-032315-021740

24. Safe Work Australia. Confined spaces [Internet]. 2014. Available from: https://www.safeworkaustralia.gov.au/system/files/documents/1705/mcop-confined-spaces-v2.pdf

25. Naghavi ZK, Mortazavi SB, Asilian HN, Hajizadeh E. Exploring the Contributory Factors of Confined Space Accidents Using Accident Investigation Reports and Semistructured Interviews. Safety and Health at Work [Internet]. 2019;10(3):305 13. Available from: https://doi.org/10.1016/j.shaw.2019.06.007

26. Flouris AD, Dinas PC, Ioannou LG, Nybo L, Havenith G, Kenny GP, et al. Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis. Lancet Planet Health [Internet]. 2018;2(12):e521 31. Available from: https://doi.org/10.1016/S2542-5196(18)30237-7

27. Holt M, Powell S. Health and well-being in small and medium-sized enterprises (SMEs). What public health support do SMEs really need? Perspectives in Public Health [Internet]. 2015;135(1):49 55. Available from: https://doi.org/10.1177/1757913914521157

28. Binazzi A, Levi M, Bonafede M, Bugani M, Messeri A, Morabito M, et al. Evaluation of the impact of heat stress on the occurrence of occupational injuries: Meta-analysis of observational studies. Am J Ind Med [Internet]. 2019;62(3):233 43. Available from: `https://doi.org/10.1002/ajim.22946`

29. Fatima SH, Rothmore P, Giles LC, Bi P. Outdoor ambient temperatures and occupational injuries and illnesses: Are there risk differences in various regions within a city? Science of The Total Environment [Internet]. 2022;826:153945. Available from: `https://dx.doi.org/10.1016/j.scitotenv.2022.153945`

30. Milton DK, Glencross PM, Walters MD. Risk of sick leave associated with outdoor air supply rate, humidification, and occupant complaints. Indoor Air [Internet]. 2000;10(4):212 21. Available from: `https://doi.org/10.1034/j.1600-0668.2000.010004212.x`

31. Martínez-Solanas È, López-Ruiz M, Wellenius GA, Gasparrini A, Sunyer J, Benavides FG, et al. Evaluation of the impact of ambient temperatures on occupational injuries in Spain. Environmental Health Perspectives [Internet]. 2018;126(06):067002. Available from: `https://dx.doi.org/10.1289/ehp2590`

32. Zander KK, Botzen WJW, Oppermann E, Kjellstrom T, Garnett ST. Heat stress causes substantial labour productivity loss in Australia. Nature Climate Change [Internet]. 2015;5(7):647 51. Available from: `https://dx.doi.org/10.1038/nclimate2623`

33. Cheung SS, Lee JKW, Oksa J. Thermal stress, human performance, and physical employment standards. Applied Physiology, Nutrition, and Metabolism [Internet]. 2016;41(6):S148 64. Available from: `https://dx.doi.org/10.1139/apnm-2015-0518`

34. Dunne JP, Stouffer RJ, John JG. Reductions in labour capacity from heat stress under climate warming. Nature Climate Change [Internet]. 2013;3(6):563 6. Available from: `https://dx.doi.org/10.1038/nclimate1827`

35. Kjellstrom, Tord and Otto, Matthias and Lemke, Bruno and Hyatt, Olivia and Briggs, Dave and Freyberg, Chris and Lines, Lauren. Climate change and labor: impacts of heat in the workplace [Internet]. United Nations Development Programme; 2016. Available from: `https://www.undp.org/content/undp/en/home/librarypage/climate-and-disaster-resilience-/tackling-challenges-of-climate-change-and-workplace-heat-for-dev.html`

36. Fatima SH, Rothmore P, Giles LC, Varghese BM, Bi P. Extreme heat and occupational injuries in different climate zones: A systematic review and meta-analysis of epidemiological evidence. Environment International [Internet]. 2021;148:106384. Available from: `https://dx.doi.org/10.1016/j.envint.2021.106384`

37. Xiang J, Bi P, Pisaniello D, Hansen A, Sullivan T. Association between high temperature and work-related injuries in Adelaide, South Australia, 2001 2010. Occupational and Environmental Medicine [Internet]. 2014;71(4):246 52. Available from: `https://dx.doi.org/10.1136/oemed-2013-101584`

38. Poulianiti KP, Havenith G, Flouris AD. Metabolic energy cost of workers in agriculture, construction, manufacturing, tourism, and transportation industries. Industrial Health [Internet]. 2019;57(3):283 305. Available from: `https://dx.doi.org/10.2486/indhealth.2018-0075`

39. Varghese BM, Barnett AG, Hansen AL, Bi P, Hanson-Easey S, Heyworth JS, et al. The effects of ambient temperatures on the risk of work-related injuries and illnesses: Evidence from Adelaide, Australia 2003-2013. Environmental Research [Internet]. 2019;170:101 9. Available from: `https://doi.org/10.1016/j.envres.2018.12.024`

40. Varghese BM, Barnett AG, Hansen AL, Bi P, Heyworth JS, Sim MR, et al. Geographical variation in risk of work-related injuries and illnesses associated with ambient temperatures: A multi-city case-crossover study in Australia, 2005-2016. Science of The Total Environment [Internet]. 2019;687:898 906. Available from: `https://doi.org/10.1016/j.scitotenv.2019.06.098`

41. Lemke B, Kjellstrom T. Calculating Workplace WBGT from Meteorological Data: A Tool for Climate Change Assessment. Industrial Health [Internet]. 2012;50(4):267 78. Available from: `https://dx.doi.org/10.2486/indhealth.ms1352`

42. Wondmagegn BY, Xiang J, Williams S, Pisaniello D, Bi P. What do we know about the healthcare costs of extreme heat exposure? A comprehensive literature review. Science of The Total Environment [Internet]. 2019;657:608 18. Available from: `https://doi.org/10.1016/j.scitotenv.2018.11.479`

43. Pandit A. Health Economic Evaluation-Methods and Techniques. IOSR Journal of Economics and Finance [Internet]. 2016;7(1):1 9. Available from: `https://www.iosrjournals.org/iosr-jef/papers/Vol7-Issue1/Version-2/A07120109.pdf`

44. Australian Institute of Health and Welfare. Disease expenditure in Australia 2018-19 [Internet]. Canberra: Australia; 2021. Available from: `https://www.aihw.gov.au/reports/health-welfare-expenditure/disease-expenditure-australia/contents/australian-burden-of-disease-groups`

45. Forbes MP, Abelson P, Driscoll T. Valuing the mortality and morbidity of work related injury and illness: a life cycle costing of incidents reported in NSW in 2000-2001 [Internet]. Sydney, Australia: NSW Injury Risk Management Research Centre, The University of New South Wales; 2006. Available from: `http://www.irmrc.unsw.edu.au/documents/IRMRC%20Work%20Cover%20Report%20Sept06.pdf`

46. McCarthy RB, Shofer FS, Green-McKenzie J. Outcomes of a heat stress awareness program on heat-related Illness in municipal outdoor workers. Journal of Occupational and Environmental Medicine [Internet]. 2019;61(9):724 8. Available from: `https://doi.org/10.1097/JOM.0000000000001639`

