PROGETTO WORKLIMATE

Impatto dello stress termico ambientale sulla salute e produttività dei lavoratori: strategie di intervento e sviluppo di un sistema integrato di allerta meteo-climatica ed epidemiologica per vari ambiti occupazionali

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OBIETTIVO SPECIFICO 1

Analisi epidemiologica per la stima dei costi sociali degli infortuni sul lavoro correlati a temperature estreme.

REPORT Attività 1:

Stima dei costi sociali dell'esposizione occupazionale a temperature estreme

REPORT A1.1 Revisione della letteratura sulla stima dei costi sociali degli infortuni sul lavoro correlati a temperature estreme.

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Introduzione

I lavoratori che svolgono mansioni all'aperto, e quelli che lavorano in ambienti interni molto caldi (forni industriali, acciaierie, raffinerie, vetrerie, etc.) rappresentano un sottogruppo di popolazione suscettibile agli effetti del caldo.

Il caldo provoca effetti avversi sulla salute nel momento in cui viene superata la naturale capacità fisiologica di termoregolazione dell'organismo (Linee Guida Ministero Salute Caldo e Inquinamento atmosferico). L'incremento di temperatura può provocare effetti acuti come disidratazione, lipotimia da caldo, stress da calore e colpo di calore, soprattutto nei lavoratori non acclimatati, che svolgono mansioni pesanti e con abbigliamento pesante (es. DPI) e in assenza di adeguate misure protettive (pause in luoghi rinfrescati, idratazione frequente, etc).

Il caldo può anche provocare eventi acuti cardio- e cerebro-vascolari attraverso un aumento della viscosità del sangue, del colesterolo plasmatico e delle piastrine, aggravamenti delle patologie croniche, come la broncopneumopatia cronica ostruttiva. Inoltre, nei lavoratori esposti in maniera cronica al caldo, possono inoltre manifestarsi danni a medio e lungo termine come alterazioni della funzione renale (Chicas 2019).

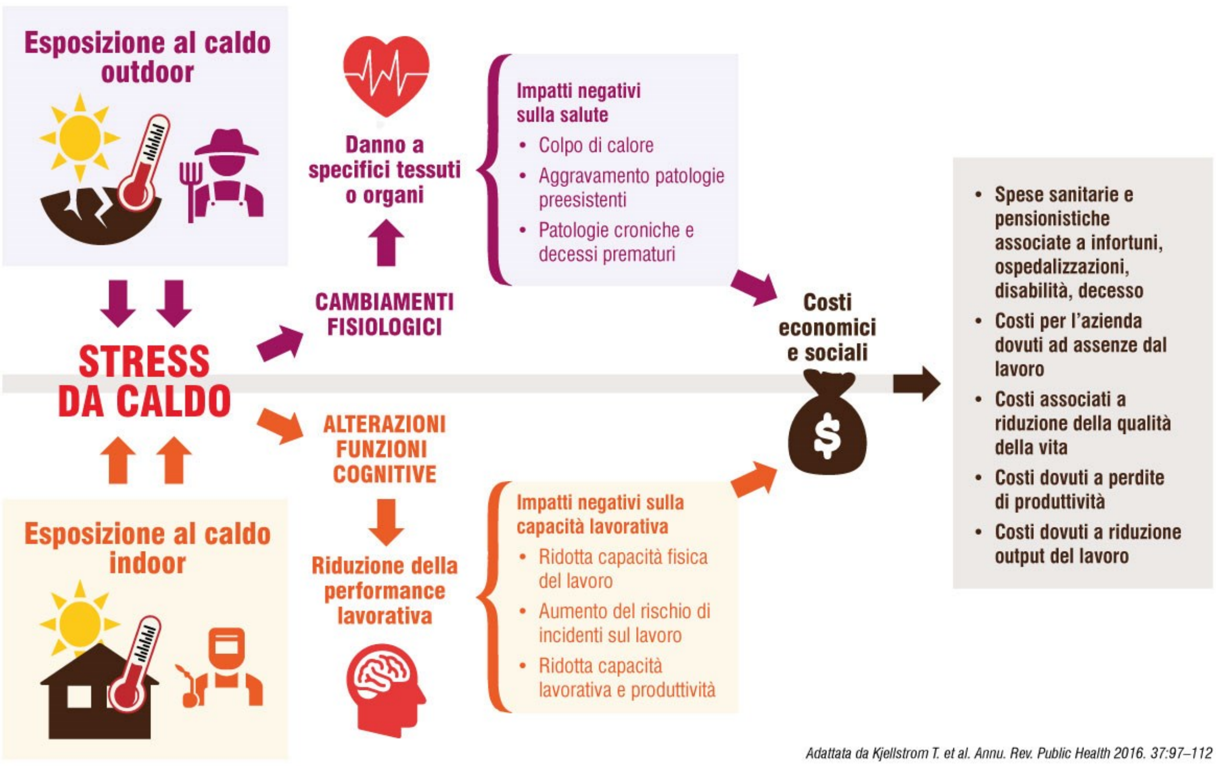
Nei lavoratori inoltre, il caldo può aumentare il rischio di incidenti sul lavoro e infortuni a causa di alterazioni a livello cognitivo in particolare su attenzione, capacità di concentrazione e tempo di reazione (Spector 2019).

Gli impatti sanitari associati al caldo corrispondono a costi sociali ed economici *in primis* per il lavoratore e per la sua azienda, ma anche per il sistema sanitario e previdenziale, le compagnie di assicurazione, etc. La stima di tali costi è complessa in quanto entrano in gioco diversi fattori, come esemplificato nella **Figura 1**: costi legati alle assenze dal lavoro a causa dell'infortunio e costi necessari per sostituire il lavoratore; costi associati alla spesa sanitaria in caso di ricovero e costi per risarcire il lavoratore in caso di infortunio o invalidità; costi dovuti a perdite di produttività del lavoratore e dell'azienda; costi dovuti a riduzione output del lavoro; costi associati a riduzione della qualità della vita per il lavoratore, ad esempio in caso di danno funzionale ad un organo che impedisce di tornare a svolgere la mansione che il lavoratore svolgeva prima dell'infortunio.

In termini economici, a livello globale, il danno economico conseguente a decessi, infortuni e malattie professionali risulta essere pari al 3.9% del PIL mondiale e, una stima di entità simile (3.3%), è disponibile anche a livello Europeo (EU OSHA 2017). Quanta parte di questa riduzione sia attribuibile al caldo è ancora oggetto di dibattito, e un crescente numero di studi condotti a livello internazionale ed europeo, cerca di rispondere a questa domanda, con diversi disegni di studio, diversi esiti di salute, diverse stime per i costi o perdite di produttività. Inoltre, i cambiamenti climatici in atto possono ulteriormente amplificare gli impatti sulla salute dei lavoratori associati al caldo. L'ultimo report del Panel Intergovernativo di esperti sui cambiamenti climatici evidenzia un aumento degli eventi estremi come le ondate di calore con impatti osservati sulla salute della popolazione e gli impatti attesi in futuri sono ancora maggiori, specialmente secondo lo scenario peggiore (nessuna azione di mitigazione).

Considerata l'eterogeneità degli studi disponibili e la complessità del fenomeno di interesse, è necessaria una sintesi delle evidenze sulla valutazione economica delle perdite di produttività e di salute dovute ad una esposizione al caldo in ambiente di lavoro, al fine di fornire ai decision-maker una stima delle risorse perse a causa di questa esposizione professionale, in modo da programmare azioni di prevenzione sul luogo di lavoro e indirizzarle sui settori lavorativi più colpiti.

Figura 1. Possibili meccanismi con cui il caldo provoca effetti sulla salute dei lavoratori e corrispondenti costi sociali ed economici.



Obiettivo

Il presente rapporto sintetizza i risultati di una scoping review della letteratura, condotta nell'ambito del progetto WORKLIMATE, che si proponeva l'obiettivo di sintetizzare le evidenze sui costi economici e sociali associati all'esposizione al caldo in ambito occupazionale nei lavoratori sia indoor che outdoor, al fine di avere un quadro di riferimento sulle metodologie e sulle evidenze in letteratura a supporto della conduzione di studi per la stima dei costi sociali ed economici associati al caldo in ambito occupazionale. A questo report seguirà una pubblicazione scientifica con i principali risultati della revisione di letteratura. Come evidenziato in precedenza, i costi legati ad infortuni e malattie professionali sono complessi da misurare perché si compongono di differenti fattori descritti in Figura 1, di difficile definizione e misura. Nella presente revisione sono stati presi in considerazione tre principali disegni di studio e di misura dei costi economici e sociali associati al caldo per la salute dei lavoratori:

1. Produttività perduta a causa del caldo in specifici gruppi di lavoratori, valutata soprattutto attraverso studi descrittivi su campo;

2. Impatti economici/costi attuali stimati sulla base degli infortuni o altri esiti sanitari associati al caldo nei lavoratori, valutati soprattutto attraverso studi analitici di serie temporale o case-crossover;

3. Scenari di climate change e stime di impatti economici/costi futuri, valutati tramite studi basati su modellistica, a livello globale e regionale.

Metodi

È stata condotta una ricerca della letteratura in due database bibliografici (Web of Science e Pubmed), aggiornata ad aprile 2022, utilizzando termini liberi e vocabolario controllato (Appendice 1) per selezionare studi sui lavoratori, sul caldo (alte temperature, ondate di calore, cambiamenti climatici) e sulla produttività o sui costi economici o sociali. Sono stati inclusi studi osservazionali sia qualitativi che quantitativi e studi basati su modelli economici. Sono stati esclusi gli studi sperimentali, gli studi che non stimavano la produttività o i costi o che non consideravano il caldo. La selezione degli studi e l'estrazione dei dati è stata condotta secondo le linee guida PRISMA. Come setting e partecipanti sono stati inclusi studi condotti a livello globale o specifiche regioni o aree e tutte le categorie di lavoratori esposti al caldo indoor o outdoor. Le principali misure di esito sono state:

a. produttività perduta stimata o percepita dal lavoratore associata al caldo;

b. costi economici associati a infortuni o ospedalizzazione associate al caldo nei lavoratori;

c. costi economici futuri attesi secondo gli scenari di cambiamenti climatici.

Considerata l'eterogeneità delle misure e dei metodi per stimare i costi o la produttività e i diversi disegni di studio (studi epidemiologici e studi basati su modelli economici di stima dei costi), non è stato possibile effettuare una metanalisi dei risultati ed è stata condotta una sintesi narrativa, raggruppando gli studi in base al disegno (studi su campo per misurare gli effetti del caldo su specifici gruppi di lavoratori, stime dei costi associati agli effetti del caldo sulla salute dei lavoratori, studi basati su modelli economici).