47. Borg MA, Xiang J, Anikeeva O, Pisaniello D, Hansen A, Zander K, et al. Occupational heat stress and economic burden: A review of global evidence. Environmental Research [Internet]. 2021;195:110781. Available from: `https://doi.org/10.1016/j.envres.2021.110781`

48. Zhang Y, Shindell DT. Costs from labor losses due to extreme heat in the USA attributable to climate change. Climatic Change [Internet]. 2021;164(3-4). Available from: `https://dx.doi.org/10.1007/s10584-021-03014-2`

49. Graff Zivin J, Neidell M. Temperature and the Allocation of Time: Implications for Climate Change. Journal of Labor Economics [Internet]. 2014;32(1):1 26. Available from: `http://dx.doi.org/10.1086/671766`

50. Kjellstrom T, Freyberg C, Lemke B, Otto M, Briggs D. Estimating population heat exposure and impacts on working people in conjunction with climate change. Int J Biometeorol [Internet]. 2018;62(3):291 306. Available from: `https://doi.org/10.1007/s00484-017-1407-0`

51. Neidell M, Graff Zivin J, Sheahan M, Willwerth J, Fant C, Sarofim M, et al. Temperature and work: Time allocated to work under varying climate and labor market conditions. PLOS ONE [Internet]. 2021;16(8):e0254224. Available from: `https://dx.doi.org/10.1371/journal.pone.0254224`

52. Oliveira J, Palialol B, Pereda P. Do temperature shocks affect non-agriculture wages in Brazil? Evidence from individual-level panel data. Environment and Development Economics [Internet]. 2021;1 16. Available from: `https://dx.doi.org/10.1017/s1355770x21000073`

53. Parsons LA, Shindell D, Tigchelaar M, Zhang Y, Spector JT. Increased labor losses and decreased adaptation potential in a warmer world. Nature Communications [Internet]. 2021;12(1). Available from: `https://dx.doi.org/10.1038/s41467-021-27328-y`

54. Australian Bureau of Statistics. Australian Industry [Internet]. Canberra, Australia; 2022. Available from: https://www.abs.gov.au/statistics/industry/industry-overview/australian-industry/latest-release

55. Australian Bureau of Statistics. Labour Force, Australia, Detailed, Mar 2022 [Internet]. Canberra, Australia; 2022. Available from: https://www.abs.gov.au/statistics/labour/employment-and-unemployment/labour-force-australia-detailed/mar-2022

56. Beck HE, Zimmermann NE, McVicar TR, Vergopolan N, Berg A, Wood EF. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific Data [Internet]. 2018;5(1):180214. Available from: https://dx.doi.org/10.1038/sdata.2018.214

57. Google. Australian capital cities [Internet]. n.d. Available from: https://www.google.com/maps

58. Australian Bureau of Statistics. Australian Statistical Geography Standard (ASGS): Volume 1 - Main Structure and Greater Capital City Statistical Areas, July 2016, cat. no. 1270.0.55.001 [Internet]. Canberra, Australia; 2016. Available from: https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/1270.0.55.001July%202016?OpenDocument

59. Australian Bureau of Statistics. Australian Statistical Geography Standard (ASGS): Volume 3 - Non ABS Structures, June 2020, cat. no. 1270.0.55.003 [Internet]. Canberra, Australia; 2020. Available from: https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/1270.0.55.003June%202020?OpenDocument

60. Safe Work Australia. Workers' compensation [Internet]. Canberra, Australia; 2022. Available from: https://www.safeworkaustralia.gov.au/workers-compensation

61. Lane, Tyler and Collie, Alex and Hassani-Mahmooei, Behrooz. Work-related injury and illness in Australia, 2004 to 2014 [Internet]. 2016. Report No.: 118-0616-R02. Available from: https://research.iscrr.com.au/__data/assets/pdf_file/0020/540830/work-related-injury-illness-in-Australia-20042014.pdf

62. Gray SE, Lane TJ, Sheehan L, Collie A. Association between workers' compensation claim processing times and work disability duration: Analysis of population level claims data. Health Policy [Internet]. 2019;123(10):982 91. Available from: https://dx.doi.org/10.1016/j.healthpol.2019.06.010

63. Safe Work Australia. Comparison of workers' compensation arrangements in Australia and New Zealand (2021) [Internet]. 2022. Available from: https://www.safeworkaustralia.gov.au/sites/default/files/2022-08/comparison_of_workers_compensation_arrangements_in_australia_and_new_zealand_2021_swa.pdf

64. Safe Work Australia. National data set for compensation-based statistics 3rd edition [Internet]. Canberra, Australia; 2019. Available from: https://www.safeworkaustralia.gov.au/doc/national-data-set-compensation-based-statistics-3rd-edition

65. Safe Work Australia. Comparison of workers' compensation arrangements in Australia and New Zealand [Internet]. 2019. Available from: https://www.safeworkaustralia.gov.au/system/files/documents/2001/comparison-report-2019.pdf

66. Safe Work Australia. Workers' compensation premiums [Internet]. 2021. Available from: https://www.safeworkaustralia.gov.au/doc/workers-compensation-premiums

67. Return to WorkSA. Your premium explained [Internet]. Adelaide, Australia; 2022. Available from: https://www.rtwsa.com/insurance/insurance-with-us/premium-calculations/your-premium-explained

68. South Australian Current Acts. Return to Work Act 2014 - Sect 64 [Internet]. South Australia; 2014. Available from: http://www8.austlii.edu.au/cgi-bin/viewdoc/au/legis/sa/consol_act/rtwa2014207/s64.html

69. Return to WorkSA. ReturnToWorkSA Annual Report 2015-16 [Internet]. 2017. Available from: https://www.rtwsa.com/__data/assets/pdf_file/0006/104829/Annual-report-2015-16.pdf

70. NT WorkSafe. Changes to the Return to Work Legislation 2015 [Internet]. Darwin, Australia: Northern Territory Government of Australia,; 2022. Available from: https://worksafe.nt.gov.au/laws-and-compliance/workers-compensation-laws/changes-to-the-workers-compensation-legislation

71. Gray SE, Lane TJ, Hassani-Mahmooei B, Collie A. Evaluating the success of legislative amendments designed to reduce work disability. Policy Design and Practice [Internet]. 2019;2(3):291 304. Available from: https://dx.doi.org/10.1080/25741292.2019.1610147

72. Collie A, Lane TJ, Hassani-Mahmooei B, Thompson J, McLeod C. Does time off work after injury vary by jurisdiction? A comparative study of eight Australian workers' compensation systems. BMJ Open [Internet]. 2016;6(5):e010910. Available from: http://dx.doi.org/10.1136/bmjopen-2015-010910

73. Lefebvre, Marnina and Cavanough, Edward and Buckland, Michael. It's broken: workers' compensation in NSW since 2012 [Internet]. The McKell Institute; 2022. Available from: https://mckellinstitute.org.au/wp-content/uploads/2022/07/McKell_Workers-Comp_final.pdf

74. Markey, Ray and Holley, Sasha and O'Neill, Sharron and Thornthwaite, Louise. The impact of injured workers of changes to NSW workers' compensation [Internet]. Macquarie University; 2013. Available from: https://www.mq.edu.au/__data/assets/pdf_file/0011/76637/1_Dec_The_Impact_on_Injured_Workers_of_Changes_to_NSW_Workers_.pdf

75. Safe Work Australia. Comparative Performance Monitoring Report [Internet]. Institution; 2021. Available from: https://www.safeworkaustralia.gov.au/sites/default/files/2021-11/CPM%2023%20-%20Entitlements.PDF

76. Jakob D, Su CH, Eizenberg N, Kociuba G, Steinle P, Fox-Hughes P, et al. An atmospheric high-resolution regional reanalysis for Australia. The Bulletin of the Australian Meteorological and Oceanographic Society. 2017;30(3):16 23.

77. World Meteorological Organization. Guide to Climatological Practices WMO-No. 100, [Internet]. 2018. Available from: https://library.wmo.int/doc_num.php?explnum_id=5541

78. National Weather Service. Climate Normals 1991-2020 [Internet]. 2021. Available from: https://www.weather.gov/rah/ClimateNormals1991-2020

79. Nairn JR, Fawcett RJ. The excess heat factor: a metric for heatwave intensity and its use in classifying heatwave severity. International Journal of Environmental Research and Public Health [Internet]. 2014;12(1):227 53. Available from: https://doi.org/10.3390/ijerph120100227

80. Australian Government Bureau of Meteorology. Weather Station Directory [Internet]. Australia; 2022. Available from: http://www.bom.gov.au/climate/data/stations/

81. Spokas K, Forcella F. Estimating Hourly Incoming Solar Radiation from Limited Meteorological Data. Weed Science [Internet]. 2006;54(1):182 9. Available from: https://doi.org/10.1614/WS-05-098R.1

82. Colston JM, Ahmed T, Mahopo C, Kang G, Kosek M, De Sousa Junior F, et al. Evaluating meteorological data from weather stations, and from satellites and global models for a multi-site epidemiological study. Environmental Research [Internet]. 2018;165:91 109. Available from: https://dx.doi.org/10.1016/j.envres.2018.02.027

83. Steadman RG. Norms of apparent temperature in Australia. Australian Meteorological Magazine [Internet]. 1994;43:1 16. Available from: http://www.bom.gov.au/jshess/docs/1994/steadman.pdf

84. Commonwealth Scientific and Industrial Research Organisation. Download “NRM” datasets [Internet]. 2021. Available from: https://www.climatechangeinaustralia.gov.au/en/obtain-data/download-datasets/

85. Commonwealth Scientific and Industrial Research Organisation. Eight-model sub-set for application-ready data [Internet]. 2021. Available from: https://www.climatechangeinaustralia.gov.au/en/obtain-data/application-ready-data/eight-climate-models-data/

86. Inter-Sectoral Impact Model Intercomparison Project. The Inter-Sectoral Impact Model Intercomparison Project [Internet]. Potsdam, Germany; 2022. Available from: https://www.isimip.org/

87. SILO. High Resolution Projections Data [Internet]. Brisbane, Australia: The Long Paddock Queensland Government; 2022. Available from: https://www.longpaddock.qld.gov.au/qld-future-climate/data-info/tern/

88. Australian Bureau of Statistics. Projected population, components of change and summary statistics - Australia, state/territory, greater capital city and rest of state, 2017 (base) to 2066, data cube: Excel spreadsheet, cat. no. 3222.0. [Internet]. Canberra, Australia; 2018. Available from: https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3222.02017%20(base)%20-%202066?OpenDocument

89. Ma R, Zhong S, Morabito M, Hajat S, Xu Z, He Y, et al. Estimation of work-related injury and economic burden attributable to heat stress in Guangzhou, China. Science of The Total Environment [Internet]. 2019;666:147 54. Available from: https://dx.doi.org/10.1016/j.scitotenv.2019.02.201

90. Wondmagegn BY, Xiang J, Dear K, Williams S, Hansen A, Pisaniello D, et al. Impact of heatwave intensity using Excess Heat Factor on emergency department presentations and related healthcare costs in Adelaide, South Australia. Science of The Total Environment [Internet]. 2021;781:146815. Available from: https://dx.doi.org/10.1016/j.scitotenv.2021.146815

91. Wondmagegn BY, Xiang J, Dear K, Williams S, Hansen A, Pisaniello D, et al. Increasing Impacts of Temperature on Hospital Admissions, Length of Stay, and Related Healthcare Costs in the Context of Climate Change in Adelaide, South Australia. Science of The Total Environment [Internet]. 2021;145656. Available from: https://dx.doi.org/10.1016/j.scitotenv.2021.145656

92. Tong MX, Wondmagegn BY, Williams S, Hansen A, Dear K, Pisaniello D, et al. Hospital healthcare costs attributable to heat and future estimations in the context of climate change in Perth, Western Australia. Advances in Climate Change Research [Internet]. 2021; Available from: `https://dx.doi.org/10.1016/j.accre.2021.07.008`

93. Tong M, Wondmagegn BY, Xiang J, Williams S, Hansen A, Dear K, et al. Heat-attributable hospitalisation costs in Sydney: Current estimations and future projections in the context of climate change. Urban Climate [Internet]. 2021;40:101028. Available from: `https://doi.org/10.1016/j.uclim.2021.101028`

94. Tong M, Wondmagegn B, Xiang J, Hansen A, Dear K, Pisaniello D, et al. Hospitalization Costs of Respiratory Diseases Attributable to Temperature in Australia and Projections for Future Costs in the 2030s and 2050s under Climate Change. International Journal of Environmental Research and Public Health [Internet]. 2022;19(15):9706. Available from: `https://dx.doi.org/10.3390/ijerph19159706`

95. Gasparrini A, Armstrong B, Kenward MG. Distributed lag non-linear models. Statistics in Medicine [Internet]. 2010;29(21):2224 34. Available from: `https://dx.doi.org/10.1002/sim.3940`

96. Bhaskaran K, Gasparrini A, Hajat S, Smeeth L, Armstrong B. Time series regression studies in environmental epidemiology. International Journal of Epidemiology [Internet]. 2013;42(4):1187 95. Available from: `https://doi.org/10.1093/ije/dyt092`

97. Imai C, Armstrong B, Chalabi Z, Mangtani P, Hashizume M. Time series regression model for infectious disease and weather. Environmental Research [Internet]. 2015;142:319 27. Available from: `https://doi.org/10.1016/j.envres.2015.06.040`

98. Maclure M. The Case-Crossover Design: A Method for Studying Transient Effects on the Risk of Acute Events. American Journal of Epidemiology [Internet]. 1991;133(2):144 53. Available from: `https://dx.doi.org/10.1093/oxfordjournals.aje.a115853`

99. Perrakis K, Gryparis A, Schwartz J, Tertre AL, Katsouyanni K, Forastiere F, et al. Controlling for seasonal patterns and time varying confounders in time-series epidemiological models: a simulation study. Statistics in Medicine [Internet]. 2014;33(28):4904 18. Available from: `https://doi.org/10.1002/sim.6271`

100. Guo Y, Barnett AG, Zhang Y, Tong S, Yu W, Pan X. The short-term effect of air pollution on cardiovascular mortality in Tianjin, China: Comparison of time series and case crossover analyses. Science of The Total Environment [Internet]. 2010;409(2):300 6. Available from: `https://dx.doi.org/10.1016/j.scitotenv.2010.10.013`