Risultati

Selezione degli studi

La figura 2 mostra il diagramma di flusso della selezione degli studi. Un totale di 8156 record è stato identificato dopo rimozione dei duplicati, dei quali 141 sono stati giudicati rilevanti e valtati come full text. 102 studi sono stati identificati da altre fonti, letteratura grigia o articoli presenti nella bibliografia di revisioni della letteratura sul tema (Flouris 2018, Gubernot 2014, Kjellstrom 2016, Levi 2018, Nunfam 2018, Borg 2021), il rapporto del WGII dell'IPCC. A seguito della esclusione degli studi non eleggibili poiché non stimavano i costi o produttività o non valutavano gli effetti del caldo, 93 studi sono stati inclusi nella sintesi qualitativa. Come evidenziato dalla figura 3 dei 93 studi selezionati, e 54 studi basati su modelli economici (con o senza scenari di cambiamenti climatici), 31 studi osservazionali su gruppi di lavoratori (survey e studi qualitativi) e 8 studi valutavano i costi associati ad infortuni o altri esiti sanitari associati al caldo nei lavoratori.

Figura 2. Diagramma di flusso PRISMA

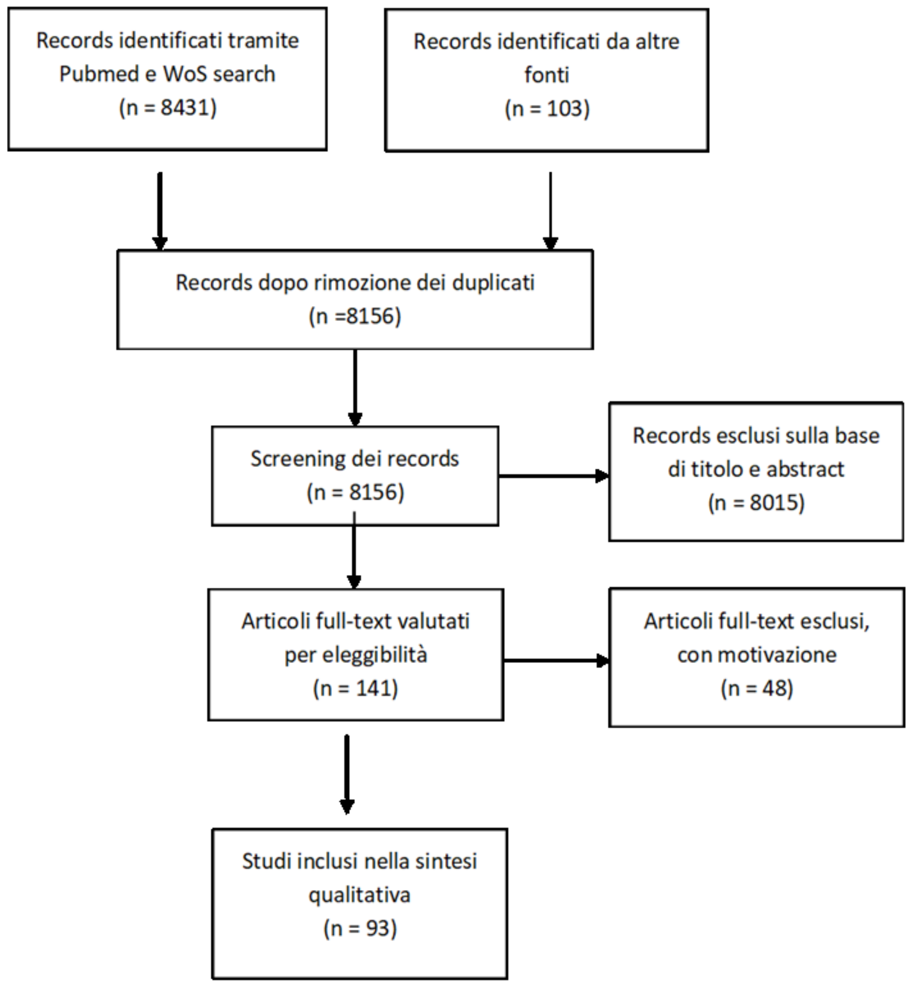
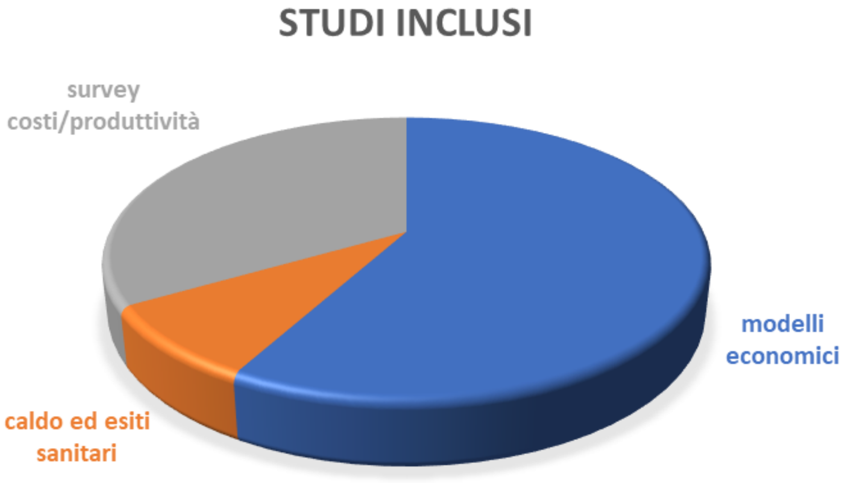


Figura 3. Distribuzione degli studi sui costi inclusi nella revisione.



Studi osservazionali su gruppi di lavoratori (survey e studi qualitativi).

La Tabella 1 descrive i risultati degli studi su campo. La maggior parte degli studi su campo (19 su 30) è stata condotta in paesi a reddito basso o medio (Amini 2021, Budhathoki 2019, Dally 2018, Das 2015, Delgado-Cortez 2009, Langkulsen 2010, Lee 2020, Li 2016, Lundgren 2014, Lundgren-Kownacki 2018, Mathee 2010, Nunfam 2021, Pradhan 2013, Sadiq 2019, Sahu 2013, Sett 2014, Venugopal 2016a, Venugopal 2016b, Yi 2017, Zander and Mathew 2019), con solo 9 studi condotti in Europa, Stati Uniti e Australia/Nuova Zelanda (Davey 2021, Gun & Budd 1995, Lamb 2016, Lao 2016, Messeri 2019, Messeri 2021 Quiller 2017, Singh 2013, Vanos 2019, Zander 2015) e uno studio multicentrico (Morabito 2020). Nove studi riguardavano gruppi di lavoratori in agricoltura, 4 studi includevano lavoratori nel settore costruzioni, 1 studio aveva arruolato dei minatori e 17 studi avevano incluso lavoratori in diversi settori. Lavoratori indoor sono stati considerati in 12 studi. Il numero di lavoratori inclusi variava tra 16 (Li 2016) a 4095 (Dally 2018). Tre studi erano di tipo qualitativo basati su descrizioni narrative delle risposte a interviste o focus group di gruppi di lavoratori (Singh 2013, Mathee 2010, Lao 2016), mentre gli altri studi erano di tipo quantitativo in cui l'associazione tra caldo e produttività lavorativa veniva stimata sulla base dei dati raccolti nello studio o attraverso la misura della perdita di produttività riferita dai lavoratori.

Nonostante la grande eterogeneità nelle tipologie dei lavoratori e nella loro numerosità, **tutti gli studi, eccetto Lamb 2016, hanno evidenziato una riduzione della produttività associata al caldo**. Nello studio di Lamb 2016 su lavoratori indoor, l'indicatore di stress termico era riferito sia al caldo che al freddo e questo potrebbe forse spiegare i risultati contrari all'atteso.

È importante notare che considerato l'approccio cross-sectional adottato nella maggior parte degli studi, i risultati non permettono di fare inferenza sulla possibile associazione causale tra produttività e caldo nei lavoratori. Nello studio di Langkulsen et al. (2010) in due settori lavorativi (ceramica e costruzioni) si osserva la riduzione della produttività, ma non negli altri settori considerati. Le perdite di produttività stimate negli studi variano tra 0.3-10% di riduzione per un incremento di 1°C di temperatura (Yi 2017, Sett 2014, Sahu 2013, Li 2016). Altri studi che avevano quantificato la perdita di produttività, in tonnellate in meno di prodotto raccolto (Dally 2018), in ore in meno lavorate (Das 2015, Vanos 2019, Yi 2017), come riduzione in termini percentuali rispetto all'output giornaliero (Langkulsen et al. (2010), Sahu 2013, Venugopal et al. (2016)a,b), o dei giorni (Zander and Mathew, 2019) o delle ore lavorate (Li 2016), come maggiore durata del lavoro in estate rispetto in inverno (Pradhan 2013). Quattro studi (Zander 2015, Zander and Mathew, 2019, Morabito 2020, Vanos 2019) hanno fornito anche una stima dei costi associati alla perdita di produttività, in cui i costi erano stimati sulla base degli stipendi lordi a cui veniva applicata la perditá di produttività riferita dai lavoratori oppure sulla base delle ore di lavoro perse a causa del caldo.

Grazie alla raccolta di informazioni sulle caratteristiche individuali e sulle misure di prevenzione disponibili, negli studi su campo è stato possibile valutare se queste caratteristiche modificavano l'associazione tra caldo e riduzione della produttività. Alcuni sottogruppi di lavoratori sono risultati maggiormente suscettibili alla perdita di produttività associata al caldo: gli uomini (Nunfam 2021, Venugopal et al. (2016b), Zander 2015), i lavoratori più giovani, meno istruiti o con meno anni di esperienza lavorativa (Nunfam 2021), i lavoratori esposti al sole diretto (Morabito 2020), i lavoratori che svolgevano carichi di lavoro intensi (Venugopal et al. 2016b, Zander 2015), coloro che utlizzavano misure di protezione individuali come le mascherine FFP2 (Davey 2021, Lee 2020, Messeri 2021), coloro che erano affetti da comorbidità come l'insufficienza renale o altre condizioni (Dally 2018, Das 2015), i lavoratori immigrati (Messeri 2019), i lavoratori che non avevano messo in atto misure di prevenzione come idratarsi, fare pause in luoghi rinfrescati etc. (Nunfam 2021, Budhathoki, N. K. 2019).

Studi basati sulla stima dei costi associati agli infortuni o ospedalizzazioni causati dal caldo

La Tabella 2 descrive i risultati degli studi sulla stima dei costi associati ad infortuni o rimborsi ai lavoratori associati al caldo. A differenza di quanto osservato per gli studi su campo, tutti gli studi che hanno stimato i costi sulla base degli infortuni o ospedalizzazioni associate al caldo sono stati condotti in paesi a reddito elevato come Europa, Australia e Stati Uniti e Canada (Bonauto et al.

2007, Fortune 2013, Hesketh 2020, Ma et al. 2019, Martínez-Solanas 2018, Rameezdeen and Elmualim 2017, Spector 2014, Xiang 2018). Sei studi avevano valutato lavoratori di tutti i settori occupazionali, mentre 3 studi avevano valutato specifici settori occupazionali come agricoltura e costruzioni. Quattro studi avevano un approccio descrittivo, in cui venivano quantificati i risarcimenti per infortunio o malattia professionale (Hesketh 2020, Bonauto et al. 2007, Fortune 2013 e Spector 2014) e stimati i relativi costi. Quattro studi avevano adottato un approccio di serie temporale o case-crossover sugli infortuni associati al caldo (Ma et al. 2019, Martínez-Solanas et al., 2018, Rameezdeen and Elmualim 2017, Xiang 2018) a partire dal quale sono stati stimati i costi associati ai relativi indennizzi.

Bonauto 2007 e Hesketh 2020 sono stati condotti sulla stessa popolazione in due tempi successivi, e permettono quindi anche un confronto temporale sui costi associati agli infortuni caldo-correlati. In particolare, si evidenzia un incremento di due volte nel tasso annuale di infortuni o malattie professionali nel settore dell'agricoltura e un maggior numero di infortuni verificatisi a temperature più elevate (la temperatura mediana a cui si registra l'infortunio è aumentata da 85°C a 90°F. I giorni lavorativi persi a causa dell'infortunio associato al caldo sono stati 13 (mediana), con un costo maggiore rispetto agli infortuni non caldo-correlati (Hesketh 2020).

Nello studio descrittivo di Fortune 2013, il tasso di infortuni associati a perdita di produttività (lost time injuries) è stato di 1.7 casi ogni milione di mesi di lavoro a tempo indeterminato). Nello studio descrittivo di Spector 2014, sono stimati i costi associati agli infortuni con risarcimento (compensable claims) e senza risarcimento (non compensable claims) e in particolare i maggiori costi sono associati ai primi, in particolare nel settore agricoltura e foreste, suggerendo una possibile sottonotifica degli eventi di infortunio in questo settore da parte dei lavoratori.

Lo studio di serie temporale di Ma (2019) ha stimato che la quota di risarcimento economico degli infortuni associati al caldo (esposizione a temperature superiori al limite del wet bulb globe temperature (WBGT) in accordo con gli standard internazionali sul rischio associato allo stress termico sul luogo di lavoro) è pari al 4.1% (95% eCI: 0.2%–7.7%) di tutti i risarcimenti per infortuni.

Lo studio di serie temporale di Martinez-Solanas (2019) ha valutato i costi associati ad infortuni derivanti dall'esposizione a stress da caldo in ambito lavorativo, ma ha anche valutato lo stress da freddo. In particolare, sono state valutate temperature estreme, al di sopra del 97,5° percentile, e temperature moderate, inferiori al 97,5° percentile. I costi totali associati agli infortuni vengono disaggregati in costi associati alle perdite nel lungo termine, costi sanitari, costi associati al mantenimento della produzione, costi associati al dolore e alla sofferenza. L'impatto economico totale nel periodo in studio è pari a 370 milioni di euro, pari al 0.03% del PIL della Spagna. I costi associati al dolore e alla sofferenza sono i più elevati rispetto agli altri tipi di costi.

Lo studio case-crossover di Rameezdeen 2017 ha confrontato i costi associati agli infortuni nei giorni di ondata di calore rispetto a giorni di controllo, evidenziando in particolare nel settore delle costruzioni i maggiori costi associati agli infortuni. Infine, nello studio di serie temporale di Xiang 2018, un incremento nella temperatura massima al di sopra di 33°C è stato associato ad un incremento del 41.6% nei costi sanitari e del 74.8% nei giorni di lavoro persi a causa degli infortuni associati al caldo.

Coerentemente con i risultati degli studi trasversali su campo, anche in questi studi si osservano i maggiori costi in specifici sottogruppi di lavoratori, per i quali quindi si può ipotizzare che l'infortunio sia più grave o sia necessaria una maggiore attenzione in termini di prevenzione. In particolare, sono stati associati a costi o perdite di giorni lavorativi maggiori i lavoratori manuali (Fortune 2013), i lavoratori neri e Latinos (Hesketh 2020), i lavoratori assunti da meno di 1 mese o da 1-2 mesi (Fortune 2013), i lavoratori di 15-24 anni (Fortune 2013), le donne (Ma 2019), i lavoratori di aziende di medie dimensioni (Ma 2019, Xiang 2018) o di piccole dimensioni (Rameezdeen 2017)

Studi basati su modelli economici

La Tabella 3 descrive i risultati degli studi su modelli economici. Gli studi basati su modelli economici hanno utilizzato diversi approcci per stimare i costi economici associati a riduzioni-associate al caldo nella produttività dei lavoratori. Il metodo più semplice parte dalle stime della produttività dei diversi settori occupazionali e la moltiplica per la quota a cui ciascun settore lavorativo contribuisce al PIL. Questo metodo non considera le relazioni e influenza tra settori economici, aspetto preso in considerazione dai più complessi modelli economici basati sui cosiddetti computable general equilibrium (CGE) model o modelli di equilibrio generale. I modelli di equilibrio generale calcolabili sono una classe di modelli economici che utilizzano dati economici effettivi per stimare come un'economia potrebbe reagire ai cambiamenti nella politica, nella tecnologia o in altri fattori esterni

La maggior parte degli studi inclusi stimano la produttività come funzione dello standard ISO 7243 sul rischio associato allo stress termico considerando il superamento di una soglia dell'indicatore wet bulb globe temperature (WBGT) sul luogo di lavoro o sulla base dello standard di comfort termico, il Predicted Mean Vote Index, e associano i dati climatici a quelli economici. Nella maggior parte dei casi, è stato stimato l'impatto dei cambiamenti climatici al 2030, 2050 e 2080 considerando scenari a basse e alte emissioni di gas serra (assenza di mitigazione) a livello globale e regionale. Altri studi hanno valutato l'impatto in specifiche regioni, e altri hanno considerato gli impatti economici del clima attuale.

Alcuni studi hanno stimato la perdita di produttività in termini di costi sia a livello globale (Roson et al.,2016, Kjellstrom T 2016a, Kjellstorm et al.,2019a grey (ILO report) che negli studi regionali o locali (Costa and Floater 2015, Deloitte 2020, Heal & Park 2013, Hübler et al., 2008, Kershaw 2013, Kovats et al.,2011, Licker 2022, Martinich 2019, Orlov et al., 2019, TNC 2021, Xia et al., 2018, Zhang 2021, Zhao 2016). Le perdite di produttività associate ai cambiamenti climatici entro il 2100 a livello globale variano da 1% (DARA 2012) a 47% (Kuhla 2021) secondo lo scenario peggiore (nessuna mitigazione).

In specifici settori come quello dell'agricoltura e in specifici paesi la perdita di produttività espressa come riduzione percentuale del GDP è anche maggiore del 30-50% (De Lima 2021, Knittel 2020, Matsumoto 2021) in particolare le perdite di produttività maggiori sono associate ai lavoratori che svolgono attività fisiche più intense (400W) all'aperto (Knittel 2020).

A livello regionale dagli studi emerge che le regioni più colpite sono quelle tropicali come Africa occidentale, sud-est asiatico, centro e sud America. Anche le regioni del sud del Mediterraneo come l'Italia hanno un impatto atteso non trascurabile, maggiore rispetto alle regioni di nord Europa. L'agricoltura è il settore più colpito dello stress termico dovuto al caldo sia considerando il clima attuale che scenari futuri.

Conclusioni

La revisione della letteratura conferma i risultati delle revisioni precedenti (Flouris 2018, Gubernot 2014, Kjellstrom 2016, Levi 2018, Nunfam 2018, Borg 2021) aggiungendo ulteriore evidenza all'associazione tra esposizione a caldo (indoor e outdoor) e perdita di produttività o costi per il lavoratore e per l'azienda. Le diverse metodologie utilizzate, sebbene non permettano un confronto diretto tra i risultati dei singoli studi, forniscono una chiara indicazione di consistenza degli effetti del caldo sulla produttività e sui costi per i lavoratori, indicazione utile per i decision-maker al fine di iniziare la prevenzione in modo prioritario partendo dai settori più colpiti. Le evidenze disponibili suggeriscono che gli impatti attesi per effetto dei cambiamenti climatici potranno essere ancora maggiori e per questo è necessario rinforzare la diffusione delle informazioni e della prevenzione e sicurezza nei luoghi di lavoro a livello globale, in particolare nei paesi a reddito basso e medio. Gli studi disponibili suggeriscono che i costi e la perdita di produttività possano essere maggiori in alcuni sottogruppi di lavoratori, perché sono affetti da infortuni più gravi, o perché meno consapevoli dei rischi e delle strategie di prevenzione, come avviene nel caso dei lavoratori più giovani e nelle aziende di piccole dimensioni che possono investire meno risorse in prevenzione e protezione nel luogo di lavoro. Questi sottogruppi comprendono le donne, i lavoratori con patologie croniche, i lavoratori di basso reddito, i lavoratori più giovani (età minore di 24 anni) e dovranno essere la popolazione target di specifici interventi informativi e formativi in ambito salute e sicurezza sul luogo di lavoro, sia nel caso di caldo indoor che outdoor.

Tabella 1. Risultati degli studi su campo

Reference	Country	Heat exposure	Study population	Study period and duration	Cost calculation	Economic loss estimation (unit measure)
Amini 2021	southwest Iran	predicted mean vote (PMV) and 2 expected parameters (clothing and metabolism rate)	agriculture workers	2016	Productivity calculated based on equation in Mohamed 2005 doi: 10.1016/j.ergon.2004.09.008.	Manpower productivity index
Budhathoki, N. K. 2019	Nepal	Perceived stress	350 farmers	2012-2017	na	perceived labour productivity due to heat
Dally 2018	Guatemala	WBGT	4,095 sugarcane cutters	November 2015 to May 2016 harvest season.	distributed lag non-linear models were used to model the relationship between temperature exposure and productivity (lag	change in average daily tons
Das 2015	India (two cities)	heat wave days	150 low-income urban informal workers (mostly outdoor)	April-May 2013	survey and analysis of Change in time allocation and work time loss as a function of workplace, family size and income, and	Lost worktime (in hours)
Davey 2021	UK	perceived heat stress and heat-related illness	healthcare workers	May and August 2020	difficulty in performing specific work procedures	reported cognitive and physical performance
Delgado-Cortez (2009)	Nicaragua	WBGT	22 sugarcane workers	2006/2007 harvesting season (15 days)	field study and descriptive analysis of production output and water intake (no analysis of production output and temperature)	daily productivity output (in tons)
Gun & Budd 1995	Australia	WBGT	43 male sheep shearers	January-March of two consecutive years (54 days)	linear regression analysis between productivity and thermal stress variables	Shearers and press operators were paid by the hourly number of sheep shorn and wool bales pressed, respectively, which were recorded in a tally book maintained by the employing contractor; these records thus provide an accurate measure of productivity. Because of the dissimilarity of the units (sheep vs. bales), tallies reported in this paper are those of the shearers only
Lamb 2016	New Zealand	Indoor Environmental Quality (thermal stress including both cold and heat stress)	114 office workers	8 months	longitudinal within-subjects design	An 11-point scale measured work performance relative to perceived average work performance
Langkulsen et al. (2010)	Thailand	WBGT	21 workers in pottery industry, power plant,	October 5 to October 16, 2009	cross-sectional study of perceived productivity loss due to heat stress	Productivity loss measured as percent change of the daily work output