101. Adam-Poupart A, Smargiassi A, Busque MA, Duguay P, Fournier M, Zayed J, et al. Effect of summer outdoor temperatures on work-related injuries in Quebec (Canada). Occupational and Environmental Medicine [Internet]. 2015;72(5):338 45. Available from: `http://dx.doi.org/10.1136/oemed-2014-102428`

102. Peng RD, Dominici F, Louis TA. Model choice in time series studies of air pollution and mortality. Journal of the Royal Statistical Society: Series A (Statistics in Society) [Internet]. 2006;169(2):179 203. Available from: `https://dx.doi.org/10.1111/j.1467-985x.2006.00410.x`

103. Gasparrini A, Armstrong B, Kenward MG. Multivariate meta-analysis for non-linear and other multi-parameter associations. Statistics in Medicine [Internet]. 2012;31(29):3821 39. Available from: `https://dx.doi.org/10.1002/sim.5471`

104. Sera F, Armstrong B, Blangiardo M, Gasparrini A. An extended mixed-effects framework for metaanalysis. Statistics in Medicine [Internet]. 2019;38(29):5429 44. Available from: `https://dx.doi.org/10.1002/sim.8362`

105. Aert RCM, Schmid CH, Svensson D, Jackson D. Study specific prediction intervals for randomeffects metaanalysis: A tutorial. Research Synthesis Methods [Internet]. 2021;12(4):429 47. Available from: `https://dx.doi.org/10.1002/jrsm.1490`

106. Campbell H. The consequences of checking for zeroinflation and overdispersion in the analysis of count data. Methods in Ecology and Evolution [Internet]. 2021;12(4):665 80. Available from: `https://dx.doi.org/10.1111/2041-210x.13559`

107. Kurz CF. Tweedie distributions for fitting semicontinuous health care utilization cost data. BMC Medical Research Methodology [Internet]. 2017;17(1). Available from: `https://dx.doi.org/10.1186/s12874-017-0445-y`

108. Smyth GK, Jørgensen B. Fitting Tweedie's Compound Poisson Model to Insurance Claims Data: Dispersion Modelling. ASTIN Bulletin [Internet]. 2002;32(1):143 57. Available from: `https://dx.doi.org/10.2143/ast.32.1.1020`

109. Bonat WH, Kokonendji CC. Flexible Tweedie regression models for continuous data. Journal of Statistical Computation and Simulation [Internet]. 2017;87(11):2138 52. Available from: `https://dx.doi.org/10.1080/00949655.2017.1318876`

110. Neelon B, O'Malley AJ. Two-Part Models for Zero-Modified Count and Semicontinuous Data. In Springer US; 2019. p. 695 716. Available from: `https://dx.doi.org/10.1007/978-1-4939-8715-3_39`

111. Bellego C, Benatia D, Pape LD. Dealing with Logs and Zeros in Regression Models. Working Papers [Internet]. 2022; Available from: https://dx.doi.org/10.48550/arxiv.2203.11820

112. Eisenberg T, Eisenberg T, Wells MT, Zhang M. Addressing the Zeros Problem: Regression Models for Outcomes with a Large Proportion of Zeros, with an Application to Trial Outcomes. Journal of Empirical Legal Studies [Internet]. 2015;12(1):161 86. Available from: https://dx.doi.org/10.1111/jels.12068

113. Delong L, Lindholm M, Wüthrich MV. Making Tweedie's compound Poisson model more accessible. European Actuarial Journal [Internet]. 2021;11(1):185 226. Available from: https://dx.doi.org/10.1007/s13385-021-00264-3

114. Foster SD, Bravington MV. A Poisson Gamma model for analysis of ecological non-negative continuous data. Environmental and Ecological Statistics [Internet]. 2013;20(4):533 52. Available from: https://dx.doi.org/10.1007/s10651-012-0233-0

115. Schisterman EF, Cole SR, Platt RW. Overadjustment Bias and Unnecessary Adjustment in Epidemiologic Studies. Epidemiology [Internet]. 2009;20(4):488 95. Available from: https://dx.doi.org/10.1097/ede.0b013e3181a819a1

116. Jain N. Towards Machine Learning: Alternative Methods for Insurance Pricing Poisson-Gamma GLM's, Tweedie GLM's and Artificial Neural Networks [Internet] [Thesis]. 2018. Available from: https://www.actuaries.org.uk/system/files/field/document/F7%20Navarun%20Jain.pdf

117. Amemiya T. Tobit models: A survey. Journal of Econometrics [Internet]. 1984;24(1):3 61. Available from: https://doi.org/10.1016/0304-4076(84)90074-5

118. Mihaylova B, Briggs A, O'Hagan A, Thompson SG. Review of statistical methods for analysing healthcare resources and costs. Health Economics [Internet]. 2011;20(8):897 916. Available from: https://dx.doi.org/10.1002/hec.1653

119. Wang Y, Liu Y, Ye D, Li N, Bi P, Tong S, et al. Temperatures and health costs of emergency department visits: A multisite time series study in China. Environmental Research [Internet]. 2021;197:111023. Available from: https://dx.doi.org/10.1016/j.envres.2021.111023

120. Dunn PK, Smyth GK. Series evaluation of Tweedie exponential dispersion model densities. Statistics and Computing [Internet]. 2005;15(4):267 80. Available from: https://dx.doi.org/10.1007/s11222-005-4070-y

121. Dunn PK, Smyth GK. Generalized linear models with examples in R [Internet]. New York: Springer; 2018. (Springer texts in statistics). Available from: https://doi.org/10.1007/978-1-4419-0118-7

122. Wood SN, Li Z, Shaddick G, Augustin NH. Generalized Additive Models for Gigadata: Modeling the U.K. Black Smoke Network Daily Data. Journal of the American Statistical Association [Internet]. 2017;112(519):1199 210. Available from: https://dx.doi.org/10.1080/01621459.2016.1195744

123. Wood SN, Pya N, Säfken B. Smoothing Parameter and Model Selection for General Smooth Models. Journal of the American Statistical Association [Internet]. 2016;111(516):1548 63. Available from: https://dx.doi.org/10.1080/01621459.2016.1180986

124. Wood SN. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. Journal of the Royal Statistical Society: Series B (Statistical Methodology) [Internet]. 2011;73(1):3 36. Available from: https://dx.doi.org/10.1111/j.1467-9868.2010.00749.x

125. Dunn PK. Tweedie: Evaluation of Tweedie exponential family models [Internet]. 2017. Available from: https://cran.r-project.org/web/packages/tweedie/index.html

126. Marinaccio A, Scortichini M, Gariazzo C, Leva A, Bonafede M, Donato FK de', et al. Nationwide epidemiological study for estimating the effect of extreme outdoor temperature on occupational injuries in Italy. Environment International [Internet]. 2019;133(Pt A):105176. Available from: https://doi.org/10.1016/j.envint.2019.105176

127. Bonafede M, Marinaccio A, Asta F, Schifano P, Michelozzi P, Vecchi S. The association between extreme weather conditions and work-related injuries and diseases. A systematic review of epidemiological studies. Ann Ist Super Sanita [Internet]. 2016;52(3):357 67. Available from: https://doi.org/10.4415/ann_16_03_07