Reference	Country	Heat exposure	Study population	Study period and duration	Cost calculation	Economic loss estimation (unit measure)
Lao, 2016	South Australia	na	32 male outdoor workers	July 2014	Focus groups on heat impact on work productivity	productivity self-evaluated in a narrative way by workers
Lee 2020	India and Singapore	perceived heat stress	165 hospital workers using PPE during covid-	May-June 2020	cross-sectional study of perceived productivity loss due to heat stress and PPE	perceived productivity self-assessed from questionnaire
Li 2016	China	WBGT	16 rebar workers	summer 2014	Three regression models were constructed that focused on direct work time, indirect work time, and idle time to analyze the impacts of the WBGT and other factors	labor productivity measurements of direct work time, indirect work time and idle time
Lundgren, 2014	Chennai, India	WBGT	77 workers in industrial, service, and agricultural sectors (most workers	JanuaryFebruary and AprilMay	Cross-sectional study with Heat strain and as	Productivity loss based on Predicted Heat Strain (PHS) model from core temperature and maximum water loss
Lundgren-Kownacki1 2018	India	perceived heat stress	87 brick kiln workers in summer and 61 in winter	June–July 2013, March–April 2014 (hot season); February 2013, January–February 2015 (cool season)	Cross-sectional study with productivity measured by questionnaire	Absenteeism/taken sick leave due to heat; Less productivity/more time to complete task/work extra hours; Irritation/interpersonal issues; Wages lost
Mathee 2010 - HOTHAPS study	South Africa	perceived heat stress	151 workers involved in sun-exposed	March 2009	no analysis was carried out, only narrative description of interviews	self-reported productivity loss
Messeri 2019 (EU HEAT-SHIELD project)	Italy	perceived heat stress	104 migrant workers in agriculture and construction	summer months of 2017	Self-reported data (the worker noticed to be less productive during a heat wave or need more energy for the same work)	perceived productivity loss due to heat
Messeri 2021 (WORKLIMATE project)	Italy	perceived heat stress	191 hospital workers using PPE during covid-19	June-October 2020	Cross-sectional study of perceived productivity loss due to heat stress and PPE.	perceived productivity self-assessed from questionnaire

Reference	Country	Heat exposure	Study population	Study period and duration	Cost calculation	Economic loss estimation (unit measure)
Morabito et al., 2020	Florence and Guangzhou	WBGT	18 outdoor workers in agriculture	Summer 2017-2018	Cross-sectional study to assess productivity loss in outdoor workers for moderate (300 W) work activities in sun and shady areas. Exposure-response function of WGBT and productivity is assessed by using two risk functions: based on ISO standard and on epidemiological data (Kjellstrom et al., 2018)	Percent productivity loss (%) self-assessed from questionnaire and economic costs estimated from workers' salaries multiplied for productivity losses.
Nunfam 2021	Ghana	perceived heat stress	320 miners	October 2017-January 2018	Cross-sectional study to assess health and productivity related to heat	perceived productivity self-assessed from questionnaire
Pradhan 2013 - HOTHAPS study	Nepal	WBGT	120 workers indoor and outdoor	2010	descriptive comparison of work time across months	average work hours by season (work efficiency)
Quiller, 2017*	Washington, US	WBGT	46 tree harvesters	2015 August and September	Cross-sectional study estimating the relationship between WBGT and productivity	productivity (total weight of fruit bins collected per time worked)
Sadiq 2019	Nigeria	WBGT	396 maize farmers	July to September, 2016	multiple linear regression was used to determine the influence of temperature (WBGT), body mass index (BMI), age, and	work output based on the number of ridges cultivated during the working hours
Sahu et al. (2013).	India	WBGT	124 rice harvesters	April-June 2011	Cross-sectional study to assess health and productivity related to heat. Productivity estimated for WBGT exceeding the standard (26-32°C) corresponding to 30-38°C of air temperature	change of the hourly work output. Daily work output was measured in terms of volume or quantity of items collected
Sett, 2014*	West Bengal, India	WBGT	120 female brickfield	Oct 2008 to May 2009 (first session), from Oct2009 to May 2010 (second session), Oct 2010 to May 2011 (third session)	Longitudinal study to assess health and productivity related to heat. Productivity estimated for WBGT exceeding the standard (26-32°C) corresponding to 30-38°C of air temperature	throughout the 8-month working period, their productivity was recorded on a weekly basis from the record register book for three sessions, and it was calculated as productivity per person per week
Singh 2013	Australia	n.a.	47 workers outdoor in several industries	summer 2010	no analysis was carried out, only narrative description of interviews	self-reported productivity loss
Vanos et al. 2019	Ontario, Canada	WBGT	outdoor laborers at an industrial site	2012 - 2018 (May-October)	Cross-sectional study to assess workers health and productivity related to heat	loss of money due to heat per 15-minute work interval by laborer type (via hourly wages)

Reference	Country	Heat exposure	Study population	Study period and duration	Cost calculation	Economic loss estimation (unit measure)
Venugopal et al. (2016)a	South India	WBGT	84 steel workers	April 2014	cross-sectional study of perceived productivity loss due to heat stress	Productivity loss due to heat stress was defined as loss in production, not achieving work targets, loss of workdays/work hours due to fatigue/exhaustion, sickness/hospitalization, and/or wages lost due to heat or heat-related illnesses
Venugopal et al. (2016)b	India	WBGT	several occupation types (indoor and outdoor, heavy, moderate and light)	cooler (2012) and hotter (2013) seasons	Cross-sectional study to assess workers health and productivity related to heat and cold stress	Productivity loss due to heat stress was defined as loss in production, or not achieving set work targets, or loss workdays/work hours due to fatigue/exhaustion, or sickness/hospitalization, and/or wages lost due to heat or heat related illnesses.
Yi, 2017	Hong-Kong	WBGT	14 male construction workers	August and September 2016	Cross-sectional study to assess workers health and productivity related to heat stress to built a model for predicting labor productivity loss	productive work activities (Make use of wrenches to connect, cut, band, and modify reinforcing steel bars, Place reinforcing steel bars, Modify reinforcing steel bars, Carry reinforcing steel bars, Use meter sticks for measurements, Bending), Non-Productive Activities (Employees or machines, or both, due to work stoppage from any cause; Chat, smoke, drink, sit, use cell phones, go to the washroom)
Zander et al. 2015	Australia	self reported heat stress	1726 workers in several occupation types	2013/2014	self-reported estimates of work absenteeism and reductions in work performance caused by heat	Self-reported estimates of absenteeism and reductions in work performance (presenteeism) caused by heat
Zander and Mathew, 2019	Urban Malaysia	self reported heat stress	514 workers several occupation types	2017–2018	self-reported estimates of work absenteeism and reductions in work performance caused by heat	Individual economic losses from heat stress related productivity losses estimated from productivity loss per daily average income per number of affected days

Tabella 2. Studi basati sulla stima dei costi associati agli infortuni o ospedalizzazioni causati dal caldo

Reference	Country	Exposure	Analysis of costs	Study population	Study period	Economic loss estimation (unit measure)	Results
Bonauto et al. 2007	US Washington State	none	descriptive analysis of heat-related illness compensation claims and risk factors (outdoor/indoor, comorbidity, hours of the day, acclimatization)	all work sectors (480 compensation claims for heat-related illness in the study period)	1995-2005	A claim is assigned a 'compensable' claim status code if it involves 4 or more days of time loss from work. Both compensable and noncompensable claims were included in the study.	Median cost per compensable claim for heat-related illness was 1,916 US dollars. Median cost for non-compensable claim was $513.
Fortune 2013	Ontario, Canada	none	Incidence rates calculated using denominator estimates from national labour market surveys and estimates were adjusted for workers' compensation insurance coverage. Proportional morbidity ratios were estimated	all work sectors (612 compensation claims for heat-related illness in the study period)	2004-2010	lost time claims	incidence of heat illness is highest in the June to August period. A total of 40% of all heat illnesses were clustered in epidemics over contiguous days. The rates of lost time claims were highest among workers aged 15-24, males, and among Manufacturing (25%), Government Service (15%), Construction (10%) and self-insured public sector employers (10%) sectors.
Hesketh 2020	US Washington State	maximum daily and 3-days temperature (°F) > 89°F (threshold to protect workers)	descriptive analysis of time losses and costs per injury	645 heat related injuries occurred in all work sectors	2006-2017	work time loss due to heat related injuries. Claim costs (in US dollars) for compensable and non compensable (medical aid only) claims, excluding indirect costs to employers and workers and the administrative costs of managing the claim	Median time loss 13 work days related to heat injury. Higher costs of heat related injuries than for the total injuries (909 US dollars and 800 US dollars respectively), for both compensable and non compensable claims.
Ma et al. 2019	China	Wet-bulb Globe Temperature (WBGT) index of heat stress	Time series study to examine the association between heat stress (WBGT values) and insurance payouts for work related injuries	all work sectors	2011-2012	The daily insurance payouts calculated by aggregating amounts of individual payouts, and also showed as US dollars	4.1% of insurance payout was attributable to heat stress (all days in the study period with WBGT>25°C), corresponding to 11.58 million Chinese Yuan. Stronger associations in female workers, workers employed in medium-sized enterprises, and workers with intermediate education level
Martínez-Solanas et al., 2018	Spain	Extreme cold and heat (temperatures below the 2.5 th and above the 97.5th percentiles) and moderate heat and cold (between MMand extreme))	Time series study between daily maximum temperature and the daily count of occupational injuries causing at least one day of leave. Economic analyses based on a previous study on the costs of occupational injuries in the Catalonia region (Abiuso and Serra2008)	occupational injuries in specific economic sectors for investigation based on previous research	1994–2013 (both heat and cold)	Costs estimated based on a previous study in 2007-2008 estimating a) costs associated with maintaining production (including overtime payments and costs of replacement and training), b) longterm lost incomes (total income lost when a worker suffers an injury and cannot come back to work), c) health costs associated with costs of treatment and rehabilitation, and d) costs of pain and suffering (level of disability).	€319.39 million annually related to heat (297.82 moderate heat, 21.57 extreme heat). Annual costs related to moderate and extreme heat from pain and suffering: 182.97€, maintaining production:59.21€, longterm lost incomes: 49.16€, and health costs: 28.06€.
Rameezdeen and Elmualim (2017)	Adelaide, Australia	Heat wave: 5+ consecutive days of Tmax > 35°C or 3+ consecutive days of T>40°C	analysis of the impact of heat waves on occurrence and severity of construction accidents. Compensation claims recorded during the heat wave periods were compared with those during similar "control periods".	construction sector (29,438 compensation claims during the study period)	heat waves 2000-2010	Compensation claims and costs (australian dollars)	Worker characteristics, type of work, work environment, and agency of accident increase the risk of severe compensation claim during heat waves. Small companies had a proportionately higher share of severe injuries. Mean cost of injury was higher in central part of Adelaide, and in small campanies and for specific agencies of accident (structure, electricity, environment, small tool, and vehicle).
Spector 2014	Washington, US	Maximum and minimum temperature and temperature range, heat index	Analysis of determinans of heat-related compensation claims	agriculture and forestry sector (84 heat-related claims in the study period)	1995-2009	Cost per compensation claim (US dollars). Time-loss days per claim (days)	Comorbidity and drug use increase risk of heat-related claim. The mean cost per heat-related claim was 3502 US dollars and 3071 US dollars for total and non-compensable claims respectively. Costs were several times lower than average cost of all claims. Severe heat-related claims mean cost was 24,533 US dollars. Mean number of time-loss days was 25 (0-96) days.
Xiang 2018	South Australia	Maximum temperature	Medical costs related to injuries	all work sectors (438 heat related occupational injuries in the study period)	2000-2014	Costs (Australian dollars) Day lost due to injury	A 1 °C increase in Tmax above about 33 8C was associated with a 41.6% increase in medical costs and a 74.8% increase in days lost due to OHI, respectively

Tabella 3. Studi basati su modelli economici

Reference	Temporal period	Cost calculation	Economic loss unit measure	Work sectors	Results
Global studies using current and future climate projections					
Burke 2015	2050-2100 compared to 1960-2010 (two socioeconomic scenario consistent with RCP 8.5)	non linear analysis between global and country economic production and temperature	productivity of industries non of individuals (change in GDP per capita)	several occupation types	climate change reduces projected global GDP by 23% in 2100 (best estimate, SSP5) relative to a world without climate change. Reductions are similar in rich and poor countries, while are larger in countries becoming warmer
Chavaillaz et al. 2019	different emission scenarios (1% CO2, RCP4.5 and RCP8.5) compared to the pre-industrial period (1861–1880)	analysis between CO_2 and other greenhouse gases emissions (predictor of mean temperature increase) and GDP losses	The change in mean number of annual hours employees lost in vulnerable occupational sectors due to the increase in heat exposure, expressed as % of GDP	vulnerable industries to heat exposure (agriculture, mining and quarrying, manufacturing and construction workers)	The relationship between productivity loss and CO2 emissions is linear at global scale. For each trillion tonne of carbon emitted, the annual productivity loss will globally increase by 1.84% (±0.94, 1σ-intervals due to climate and inter-model variability), 2.96% (±1.97) and 3.61% (±1.77) of total GDP in the 1% CO2, RCP4.5 and RCP8.5 scenarios, respectively.
DARA 2012 grey lit	2010-2100 scenarios	analysis of labour productivity losses from international labour standards and estimates of wet bulb globe temperature (WBGT) change for populations assumed to be acclimatized. The model accounts for productivity gains to countries in high latitudes that will experience a reduction in extreme cold.	loss of labour productivity is calculated for both indoor and outdoor workers and expressed in USD	several occupation types	These results projected a total global GDP loss of US$2.5 trillion (PPP $) per year for 2030 (1% loss of global GDP in 2030, 0.5% loss in 2010). As a percentage of the national GDP, losses varied markedly and were greatest in tropical low- or middle-income countries (e.g., 0.0% in the United Kingdom and Japan, 0.2% in the United States, 0.8% in China, 3.2% in India, 6.0% in Indonesia and Thailand, and 6.4% in Nigeria and Ghana)
Dasgupta 2021	1·5°C, 2·0°C, and 3·0°C of global warming compared with the historical baseline period (1986–2005)	the effect of climate change on labour productivity using five different exposure-response estimated from literature	Change in Effective Labour=(100% + Change in Labour Supply), Change in Labour Productivity	low-exposure working conditions (labour outside in the shade or indoors) and high-exposure working conditions (outside with no shade)	Europe is expected to be the least affected region, while the highest impact will be in Sub-Saharan Africa
De Lima 2021	1·5°C, 2·0°C, and 3·0°C of global warming compared with the 1986–2005 baseline	1) National Institute for Occupational Safety and Health (NIOSH) labor standards for agricultural workers (400 W) [29, 48], and an associated function for labor capacity 2) Dunne algorithm to estimate labour capacity	Change of unskilled employment in agriculture accounting for impacts in crop yields	agricolture	In sub-Saharan Africa and Southeast Asia heat stress with 3°C global warming could reduce labor capacity in agriculture by 30%–50%, increasing food prices and requiring much higher levels of employment in the farm sector
Dunne et al. 2013	Reanalysis 1971–1980 and 2001–2010, projected 2091–2100 and 2191–2200	analysis focused on the loss of labor productivity as a function of WBGT levels during the hottest months in each part of the world over the period 1975–2200 under high emissions (RCP 8.5) and mitigation (RCP 4.5) scenarios	Population-weighted individual labour capacity (%) during annual mimimum and maximum heat stress months estimated from WBGT applied to US and international standards for safe work intensities (90% means 10% losses in labour capacity)	outdoor workers	Reductions in work capacity during the hottest months already occur at the global level (10% reduction). By 2050 under both scenarios, work capacity loss is two-fold higher than in the historical period (20% reduction). By 2100, the reductions in the hottest month may reach 37% with RCP8.5 and 20% withn RCP4.5. By 2200, further changes in work capacity are projected for the hottest month based on RCP8.5 (61% reduction), and 12% of population is exposed to work capacity losses
Kjellstrom et al. 2009a	2020, 2050 and 2080 compared to 1961–1990	Projections of future labor productivity losses (in terms of lost labor days) under climate scenarios A2 (worst) and B2 compared to baseline climate applying dose-response function between WBGT and work capacity estimated in Kjellstrom et al. 2009b	The change in labor productivity is expressed as percent work days lost and incremental change relative to baseline	all work sectors (service, industry, and agriculture) both indoor and outdoor	By the 2080s, the greatest absolute losses of population based labor work capacity (in the range 11% to 27%) are seen under the A2 scenario in Southeast Asia, Andean and Central America, and the Caribbean. Under B2 scenario smaller impacts in all regions (the greatest loss being 16% in Central America), and labor productivity gains in some regions (up to 6%)

Reference	Temporal period	Cost calculation	Economic loss unit measure	Work sectors	Results
Global studies using current and future climate projections					
Kjellstrom T 2015	2030 and 2050 versus 1960-1989	lost work capacity calculated using exposure–response relationships from literature	Cost of labor productivity loss due to excessive heat, % of GDP	all work sectors (outdoor and indoor)	for South-East Asia the new estimates (taking workforce changes into account) indicate work capacity losses increasing from 17% to 29% (of daylight work hours) from 1975 to 2050 for outdoor workers doing heavy labor. The corresponding figures for indoor workers doing heavy labor are 3% to 8%, and for outdoor workers doing moderate labor the estimates go from 7% to 15%. Low- and middle-income countries have higher losses 6% of annual GDP compared to high income countries.
Kjellstrom T 2016a	2030 and 2050 compared to 1960-1989	Projections of future labor productivity losses (in terms of lost labor days) compared to baseline climate, applying dose-response function between WBGT and work capacity estimated in literature for moderate and heavy labor. % workdays loss per year was applied to the GNP or GDP estimates for each country.	estimated annual labor productivity losses, expressed as $US PPP or % of GDP due to excessive heat by country	all work sectors (service, industry, and agriculture) both indoor (or shade) and outdoor (or sun)	The estimated annual losses, expressed as $US PPP, are already in 2010 up to 55 billion (India) and in 2030 up to 450 billion (India and China)
Kjellstrom T 2016b	30-year periods around 1995 and 2085 at different global warming levels between 1.5 ºC (RCP2.6) and 4 ºC (RCP8.5)	Lost work hours are calculated based on the geographic distribution of adult (working age) population numbers for the year 2000, and expressed as the annual percent of daylight hours lost due to heat	annual percent of daylight hours lost due to heat at 300W. The percentages refer to potential annual daylight hours when health and productivity problems due to heat start occurring for moderate work and labour productivity falls as workers slow down or take more rest	all work sectors (service, industry, and agriculture) both indoor (or shade) and outdoor (or sun)	Now, it is so hot that productivity is lost up to 10-15% of annual daylight hour. There is a 10-times or more increase of work hours lost from 2015 to 2085 for a number of countries under RCP8.5 scenario. The worst impacts are estimated for Asia and the Pacific region with similar impacts also in West Africa. Latin America and the Caribbean have lower impacts and in Europe some impacts occur in the South. By the end of the century this will increase in the hottest areas even if temperatures are held at 1.5 ºC (RCP2.6), but the increase is much higher for the business-as-usual scenario of 4 ºC (RCP8.5), reaching more than 30%
Kjellstrom T 2018a	2011–2040, 2041–2070, and 2071–2099 versus 1981–2010 (RCP2.6 and RCP6.0 scenarios)	risk functions from epidemiological studies were used to convert an environmental heat level (expressed as WBGT) directly into a Bproductivity loss^ (percentage of reduced work capacity) if the worker reduces work intensity to avoid clinical health problems	percent of work hours lost (at moderata work intensity levels,300 W metabolic rate in the shade) relating the calculated numbers to the total potential person-hours of work in that area	all work sectors (service, industry, and agriculture) both indoor (or shade) and outdoor (or sun)	Under the more extreme climate change trend (RCP6.0; GTC increase of 2.7 °C), as much as 12–16% of annual work hours will be lost in some areas. Countries with large cool climate areas (such as USA) have limited work hour losses due to heat now (0.17%), but it may increase beyond 1.3% at the end of the century based on the current global climate policy pathway (RCP6.0)
Kjellstorm et al.,2019a grey (ILO report)	2030 and 2085 compared to 1995 (1981-2010) under RCP6.0 (worst) vs RCP2.6	Projections of future labor productivity losses (in terms of lost labor days) by combining a global temperature rise of 1.5°C by the end of the twenty-first century with labour force trends compared to baseline climate, applying dose-response function between WBGT and work capacity estimated in literature for moderate and heavy labor.	estimated annual labor productivity losses, expressed as $US PPP (or % of GDP) or equivalent full time jobs due to excessive heat by country	all work sectors (agriculture, construction, industry, services)	By 2030 the share of total working hours lost will rise to 2.2 per cent – a productivity loss equivalent to 80 million full-time jobs. The loss in monetary terms is then expected to total US$2,400 billion (PPP). Lower-middle- and low-income countries would be the worst affected, losing 4 and 1.5 per cent of their GDP in 2030, respectively.
Knittel 2020	2036-2065 (RCP4.5 and RCP8.5) vs 1981–2010	GCM projections of the annual WGBT cycle and corresponding work ability and relative changes for heavy outdoor work are calculated. To derive work ability values, the exposure-response relationships between WBGT and work ability from literature were applied	relative change in work ability (%)	heavy outdoor work (agriculture, construction)	By 2050, within Europe, reductions are most pronounced for Italy and other Mediterranean countries (Cyprus, Greece, Malta, Portugal, Spain), while other countries are only marginally affected. Other world regions are severely impacted such as Southeast Asian countries, India and oil exporting countries. In the Amazon region, heavy outdoor work (400W) is projected to decline by more than 50% under RCP8.5.
Kuhla 2021	2020-2039 versus 2000–2019 (RCP2.6 and RCP6.0 scenarios)	Perturbed productivity is calculated based on the daily mean temperature surpasses 27˚C suffers a linear reduction αs in its productivity with beta coefficient sector-specific. Absolute output losses are then determined by multiplying the perturbed productivity with the baseline production of that region	Absolute and relative heat stress-induced direct output losses	agriculture, fishing, mining and quarrying, hotels and restaurants, wholesale trade, and others	Globally, between 2000 and 2039 direct output losses increase by 47% if no further adaptation measures are taken. Regional increase in direct losses in the billions USD (e.g. in India, Saudi Arabia, or Mexico) or nearly double the direct output losses (e.g. in Northern America or Europe) within the next decades.