128. Wu J, Hu Z, Han Z, Gu Y, Yang L, Sun B. Human physiological responses of exposure to extremely cold environments. Journal of Thermal Biology [Internet]. 2021;98:102933. Available from: https://doi.org/10.1016/j.jtherbio.2021.102933

129. Mäkinen TM, Hassi J. Health Problems in Cold Work. Industrial Health [Internet]. 2009;47(3):207 20. Available from: https://dx.doi.org/10.2486/indhealth.47.207

130. Xiang J, Hansen A, Pisaniello D, Dear K, Bi P. Correlates of occupational heat-induced illness costs: case study of South Australia 2000 to 2014. Journal of Occupational and Environmental Medicine [Internet]. 2018;60(9):e463 9. Available from: https://doi.org/10.1097/jom.0000000000001395

131. Australian Bureau of Statistics. Census TableBuilder Basic [Internet]. Canberra, Australia; 2017. Available from: https://tablebuilder.abs.gov.au/webapi/jsf/login.xhtml

132. Australian Bureau of Statistics. Australian and New Zealand Standard Classification of Occupations, 2013, Version 1.3, cat. no. 1220.0 [Internet]. Canberra, Australia; 2019. Available from: https://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/1220.0

133. Statistics Canada. National Occupational Classification (NOC) 2016 Version 1.3 [Internet]. Canada; 2019. Available from: https://www.statcan.gc.ca/eng/subjects/standard/noc/2016/indexV1.3

134. Smith, Peter M. Comparing Imputed Occupational Exposure Classifications With Self-reported Occupational Hazards Among Australian Workers. 2013.

135. McInnes JA, Akram M, MacFarlane EM, Keegel T, Sim MR, Smith P. Association between high ambient temperature and acute work-related injury: a case-crossover analysis using workers' compensation claims data. Scand J Work Environ Health [Internet]. 2017;43(1):86 94. Available from: https://doi.org/10.5271/sjweh.3602

136. McInnes JA, MacFarlane EM, Sim MR, Smith P. The impact of sustained hot weather on risk of acute work-related injury in Melbourne, Australia. Int J Biometeorol [Internet]. 2018;62(2):153 63. Available from: https://doi.org/10.1007/s00484-017-1435-9

137. International Labour Organization. Welcome to the ISCO website [Internet]. Geneva, Switzerland; 2010. Available from: https://www.ilo.org/public/english/bureau/stat/isco/index.htm

138. Xiang J, Hansen A, Pisaniello D, Bi P. Workers' perceptions of climate change related extreme heat exposure in South Australia: a cross-sectional survey. BMC Public Health [Internet]. 2016;16:549. Available from: https://doi.org/10.1186/s12889-016-3241-4

139. Gray SE, Collie A. The nature and burden of occupational injury among first responder occupations: A retrospective cohort study in Australian workers. Injury [Internet]. 2017;48(11):2470 7. Available from: https://doi.org/10.1016/j.injury.2017.09.019

140. Newnam S, Xia T, Koppel S, Collie A. Work-related injury and illness among older truck drivers in Australia: A population based, retrospective cohort study. Safety Science [Internet]. 2019;112:189 95. Available from: https://doi.org/10.1016/j.ssci.2018.10.028

141. Australian Safety and Compensation Council. Type of Occurrence Classification System [Internet]. Institution; 2009. Available from: https://www.safeworkaustralia.gov.au/doc/type-occurrence-classification-system-toocs-3rd-edition-may-2008

142. Australian Bureau of Statistics. Consumer Price Index, Australia [Internet]. Canberra, Australia; 2021. Available from: https://www.abs.gov.au/statistics/economy/price-indexes-and-inflation/consumer-price-index-australia/latest-release

143. Su CH, Eizenberg N, Steinle P, Jakob D, Fox-Hughes P, White CJ, et al. BARRA v1.0: the Bureau of Meteorology Atmospheric high-resolution Regional Reanalysis for Australia. Geoscientific Model Development [Internet]. 2019;12(5):2049 68. Available from: https://dx.doi.org/10.5194/gmd-12-2049-2019

144. Dally M, Butler-Dawson J, Sorensen CJ, Van Dyke M, James KA, Krisher L, et al. Wet Bulb Globe Temperature and Recorded Occupational Injury Rates among Sugarcane Harvesters in Southwest Guatemala. International Journal of Environmental Research and Public Health [Internet]. 2020;17(21):8195. Available from: https://dx.doi.org/10.3390/ijerph17218195

145. International Organization for Standardization. Ergonomics of the thermal environment assessment of heat stress using the WBGT (Wet Bulb Globe Temperature) index [Internet]. 2017. Available from: https://www.iso.org/obp/ui/#iso:std:iso:7243:ed-3:v1:en

146. Bernard TE, Pourmoghani M. Prediction of Workplace Wet Bulb Global Temperature. Applied Occupational and Environmental Hygiene [Internet]. 1999;14(2):126 34. Available from: https://dx.doi.org/10.1080/104732299303296

147. Liljegren JC, Carhart RA, Lawday P, Tschopp S, Sharp R. Modeling the wet bulb globe temperature using standard meteorological measurements. Journal of Occupational and Environmental Hygiene [Internet]. 2008;5(10):645 55. Available from: https://dx.doi.org/10.1080/15459620802310770

148. Rothfusz, L. The Heat Index "Equation" (or, More Than You Ever Wanted to Know About Heat Index) [Internet]. Scientific Services Division, National Weather Service; 1990. Available from: https://www.weather.gov/media/ffc/ta_htindx.PDF

149. Masterton J, Richardson F. Humidex: a method of quantifying human discomfort due to excessive heat and humidity. Downsview, Canada: Environment Canada, Atmospheric Environment Service; 1979.

150. data.gov.au. Australian Statistical Geography Standard (ASGS) geographic 2016 population weighted correspondences (2016) in .xls and .xlsx formats [Internet]. Canberra, Australia: Australian Government; 2017. Available from: `https://data.gov.au/data/dataset/asgs-geographic-correspondences-2016/resource/951e18c7-f187-4c86-a73f-fcabcd19af16?inner_span=True`

151. Gasparrini A. Distributed Lag Linear and Non-Linear Models in R: The Package dlnm. Journal of Statistical Software [Internet]. 2011;43(8):1 20. Available from: `https://dx.doi.org/10.18637/jss.v043.i08`

152. Borg M. School holidays in Australian capital cities from 2004 to 2023 [Internet]. The University of Adelaide; 2022. Available from: `https://adelaide.figshare.com/articles/dataset/School_holidays_in_Australian_capital_cities_from_2004_to_2023/20732173`

153. Australian Bureau of Statistics. https://www.abs.gov.au/articles/insights-hours-worked [Internet]. 2020. Available from: `https://www.abs.gov.au/articles/insights-hours-worked`

154. Borg M. Public holidays in Australian capital cities from 2004 to 2023 [Internet]. The University of Adelaide; 2022. Available from: `https://adelaide.figshare.com/articles/dataset/Public_holidays_in_Australian_capital_cities_from_2004_to_2023/20732449`