Reference	Temporal period	Cost calculation	Economic loss unit measure	Work sectors	Results
Global studies using current and future climate projections					
Lancet Countdown 2021	1990-2020 (annual estimates)	hours of work lost calculated by linking Wet Bulb Globe Temperature with the amount of energy typically expended by workers in four sectors: agriculture, construction, service, and industry. It then combines this calculation with the proportion of people working (over 15 years old) in each country.	potential hours of labour lost due to exposure to heat by labour sector (in millions)	agricultural, construction, manufacturing and service sector workers	295 billion hours of potential work were lost due to extreme heat exposure in 2020, with 79% of all losses in countries with a low Human Development Index occurring in the agricultural sector. Conservative estimates since shade work is considered.
Lemke, unpublished observations (in Kjellstrom2016)	2085 (2070–2099) under RCP scenarios 8.5 (worst) and 2.6 compared to 1995 (1980– 2009)	Projections of future labor productivity losses (in terms of lost labor days) compared to baseline climate, applying dose-response function between WBGT and work capacity estimated in literature for moderate labor	person-hours lost due to heat in whole regions (i.e., the work capacity loss multiplied by the working population in each grid cell and then summed up for all grid cells in a region)	workers outdoor in the shade and indoor (no cooling) for moderate work	The substantial reduction in work capacity (and related labor productivity) between 1995 and 2085. The areas with the greatest risk in 2085 remain the same (Amazon region, West Africa, Arab Gulf area, Pakistan, North India, Indonesia, and parts of China), but substantial reductions in work capacity are apparent in the southeast United States, parts of Europe, Africa, and the rest of India and China
Matsumoto 2021	2100 vs 2007 (business as usual scenario)	climate change impact on labor productivity (the relationship between heat stress measured by wet bulb globe temperature [WBGT] and labor productivity).	labour productivity reductions (%)	agriculture, manufacturing, and service	the impacts were the largest for the agricultural (36.8–100% labor productivity by 2100), and 238 the lowest for the service sectors (83.0–100% productivity by 2100).
Orlov et al., 2020	2020, 2030, 2040, 2050, 2060, 2070, 2080 and 2090 compared to 1981-2005 under RCP8.5 (worst) and 2.6 scenarios	Productivity loss estimated using the Hothaps exposure-response functions or ISO functions, and the associated economic costs are assessed by using a dynamic multi-region, multi-sector computable general equilibrium model	GDP from labor productivity loss, estimated by decreased work efficiency	all work sectors agriculture and construction are assumed to be high-intensity jobs (400 W), while manufacturing and services require moderate-intensity (300 W) and low-intensity work (200 W),	Heat stress leads to substantial reductions in worker productivity, especially of high intensity work in low-latitude countries of Africa, South America, and Asia. Given the assumption of absence of ACir conditioning and constant work intensity, reductions in worker productivity in some regions under RCP8.5 could even exceed 40% by 2100 compared to the reference. Agriculture and construction are the most adversely affected by heat stress.
Parsons 2021	2001-2020	calculation of the maximum work loss in the 12-hours work day on the basis of exposure-response functions from literature	Heavy labour lost (hours) Productivity loss (Billions PPP US dollars)	all work sectors	Current global estimates of productivity losses are 670 billions PPP US dollars in the 12-hours work day. Under +2°C warmer world, productivity losses reach 1.6 trillion PPP US dollars.
Parsons 2022	2001-2020	calculation of the maximum work loss in the 12-hours work day on the basis of exposure-response functions from literature	Heavy labour lost (hours) Productivity loss (Billions PPP US dollars)	outdoor workers in heavy labor sectors (agriculture, forestry and fisheries; construction)	Global labor losses higher estimates are 2.1 trillion PPP US dollars. China and India again experiencing the largest losses, and Indonesia and the United States showing over 90 billion PPP$ losses per year. India experiences annual productivity losses equivalent to almost 7% of its 2017 GDP.
Roson et al. 2016	scenarios of 1, 2, 3, 4 and 5 °C increases in average temperature (study period not specified)	projection of loss in labor productivity from relationships between average temperature and labor productivity under scenarios of 1, 2, 3, 4 and 5 °C increases in average temperature (study period not specified)	GDP from labor productivity loss, estimated by lost hourly worktime	agriculture, manufacturing, service	Agriculture is the sector most significantly affected by higher heat stress. Some effects are felt by about half of the countries already at +1°C. The mean productivity losses range from -2.52% to -17.48%
Takakura et al., 2017	2100 under four representative	projection of loss in labor productivity from relationships between WBGT and labor productivity under scenarios of increase in WBGT	yearly average worktime reduction based on the recommendation of work/rest ratio and the estimated future wet bulb glove temperature and GDP losses (cost of heat-related illness prevention through worker breaks)	all work sectors (outdoor and indoor and different intensity)	Under the highest emission scenario, GDP losses in 2100 will+D21:H26 range from 2.6 to 4.0% compared to the current climate conditions. The relationship between the cost of heat-related illness prevention through worker breaks and global average temperature rise is approximately linear

Regional studies using current and future climate projections				
Reference	**Coverage**	**Economic loss unit measure**	**Work sectors**	**Results**
Altinsoy 2014	western Turkey	Work days lost	agricolture and construction	The most important productivity decreases are expected in the summer. The main impact on work productivity becomes evident after 2040. In Turkey decrease in labour productivity losses in agricolture vary from 1% (baseline), to 2% in 2011-2040, 5% in 2041-2070 and 8% in 2071-2100. In some areas the largest decrease reaches 52%.
Amnuaylojaroen, T. 2022	5 megacities in Thailand	Percent decrease in labour productivity (%)	not specified	A widespread increase of heat index in the country and related decrement in labour productivity between 4 and >10%
Behrer 2017 grey	US	payroll per capita (close proxies to changes in total and marginal labor product)	non agricoltural sectors	Average U.S. county experiences a -0.04% reduction in payroll per capita during a year with one additional day with maximum temperatures above 95°F (35°C). The impacts are roughly 9 times as large in exposed sectors (construction, transportation, utilities, manufacturing, and mining). For instance, lost payroll under a no adaptation scenario is at least 50% higher in 2040-2050 compared a scenario in which local economies adapt to their new (hotter) climates.
Costa and Floater 2015 grey literature	3 EU cities Antwerp (Belgium), Bilbao (Spain), and London (United Kingdom)	Annual labor productivity loss, estimated by lost hourly worktime, and expressed as % of Gross Value Added (GVA) at the sector level	all work sectors	Productivity (annual GVA) loss of 0.4% in London ($2111 million), 2.1% in Antwerp ($2778 million) and 9.5% in Bilbao ($777 million) projected in 2081–2100. GVA was observed to monotonically decrease with increasing WBGT.
Deloitte 2020	Australia	Economic losses due to job losses caused by climate change, as % of GDP or US dollars	all work sectors	the economic losses to Australia from unmitigated climate change are $3.4 trillion in present value terms – or 6% of GDP by 2070. On average over the 30 years to 2050, that is a loss of 135,000 jobs per year and 1.8% of GDP. the worst impacted industries are service sectors (both government and business), trade and tourism, manufacturing, and mining
Heal & Park 2013	US and other countries	effective labor supply – defined as a composite of labor hours, task performance, and effort	all work sectors	Very hot countries such as Thailand, India, and Nigeria suffer negative output shocks on the order of 3-4% per capita GDP per degree Celsius. Very cold countries such as the UK, Canada, Norway, and Sweden have significantly higher output in warmer years (and lower output in colder years).
Hsiang 2010	Carribean and Central America	change in production due to temperature increases (% change for 1°C increase)	different work sectors	Wholesale, retail, restaurants and hotels (-6.1% per 1 °C increase), and other services (-2.2% per 1°C increase) exhibit significant production losses
Hsiang, Kopp et al. 2014	US	The change in number of hours employees in high-risk (construction, utilities, mining, and other) and low risk (indoor services) sectors of the economy work in response to projected temperature change	all work sectors	In RCP 8.5, high-risk labor likely declines by 0.2% to 0.9% by mid-century and by 0.8% to 2.4% by late-century. In low risk industries losses are more modest. Projected changes are smaller in magnitude for RCP 4.5 and RCP 2.6. No relevant geographical heterogeneity.
Hübler et al., 2008	Germany	Average GDP loss per year in Germany in the prediction period 2071–2100 for IPCC scenario A1B	all work sectors	Considering the worst scenario (A1B), future (2071-2100) losses are 2.5 billion $ (0.12% of GDP) or 10.4 billion $ (0.48% of GDP) with labor productivity loss of 3% and 12% for strong and extreme heat, respectively. Actual losses are 540 million € and 2.4 billion € with labor productivity loss of 3% and 12% for strong and extreme heat, respectively.
Kershaw 2013	UK	cost per m2 of office building (pounds)	indoor work sectors	as the climate warms then the cost of lost productivity increases from 134 pounds per square meter in 1970s to 148, 164 and 181 pounds per square meter in 2030, 2050 and 2080 respectively

Regional studies using current and future climate projections				
Reference	**Coverage**	**Economic loss unit measure**	**Work sectors**	**Results**
Kjellstrom et al. 2009b	Delhi (india)	remaining 500 W Work Capacity at each hour (%)	outdoor work in the sun	work capacity for a person who works at a heavy work intensity of 500 W is reducing during the day, with on average only 20% of work capacity remains at 12 noon
Kjellstrom T 2013	Southeast Asia	Percent of total work time loss due to rest and slower work due to heat for moderate and heavy labor	all work sectors both indoor (or shade) and outdoor (or sun), for heavy and moderate work	1975 in the hottest locations 30-40% of afternoon work time is lost in the shade and 60-70% lost in the sun. In 2050 in hottest areas afternoon worktime is lost due to heat up to 80% for heavy work and up to 50% for moderate work
Kopp, 2014 Grey literature	US	Labor Productivity as minutes worked for high-risk (agriculture, construction, utilities, and manufacturing) and low-risk labor sectors	all work sectors	In RCP 8.5, high-risk labor likely declines by 0.2% to 0.9% by 2040-2059 and by 0.8% to 2.4% by 2080-2099. For low risk labor supply, losses are more modest,with 2080-2099 losses in RCP 8.5 of 0.1% to 0.5%, with a 1-in-20 chance that labor supply falls more than 0.8% or less than 0.01%. Projected changes are smaller in magnitude for RCP 4.5 and RCP 2.6.
Kovats et al., 2011 Grey literature	Europe	Loss of labour productivity, derived from the GDP per labour force member using EU27 average productivity cost value of €287 per day.	all work sectors (agriculture, industry, and service)	Under the current climate, the only impacts are in Southern Europe, where losses were estimated to be 0.14% days lost. Higher impacts are projected for Mediterranean countries with climate change. Under A1B scenario, for Southern Europe a 0-4-0.9% loss in productive days by the 2080s. Total productivity losses (whole European area) are estimated at €120 - 320 million/ in the 2050s, rising to €300 - 740 million/ in the 2080s under A1B scenario.
Lee 2018	South Korea	outdoor labor productivity loss by intensity (moderate and heavy work)	outdoor laborers	For moderate work productivity losses by 4.8% and 15.8% by 2071-2100 under RCPs 4.5 and 8.5, respectively, compared to the current level of 99.9%. Productivity losses for heavy work are 12% (RCP4.5) and 26.1% (RCP8.5). Areas with larger productivity losses are those with higher proportion of outdoor workers.
Licker 2022	US	Annual earnings (Billions USD) at risk (%) for moderate and light workload	outdoor workers (included agriculture, construction and transportation)	the average outdoor worker in the United States risks losing approximately $1,200 in earnings per year under RCP4.5 and approximately $1,700 per year under RCP8.5. In terms of absolute dollar values, at mid-century under RCP8.5, total potential losses are highest for construction and extraction occupations.
Liu 2020	China	Changes in labor capacity are then estimated for light, moderate and heavy work	outdoor workers	Large decreases (more than 40%) in labor capacity of heavy work due to increased WBGT were found for many areas of China in the future, especially at the end of the century under RCP8.5. In South and East China, labor capacity of light work would also experience a significant decrease (by 40% to 50%) under the high emission scenario.
Martinich 2019	US	Lost Labor Hours (millions) and Lost wages (US dollars) in high-risk industries from the 2003–2007 reference period, normalized by the high-risk working population by county	as specified in Graff Zivin, J. and M. Neidell 2014	44,000 US dollars in terms of wages lost in 2050 and 160,000 US dollars wages lost in 2090 under RCP8.5
Orlov et al., 2019	10 European countries	Productivity loss estimated using the Hothaps exposure-response functions and the ISO standards under high and moderate intensity work. To assess the direct economic losses (or direct private costs), we use the social accounting data	outdoor workers (agriculture and construction)	In August of 2003, the mean value of direct economic losses resulting from heat-induced reductions in worker productivity in the agricultural sector in the top ten most affected European countries accounted for approximately $83 per worker, whereas in July of 2010, it was $59 per worker, and in July of 2015, it was $90 per worker. construction sector, the mean value of direct economic losses in August of 2003 amounted to $61 per worker, in July of 2010, it was $41 per worker, and in July of 2015, it was $72 per worker
Park 2016	US	payroll per capita change (%)	non agricoltural sectors	an additional day above 90°F results in a -0.048% decline in payroll per capita that year. Productivity losses are larger in colder than in warmer areas.
Parks	US	total cost of lost labor (%)	low and high risk sectors	In high-risk sectors, total cost of lost labor from 0.3% in 1983 to 0.58% in 2016
Rao 2020	India	Percent decrease in labour productivity (%)	not specified	he coastal regions of India (east and west coast) are found to be more vulnerable to heat stress impacts by showing a perceptible increase in the notorious impact days and a decline of 30 to 40% in the work performance, particularly in east coast region

Regional studies using current and future climate projections				
Reference	**Coverage**	**Economic loss unit measure**	**Work sectors**	**Results**
Somanathan 2015 grey	India	time series study of heat and productivity	manufacturing industry	Ambient temperatures have non-linear effects on worker productivity, with declines on hot days of 4 to 9 percent per degree rise in temperature. Sustained heat also increases absenteeism
Somanathan, E. 2021	India	time series study of heat and productivity	manufacturing industry	the impact of a 1°C increase in temperature on district output was a declines of 3% per 1°C
Suzuki-Parker 2015	Tokio and Osaka (Japan)	Hours losses (%)	light and heavy labour work	Light labor hours are projected to decrease by 30–40 % by the end of the twenty-first century, while reductions reach 60–80 % for heavy labor hours
Szewczyk, W. 2021	Europe	Labour productivity change (%)	4 classes based on occupational vulnerability to heat stress	productivity of labour can be 1.6% lower in Europe in the worst case scenario. in 2080s, with a clear geographical gradient showing that southern and eastern regions are much more affected
TNC 2021	Phoenix area (US)	Losses to Gross Regional Product (GRP)	all work sectors	Labour productivity losses are $855 and $964 million US dollars in 2020-2039 and 2040-2059 respectively
Vivid Economy UK 2017	Ethiopia, Ghana, India, Jordan, Tanzania	Total employment and 'equivalent effective workers' lost due to heat stress	agriculture, manufacturing, construction, other industry, wholesale and retail trade, transport, storage and communication, and other services.	losses are 1-5% of productivity for a 1.5 °C temperature. In India the reduction is 20% of total workforce hours lost due to heat stress, the other countries losses are lower.
Xia et al., 2018	Nanjing, China	Industrial Reduced Productive Working Time and economic loss estimated from monetary value of sector outputs	all work sectors	$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:10.7%, agriculture: 7.6%, energy supply: 3.3%, mining: 0.9%.
Zhang 2021	US	labour losses (billions US dollars) and losses as percentage of GDP (%)	light, medium and heavy work	Actual labour losses are $1.7 billion annually comparing 2006-2016 with 1980–1990. Whereas 2006–2016 losses correspond to 0.07% of the 2016 GDP, the 2100s losses rise roughly fourfold to 0.3%
Zhao 2016	China	labour losses (billions Yuan) and losses as percentage of GDP (%)	all work sectors	the total cost of high temperature subsides in China is 38.6 billion yuan/y (US $6.22 billion/y) over the 1979–2005 period, 0.2% of the gross domestic product (GDP). Costs may reach 250 billion yuan/y in the 2030s and 1,000 billion yuan/y in 2100.
Zivin 2010	US	labour supply	outdoor and indoor sectors	For labor supply, there is little response to temperatures below 80 degrees, but monotonic declines in labor supply above 85 degrees. At temperatures over 100 degrees, labor supply drops by a statistically significant 59 minutes as compared to 76-80 degrees.

Appendice 1. Search strategy

Database: Pubmed

Esposizione (caldo, elevate temperature, ondate di calore, cambiamenti climatici)	
#1	"Hot Temperature"[Mesh]
#2	(Heat[Title/Abstract] AND (exposure[Title/Abstract] OR stress[Title/Abstract] OR strain[Title/Abstract]))
#3	hot[Title/Abstract] AND weather[Title/Abstract]
#4	(hot[Title/Abstract] OR summer[Title/Abstract] OR high[Title/Abstract] OR extreme[Title/Abstract] OR ambient[Title/Abstract]) AND temperature*[Title/Abstract]
#5	heatwave*[Title/Abstract] OR WBGT[Title/Abstract]
#6	heat[Title/Abstract] AND wave*[Title/Abstract]
#7	climat*[Title/Abstract] AND (change*[Title/Abstract] or variat*[Title/Abstract])
#8	#1 or #2 or #3 or #4 or #5 or #6
Populazione (lavoratori)	
#9	Work*[Title/Abstract] OR employ*[Title/Abstract] OR labour*[Title/Abstract] OR labor*[Title/Abstract] or occupation*[Title/Abstract] or job*[Title/Abstract]
#10	"Occupational Groups"[Mesh]
#11	#9 OR #10
Outcome (costi, produttività, impatti sociali)	
#12	"Occupational Injuries/economics"[Mesh]
#13	"Cost of Illness"[Mesh]
#14	(impact*[Title/Abstract] OR burden[Title/Abstract] OR toll[Title/Abstract] OR benefit[Title/Abstract] OR gain*[Title/Abstract]) AND (Socio*[Title/Abstract] OR social*[Title/Abstract] societ*[Title/Abstract] OR economic*[Title/Abstract] OR economy[Title/Abstract])
#15	cost*[Title/Abstract]
#16	(sick*[Title/Abstract] OR disability[Title/Abstract] OR injury[Title/Abstract] OR accident[Title/Abstract]) AND (leave*[Title/Abstract] OR allowance[Title/Abstract] OR compensation[Title/Abstract])
#17	productiv*[Title/Abstract] OR efficiency[Title/Abstract] OR absenc*[Title/Abstract] OR absent*[Title/Abstract] OR loss*[Title/Abstract]
#18	"Absenteeism"[Mesh]
#19	"Efficiency"[Mesh]
#20	#12 or #13 or #14 or #15 or #16 or #17 or #18 or #19
#21	#8 AND #11 AND #20
#22	#21 AND "Humans"[Mesh]

(aggiornamento search ad Aprile 2022)

Database: Web of science (aggiornamento search ad Aprile 2022)

Esposizione (caldo, elevate temperature, ondate di calore, cambiamenti climatici)	
#1	TI=(heat AND (exposure OR stress OR strain))
#2	AB=(heat AND (exposure OR stress OR strain))
#3	TI=(hot AND weather)
#4	AB=(hot AND weather)
#5	TI=((hot OR summer OR high OR extreme OR ambient) AND temperature*)
#6	AB=((hot OR summer OR high OR extreme OR ambient) AND temperature*)
#7	TI=(heatwave* or wbgt)
#8	AB=(heatwave* or wbgt)
#9	TI=(heat AND wave*)
#10	AB=(heat AND wave*)
#11	TI=(climat* AND (change* or variat))
#12	AB=climat* AND (change* or variat))
#13	#1 or #2 or #3 or #4 or #5 or #6 or #7 or #8 or #9 or #10 or #11 or #12
Populazione (lavoratori)	
#14	TI=(Work* OR employ* OR labour* OR labor* or occupation* job*)
#15	AB=(Work* OR employ* OR labour* OR labor* or occupation* job*)
#16	#14 OR #15
Outcome (costi, produttività, impatti sociali)	
	TI=((impact* OR burden OR toll OR benefit OR gain*) AND (Socio* OR social* OR societ* OR economic* OR economy))
	AB=((impact* OR burden OR toll OR benefit OR gain*) AND (Socio* OR social* OR societ* OR economic* OR economy))
	TI=(cost*)
	AB=(cost*)
	TI= ((sick* OR disability OR injury OR accident) AND (leave* OR allowance OR compensation))
	AB= ((sick* OR disability OR injury OR accident) AND (leave* OR allowance OR compensation))
	TI=(productiv* OR efficiency or absenc* OR absent* OR loss*)
	AB=(productiv* OR efficiency or absenc* OR absent* OR loss*)
	#12 or #13 or #14 or #15 or #16 or #17 or #18 or #19
	#8 AND #11 AND #20
	Pulizia in WOS

Bibliografia

1. Amnuaylojaroen T, Atsamon Limsakul, Sukrit Kirtsaeng, Nichapa Parasin, and Vanisa Surapipith: Effect of the Near-Future Climate Change under RCP8.5 on the Heat Stress and Associated Work Performance in Thailand. 2022(Atmosphere).