155. Gasparrini A, Guo Y, Hashizume M, Lavigne E, Zanobetti A, Schwartz J, et al. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. Lancet [Internet]. 2015;386(9991):369 75. Available from: `https://doi.org/10.1016/s0140-6736(14)62114-0`

156. Higgins JPT, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med [Internet]. 2002;21(11):1539 58. Available from: `https://doi.org/10.1002/sim.1186`

157. Gasparrini A, Leone M. Attributable risk from distributed lag models. BMC Medical Research Methodology [Internet]. 2014;14(1):55. Available from: `https://dx.doi.org/10.1186/1471-2288-14-55`

158. Team RC. R: A Language and Environment for Statistical Computing [Internet]. R Foundation for Statistical Computing; 2021. Available from: `https://www.R-project.org/`

159. Casanueva A. HeatStress, Zenodo: Calculate heat stress indices [Internet]. MeteoSwiss; 2019. Available from: `https://doi.org/10.5281/zenodo.3264930`

160. Lytras T. FluMoDL: Influenza-Attributable Mortality with Distributed-Lag Models [Internet]. 2019. Available from: https://CRAN.R-project.org/package=FluMoDL

161. Smyth GK. An Efficient Algorithm for REML in Heteroscedastic Regression. Journal of Computational and Graphical Statistics [Internet]. 2002;11(4):836 47. Available from: https://dx.doi.org/10.1198/106186002871

162. Shield KD, Parkin DM, Whiteman DC, Rehm J, Viallon V, Micallef CM, et al. Population Attributable and Preventable Fractions: Cancer Risk Factor Surveillance, and Cancer Policy Projection. Current Epidemiology Reports [Internet]. 2016;3(3):201 11. Available from: https://dx.doi.org/10.1007/s40471-016-0085-5

163. Australian Bureau of Statistics. Australian National Accounts: National Income, Expenditure and Product [Internet]. Canberra, Australia; 2019. Available from: https://www.abs.gov.au/statistics/economy/national-accounts/australian-national-accounts-national-income-expenditure-and-product/jun-2019

164. Farbu EH, Skandfer M, Nielsen C, Brenn T, Stubhaug A, Höper AC. Working in a cold environment, feeling cold at work and chronic pain: a cross-sectional analysis of the Tromsø Study. BMJ Open [Internet]. 2019;9(11):e031248. Available from: https://dx.doi.org/10.1136/bmjopen-2019-031248

165. Jay O, Capon A, Berry P, Broderick C, De Dear R, Havenith G, et al. Reducing the health effects of hot weather and heat extremes: from personal cooling strategies to green cities. The Lancet [Internet]. 2021;398(10301):709 24. Available from: https://dx.doi.org/10.1016/s0140-6736(21)01209-5

166. Australian Bureau of Statistics. Environmental Issues: Energy Use and Conservation, Mar 2014 [Internet]. Canberra, Australia; 2014. Available from: http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4602.0.55.001Mar%202014?OpenDocument

167. Australian Government Bureau of Meteorology. Climate classification maps [Internet]. Canberra, Australia; 2016. Available from: http://www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp?maptype=kpn#maps

168. Workplace Gender Equality Agency. Gender segregation in Australia's workforce [Internet]. Canberra, Australia: Australian Government,; 2019. Available from: https://www.wgea.gov.au/publications/gender-segregation-in-australias-workforce

169. Australian Institute of Health and Welfare. The health of Australia's females [Internet]. Canberra, Australia; 2019. Available from: `https://www.aihw.gov.au/reports/men-women/female-health/contents/how-does-the-health-of-females-and-males-compare`

170. Australian Institute of Health and Welfare. When musculoskeletal conditions and mental disorders occur together [Internet]. Canberra, Australia; 2010. Available from: `https://www.aihw.gov.au/getmedia/dc68198e-f447-40e8-90ed-b7b92266a0c6/11155.pdf.aspx?inline=true`

171. Australian Bureau of Statistics. Work-related injuries [Internet]. Canberra, Australia; 2018. Available from: `https://www.abs.gov.au/statistics/labour/earnings-and-working-conditions/work-related-injuries/latest-release#reported-work-related-injury-or-illness-to-someone-in-the-workplace`

172. Su, Chun-Hsu and Eizenberg, Nathan. Known issues in the BARRA datasets [Internet]. Bureau of Meteorology; 2019. Available from: `http://www.bom.gov.au/research/projects/reanalysis/Known_issues_in_BARRA_dataset_July_2019.pdf`

173. Australian Government Bureau of Meteorology. Thermal Comfort observations [Internet]. Australia; 2010. Available from: `http://www.bom.gov.au/info/thermal_stress/#refs`

174. Kong Q, Huber M. Explicit Calculations of WetBulb Globe Temperature Compared With Approximations and Why It Matters for Labor Productivity. Earth's Future [Internet]. 2022;10(3). Available from: `https://dx.doi.org/10.1029/2021ef002334`

175. Carleton TA, Hsiang SM. Social and economic impacts of climate. Science [Internet]. 2016;353(6304):aad9837. Available from: `https://www.science.org/doi/abs/10.1126/science.aad9837`

176. Ebi KL, Vanos J, Baldwin JW, Bell JE, Hondula DM, Errett NA, et al. Extreme Weather and Climate Change: Population Health and Health System Implications. Annual Review of Public Health [Internet]. 2021;42(1):293 315. Available from: `https://dx.doi.org/10.1146/annurev-publhealth-012420-105026`

177. Adélaïde L, Chanel O, Pascal M. Health effects from heat waves in France: an economic evaluation. The European Journal of Health Economics [Internet]. 2021; Available from: `https://doi.org/10.1007/s10198-021-01357-2`

178. Zhao M, Lee JKW, Kjellstrom T, Cai W. Assessment of the economic impact of heat-related labor productivity loss: a systematic review. Climatic Change [Internet]. 2021;167(1-2). Available from: `https://dx.doi.org/10.1007/s10584-021-03160-7`

179. Orlov A, Sillmann J, Aaheim A, Aunan K, Bruin K de. Economic Losses of Heat-Induced Reductions in Outdoor Worker Productivity: a Case Study of Europe. Economics of Disasters and Climate Change [Internet]. 2019;3(3):191 211. Available from: https://doi.org/10.1007/s41885-019-00044-0

180. García-León D, Casanueva A, Standardi G, Burgstall A, Flouris AD, Nybo L. Current and projected regional economic impacts of heatwaves in Europe. Nature Communications [Internet]. 2021;12(1). Available from: https://dx.doi.org/10.1038/s41467-021-26050-z

181. Adnan MSG, Dewan A, Botje D, Shahid S, Hassan QK. Vulnerability of Australia to heatwaves: A systematic review on influencing factors, impacts, and mitigation options. Environmental Research [Internet]. 2022;213:113703. Available from: https://doi.org/10.1016/j.envres.2022.113703

182. Bettio L, Nairn JR, McGibbony SC, Hope P, Tupper A, Fawcett RJB. A heatwave forecast service for Australia. Proceedings of the Royal Society of Victoria [Internet]. 2019;131(1). Available from: https://dx.doi.org/10.1071/rs19006

183. Borg M, Nitschke M, Williams S, McDonald S, Nairn J, Bi P. Using the excess heat factor to indicate heatwave-related urinary disease: a case study in Adelaide, South Australia. International Journal of Biometeorology [Internet]. 2019;63(4):435 47. Available from: https://doi.org/10.1007/s00484-019-01674-5

184. Nairn J, Ostendorf B, Bi P. Performance of Excess Heat Factor Severity as a Global Heatwave Health Impact Index. International Journal of Environmental Research and Public Health [Internet]. 2018;15(11):2494. Available from: https://dx.doi.org/10.3390/ijerph15112494

185. Varghese BM, Barnett AG, Hansen AL, Bi P, Nairn J, Rowett S, et al. Characterising the impact of heatwaves on work-related injuries and illnesses in three Australian cities using a standard heatwave definition- Excess Heat Factor (EHF). Journal of Exposure Science & Environmental Epidemiology [Internet]. 2019;29(6):821 30. Available from: https://dx.doi.org/10.1038/s41370-019-0138-1

186. Oliveira A, Lopes A, Soares A. Excess Heat Factor climatology, trends, and exposure across European Functional Urban Areas. Weather and Climate Extremes [Internet]. 2022;36:100455. Available from: https://doi.org/10.1016/j.wace.2022.100455

187. Nairn J, Moise A, Ostendorf B. The impact of humidity on Australia's operational heatwave services. Climate Services [Internet]. 2022;27:100315. Available from: https://doi.org/10.1016/j.cliser.2022.100315

188. Nairn, John and Fawcett, Robert and Ray, Darren. Defining and predicting Excessive Heat events, a National system. 2009.

189. Royé D, Codesido R, Tobías A, Taracido M. Heat wave intensity and daily mortality in four of the largest cities of Spain. Environmental Research [Internet]. 2020;182:109027. Available from: https://dx.doi.org/10.1016/j.envres.2019.109027

190. Gasparrini A, Armstrong B. The Impact of Heat Waves on Mortality. Epidemiology [Internet]. 2011;22(1):68 73. Available from: https://dx.doi.org/10.1097/ede.0b013e3181fdcd99

191. Vicedo-Cabrera AM, Sera F, Gasparrini A. Hands-on Tutorial on a Modeling Framework for Projections of Climate Change Impacts on Health. Epidemiology [Internet]. 2019;30(3):321 9. Available from: https://doi.org/10.1097/ede.0000000000000982

192. Gasparrini A, Guo Y, Sera F, Vicedo-Cabrera AM, Huber V, Tong S, et al. Projections of temperature-related excess mortality under climate change scenarios. The Lancet Planetary Health [Internet]. 2017;1(9):e360 7. Available from: https://dx.doi.org/10.1016/S2542-5196(17)30156-0

193. Rai M, Breitner S, Wolf K, Peters A, Schneider A, Chen K. Future temperature-related mortality considering physiological and socioeconomic adaptation: a modelling framework. The Lancet Planetary Health [Internet]. 2022;6(10):e784 92. Available from: https://dx.doi.org/10.1016/s2542-5196(22)00195-4

194. Notley SR, Park J, Tagami K, Ohnishi N, Taylor NAS. Variations in body morphology explain sex differences in thermoeffector function during compensable heat stress. Experimental Physiology [Internet]. 2017;102(5):545 62. Available from: https://doi.org/10.1113/EP086303

195. Notley SR, Dervis S, Poirier MP, Kenny GP. Menstrual cycle phase does not modulate whole body heat loss during exercise in hot, dry conditions. Journal of Applied Physiology [Internet]. 2019;126(2):286 93. Available from: https://dx.doi.org/10.1152/japplphysiol.00735.2018

196. Venugopal V, Rekha S, Manikandan K, Latha PK, Vennila V, Ganesan N, et al. Heat stress and inadequate sanitary facilities at workplaces an occupational health concern for women? Global Health Action [Internet]. 2016;9(1):31945. Available from: https://dx.doi.org/10.3402/gha.v9.31945

197. Safe Work Australia. Managing the risks of working in heat [Internet]. Available from: https://www.safeworkaustralia.gov.au/system/files/documents/1712/guide_for_managing_the_risks_of_working_in_heat_1.pdf

198. Australian Government Bureau of Meteorology. About the heatwave service [Internet]. Adelaide, Australia; 2022. Available from: http://www.bom.gov.au/australia/heatwave/knowledge-centre/heatwave-service.shtml

199. Steadman RG. A universal scale of apparent temperature. J Climate Appl Meteor [Internet]. 1984;23(12):1674 87. Available from: https://doi.org/10.1175/1520-0450(1984)023%3C1674:AUSOAT%3E2.0.CO;2

200. Schiller C, Winters M, Hanson HM, Ashe MC. A framework for stakeholder identification in concept mapping and health research: a novel process and its application to older adult mobility and the built environment. BMC Public Health [Internet]. 2013;13(1):428. Available from: https://dx.doi.org/10.1186/1471-2458-13-428

201. Hasan MM, Dunn PK. Understanding the effect of climatology on monthly rainfall amounts in Australia using Tweedie GLMs. International Journal of Climatology [Internet]. 2012;32(7):1006 17. Available from: https://dx.doi.org/10.1002/joc.2332

202. Lippel K. Workers describe the effect of the workers' compensation process on their health: A Québec study. International Journal of Law and Psychiatry [Internet]. 2007;30(4-5):427 43. Available from: https://dx.doi.org/10.1016/j.ijlp.2007.06.013

203. Fagan KM, Hodgson MJ. Under-recording of work-related injuries and illnesses: An OSHA priority. Journal of Safety Research [Internet]. 2017;60:79 83. Available from: https://doi.org/10.1016/j.jsr.2016.12.002

204. Rappin CL, Wuellner SE, Bonauto DK. Employer reasons for failing to report eligible workers' compensation claims in the BLS survey of occupational injuries and illnesses. American Journal of Industrial Medicine [Internet]. 2016;59(5):343 56. Available from: https://dx.doi.org/10.1002/ajim.22582

205. Collie A, Sheehan L, Lane TJ, Gray S, Grant G. Injured worker experiences of insurance claim processes and return to work: a national, cross-sectional study. BMC Public Health [Internet]. 2019;19(1). Available from: https://dx.doi.org/10.1186/s12889-019-7251-x

206. Grant GM, O'Donnell ML, Spittal MJ, Creamer M, Studdert DM. Relationship Between Stressfulness of Claiming for Injury Compensation and Long-term Recovery. JAMA Psychiatry [Internet]. 2014;71(4):446. Available from: https://dx.doi.org/10.1001/jamapsychiatry.2013.4023

207. Safe Work Australia. The Costs of Workplace Injury and Illness: 2012-13 [Internet]. 2015. Report No.: 1920763589. Available from: https://www.safeworkaustralia.gov.au/system/files/documents/1702/cost-of-work-related-injury-and-disease-2012-13.docx.pdf

208. Peterson C, Xu L, Florence C. Average medical cost of fatal and non-fatal injuries by type in the USA. Injury Prevention [Internet]. 2021;27(1):1.1 10. Available from: https://dx.doi.org/10.1136/injuryprev-2019-043544

209. Dettori JR, Norvell DC, Chapman JR. The Sin of Missing Data: Is All Forgiven by Way of Imputation? Global Spine Journal [Internet]. 2018;8(8):892 4. Available from: https://dx.doi.org/10.1177/2192568218811922

210. Liu Y, Zhou Y, Lu J. Exploring the relationship between air pollution and meteorological conditions in China under environmental governance. Scientific Reports [Internet]. 2020;10(1). Available from: https://dx.doi.org/10.1038/s41598-020-71338-7

211. Buckley JP, Samet JM, Richardson DB. Commentary: Does Air Pollution Confound Studies of Temperature? Epidemiology [Internet]. 2014;25(2). Available from: https://journals.lww.com/epidem/Fulltext/2014/03000/Commentary__Does_Air_Pollution_Confound_Studies_of.14.aspx

212. Hajat S, O'Connor M, Kosatsky T. Health effects of hot weather: from awareness of risk factors to effective health protection. The Lancet [Internet]. 2010;375(9717):856 63. Available from: https://dx.doi.org/10.1016/s0140-6736(09)61711-6

213. Jacklitsch, Brenda. and Williams, W. J. and Musolin, Kristin and Coca, A. and Kim, Jung-Hyun and Turner, N. and Cincinnati, OH. Criteria for a Recommended Standard Occupational Exposure to Heat and Hot Environments [Internet]. Institution; 2016. Available from: https://www.cdc.gov/niosh/docs/2016-106/pdfs/2016-106.pdf

214. Governmental Industrial Hygienists AC of. Heat Stress and Strain: TLVő Physical Agents 7th Edition Documentation [Internet]. Cincinnati, Ohio; 2017. Available from: http://mhssn.igc.org/2017%20ACGIH%20-%20Heat%20Stress%20TLV.pdf

215. Morrissey MC, Casa DJ, Brewer GJ, Adams WM, Hosokawa Y, Benjamin CL, et al. Heat Safety in the Workplace: Modified Delphi Consensus to Establish Strategies and Resources to Protect U.S Workers. GeoHealth [Internet]. 2021;5(8):e2021GH000443. Available from: https://dx.doi.org/10.1029/2021gh000443

216. Varghese BM, Hansen AL, Williams S, Bi P, Hanson-Easey S, Barnett AG, et al. Determinants of heat-related injuries in Australian workplaces: Perceptions of health and safety professionals. Science of The Total Environment [Internet]. 2020;718:137138. Available from: https://dx.doi.org/10.1016/j.scitotenv.2020.137138

217. Zuo J, Pullen S, Palmer J, Bennetts H, Chileshe N, Ma T. Impacts of heat waves and corresponding measures: a review. Journal of Cleaner Production [Internet]. 2015;92:1 12. Available from: `http://dx.doi.org/10.1016/j.jclepro.2014.12.078`

218. Australian Government. Work health and safety [Internet]. Canberra, Australia; 2022. Available from: `https://business.gov.au/risk-management/health-and-safety/work-health-and-safety`

219. Hudson J, Fielding S, Ramsay CR. Methodology and reporting characteristics of studies using interrupted time series design in healthcare. BMC Medical Research Methodology [Internet]. 2019;19(1). Available from: `https://dx.doi.org/10.1186/s12874-019-0777-x`

220. AECOM. Economic Assessment of the Urban Heat Island Effect [Internet]. 2012. Available from: `https://www.melbourne.vic.gov.au/SiteCollectionDocuments/eco-assessment-of-urban-heat-island-effect.pdf`

221. Morris NB, Jay O, Flouris AD, Casanueva A, Gao C, Foster J, et al. Sustainable solutions to mitigate occupational heat strain an umbrella review of physiological effects and global health perspectives. Environmental Health [Internet]. 2020;19(1). Available from: `https://dx.doi.org/10.1186/s12940-020-00641-7`

222. Stratil J, Rieger MA, Voelter-Mahlknecht S. Optimizing cooperation between general practitioners, occupational health and rehabilitation physicians in Germany: a qualitative study. International Archives of Occupational and Environmental Health [Internet]. 2017;90(8):809 21. Available from: `https://dx.doi.org/10.1007/s00420-017-1239-6`

223. Williams S, Varghese BM, Hansen AL, Hanson-Easey SA, Bi P, Pisaniello DL. Workers' health and safety in the heat: current practice in Australian workplaces. Policy and Practice in Health and Safety [Internet]. 2020;18(2):67 79. Available from: `https://dx.doi.org/10.1080/14773996.2020.1765610`

224. Lim SS, Yoon JH, Rhie J, Bae S, Kim J, Won JU. The Relationship between Free Press and Under-Reporting of Non-Fatal Occupational Injuries with Data from Representative National Indicators, 2015: Focusing on the Lethality Rate of Occupational Injuries among 39 Countries. International Journal of Environmental Research and Public Health [Internet]. 2018;15(12):2856. Available from: `https://dx.doi.org/10.3390/ijerph15122856`

225. Nitschke M, Tucker G, Hansen A, Williams S, Zhang Y, Bi P. Evaluation of a heat warning system in Adelaide, South Australia, using case-series analysis. BMJ Open [Internet]. 2016;6(7):e012125. Available from: `https://doi.org/10.1136/bmjopen-2016-012125`

226. Williams S, Nitschke M, Wondmagegn BY, Tong M, Xiang J, Hansen A, et al. Evaluating cost benefits from a heat health warning system in Adelaide, South Australia. Australian and New Zealand Journal of Public Health [Internet]. 2021; Available from: `https://dx.doi.org/10.1111/1753-6405.13194`

227. McInnes JA, Clapperton AJ, Day LM, Macfarlane EM, Sim MR, Smith P. Comparison of data sets for surveillance of work-related injury in Victoria, Australia. Occupational and Environmental Medicine [Internet]. 2014;71(11):780 7. Available from: `https://dx.doi.org/10.1136/oemed-2014-102243`

228. Mustard CA, Chambers A, McLeod C, Bielecky A, Smith PM. Comparison of data sources for the surveillance of work injury. Occupational and Environmental Medicine [Internet]. 2012;69(5):317 24. Available from: `https://dx.doi.org/10.1136/oemed-2011-100222`

229. Wallace JM, Hobbs PV. Atmospheric Science: An Introductory Survey [Internet]. 2nd ed. University of Washington: Academic New York; 2006. (International geophysics series; vol. 92). Available from: `ftp://ftp.aoml.noaa.gov/phod/pub/wang/TCs_References/Atmospheric_Science.pdf`

230. Buck Research Instruments, LCC. Model CR-1A hygrometer with autofill operating manual [Internet]. 2012. Available from: `http://www.hygrometers.com/wp-content/uploads/CR-1A-users-manual-2009-12.pdf`

231. National Weather Service. The Heat Index Equation [Internet]. Maryland, USA: National Oceanic and Atmospheric Administration,; 2014. Available from: `https://www.wpc.ncep.noaa.gov/html/heatindex_equation.shtml`

232. Burke M, Sipe N, Evans R, Mellifont D. Climate, geography and the propensity to walk: environmental factors and walking trip rates in Brisbane [Internet]. 2006. Available from: `http://hdl.handle.net/10072/13325`