2. Anderson NJ, Wuellner SE, Bonauto DK: Immediate Inpatient Hospitalizations for Work-Related Injury or Illness - Washington State , 2015. 2018(5).

3. Ankrah Twumasi M, Jiang Y: The impact of climate change coping and adaptation strategies on livestock farmersâ€™ technical efficiency: the case of rural Ghana. Environmental Science and Pollution Research 2021, 28(12):14386-14400.

4. Anne deBoer w, Schwimmer E, McGregor A, Adibi S, Kapoor A, Duong S, Love J, Bonham-Carter C, Lindquist J, Bermudez D et al: Economic Assessment of Heat in the Phoenix Metro Area. 2021.

5. Ayyappan R, Sankar S, Rajkumar P, Balakrishnan K: Work-related heat stress concerns in automotive industries: A case study from Chennai, India. Global Health Action 2009, 2(1).

6. Barreca A, Clay K, Deschenes O, Greenstone M, Shapiro JS: Adapting to climate change: The remarkable decline in the US temperature-mortality relationship over the Twentieth Century. Journal of Political Economy 2016, 124(1):105-159.

7. Behrer AP, Park J: Will We Adapt? Temperature, Labor and Adaptation to Climate Change. Working Paper 2017:39p-39p.

8. Binazzi A, Levi M, Bonafede M, Bugani M, Messeri A, Morabito M, Marinaccio A, Baldasseroni A: Evaluation of the impact of heat stress on the occurrence of occupational injuries: Meta-analysis of observational studies. Am J Ind Med 2019, 62(3):233-243.

9. Bodin T, GarcÃ-a-Trabanino R, Weiss I, JarquÃ-n E, Glaser J, Jakobsson K, Lucas RAI, Wesseling C, Hogstedt C, Wegman DH et al: Intervention to reduce heat stress and improve efficiency among sugarcane workers in El Salvador: Phase 1. Occupational and Environmental Medicine 2016, 73(6):409-416.

10. Bonauto D, Anderson R, Rauser E, Burke B: Occupational heat illness in Washington state, 1995-2005. American Journal of Industrial Medicine 2007, 50(12):940-950.

11. Borg MA, Xiang J, Anikeeva O, Pisaniello D, Hansen A, Zander K, Dear K, Sim MR, Bi P: Occupational heat stress and economic burden: A review of global evidence. Environmental Research 2021, 195(June 2020):110781-110781.

12. Bosello F, Standardi G: A sub-national CGE model for the european mediterranean countries. The New Generation of Computable General Equilibrium Models: Modeling the Economy 2018(December):279-308.

13. Bosetti V, Frankel J: The Harvard Project on Climate Agreements. 2011(September).

14. Budhathoki NK, Zander KK: Socio-Economic Impact of and Adaptation to Extreme Heat and Cold of Farmers in the Food Bowl of Nepal. International journal of environmental research and public health 2019, 16(9).

15. Burke M, Hsiang SM, Miguel E: Global non-linear effect of temperature on economic production. Nature 2015, 527(7577):235-239.

16. Cachon G, Gallino S, Olivares M: Severe Weather and Automobile Assembly Productivity. SSRN Electronic Journal 2012:1-31.

17. Chavaillaz Y, Roy P, Partanen AL, Da Silva L, Bresson E, Mengis N, Chaumont D, Matthews HD: Exposure to excessive heat and impacts on labour productivity linked to cumulative CO2 emissions. Scientific reports 2019, 9:11-11.

18. Cortez OD: Heat stress assessment among workers in a Nicaraguan sugarcane farm. Global Health Action 2009, 2(1):65-71.

19. Costa H, Floater G, Hooyberghs H, Verbeke S, De Ridder K: Climate change, heat stress and labour productivity: A cost methodology for city economies. Centre for Climate Change Economics and Policy Working Paper 2016(278):15-15.

20. Dâ€™Erario N GMVA: Quali Costi per la Mancata Prevenzione ? Review, Literature. Adpt-Ministero della Salute Italiana - Inail.

21. Dally M, Butler-Dawson J, Krisher L, Monaghan A, Weitzenkamp D, Sorensen C, Johnson RJ, Carlton EJ, Asensio C, Tenney L et al: The impact of heat and impaired kidney function on productivity of Guatemalan sugarcane workers. PLoS ONE 2018, 13(10):1-15.

22. Dara: Climate Vulnerability Monitor 2nd Edition. A Guide to the Cold Calculus of a Hot Planet; 2012.

23. Das S: Temperature increase, labor supply and cost of adaptation in developing economies: Evidence on urban workers in informal sectors. Climate Change Economics 2015, 6(2):1-24.

24. Dasgupta S, van Maanen N, Gosling SN, Piontek F, Otto C, Schleussner CF: Effects of climate change on combined labour productivity and supply: an empirical, multi-model study. The Lancet Planetary Health 2021, 5(7):e455-e465.

25. Davey SL, Lee BJ, Robbins T, Randeva H, Thake CD: Heat stress and PPE during COVID-19: impact on healthcare workers' performance, safety and well-being in NHS settings. Journal of Hospital Infection 2021, 108:185-188.

26. De Lima CZ, Buzan JR, Moore FC, Baldos ULC, Huber M, Hertel TW: Heat stress on agricultural workers exacerbates crop impacts of climate change. Environmental Research Letters 2021, 16(4).

27. Dear K: Modelling Productivity Loss from Heat Stress. Atmosphere 2018, 9(7):9-9.

28. Dell M, Jones BF, Olken BA: Temperature and income: Reconciling new cross-sectional and panel estimates. American Economic Review 2009, 99(2):198-204.

29. Dell M, Jones BF, Olken BA: Temperature shocks and economic growth: Evidence from the last half century. American Economic Journal: Macroeconomics 2012, 4(3):66-95.

30. Dell M, Jones BF, Olken BA: What do we learn from the weather? The new climate-economy literature. Journal of Economic Literature 2014, 52(3):740-798.

31. Deloitte: A new choice: Australia's climate for growth. 2020(November):1-68.

32. Deryugina T, Hsiang S: The Marginal product of climate. National Bureau of Economic Research Working Paper Series 2014, No. 20750:1-47.

33. Dunne JP, Stouffer RJ, John JG: Reductions in labour capacity from heat stress under climate warming. Nature Climate Change 2013, 3(6):563-566.

34. Flouris AD, Dinas PC, Ioannou LG, Nybo L, Havenith G, Kenny GP, Kjellstrom T: Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis. The Lancet Planetary Health 2018, 2(12):e521-e531.

35. Fortune MK, Mustard CA, Etches JJ, Chambers AG: Work-attributed illness arising from excess heat exposure in Ontario, 2004-2010. Can J Public Health 2013, 104(5):e420-426.

36. Foster J, Smallcombe JW, Hodder S, Jay O, Flouris AD, Nybo L, Havenith G: An advanced empirical model for quantifying the impact of heat and climate change on human physical work capacity. International Journal of Biometeorology 2021, 65(7):1215-1229.

37. GarcÃ-a-LeÃ³n D, Casanueva A, Standardi G, Burgstall A, Flouris AD, Nybo L: Current and projected regional economic impacts of heatwaves in Europe. Nature Communications 2021, 12(1):1-10.

38. GarcÃ-a-LeÃ³n D, Standardi G, Staccione A: An integrated approach for the estimation of agricultural drought costs. Land Use Policy 2021, 100(May 2020):104923-104923.

39. Graham F, Bujak A, Hamill G, Lee M: WP 5 : Development of a cost assessment framework for adaptation D5 . 1 : Review of climate change losses and adaptation costs for case studies. RAMSES Project 2014, 308497(308497):1-158.

40. Gubernot DM, Anderson GB, Hunting KL: The epidemiology of occupational heat exposure in the United States: a review of the literature and assessment of research needs in a changing climate. International Journal of Biometeorology 2014, 58(8):1779-1788.

41. Gun RT, Budd GM: Effects of thermal, personal and behavioural factors on the physiological strain, thermal comfort and productivity of Australian shearers in hot weather. Ergonomics 1995, 38(7):1368-1384.

42. Hanna EG, Kjellstrom T, Bennett C, Dear K: Climate change and rising heat: population health implications for working people in Australia. Asia-Pacific journal of public health 2011, 23(2 Suppl):14S-26.

43. Heal G, Park J: Reflections-temperature stress and the direct impact of climate change: A review of an emerging literature. Review of Environmental Economics and Policy 2016, 10(2):347-362.

44. Heal GM, Park J: Feeling the Heat: Temperature, Physiology & the Wealth of Nations. SSRN Electronic Journal 2021(January).

45. Heinzerling A, Laws RL, Frederick M, Jackson R, Windham G, Materna B, Harrison R: Risk factors for occupational heat-related illness among California workers, 2000â€"2017. American Journal of Industrial Medicine 2020, 63(12):1145-1154.

46. Hesketh M, Wuellner S, Robinson A, Adams D, Smith C, Bonauto D: Heat related illness among workers in Washington State: A descriptive study using workers' compensation claims, 2006-2017. American Journal of Industrial Medicine 2020, 63(4):300-311.

47. Hsiang SM: Temperatures and cyclones strongly associated with economic production in the Caribbean and Central America. Proceedings of the National Academy of Sciences of the United States of America 2010, 107(35):15367-15372.

48. HÃ¼bler M, Klepper G, Peterson S: Costs of climate change. The effects of rising temperatures on health and productivity in Germany. Ecological Economics 2008, 68(1-2):381-393.

49. Ioannou LG, Mantzios K, Tsoutsoubi L, Panagiotaki Z, Kapnia AK, Ciuha U, Nybo L, Flouris AD, Mekjavic IB: Effect of a simulated heat wave on physiological strain and labour productivity. International Journal of Environmental Research and Public Health 2021, 18(6):1-17.

50. Kenefick RW, Sawka MN: Hydration at the Work Site. Journal of the American College of Nutrition 2007, 26(October 2014):597S-603S.

51. Kershaw T, Lash D: Investigating the productivity of office workers to quantify the effectiveness of climate change adaptation measures. Building and Environment 2013, 69:35-43.

52. Kjellstrom T: 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-Pacific Journal of Public Health 2014, 28:28S-37S.

53. Kjellstrom T: 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 Public Health 2016, 28(2 Suppl):28s-37s.

54. 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 2016, 37:97-112.

55. Kjellstrom T, Crowe J: Climate Change, Workplace Heat Exposure, and Occupational Health and Productivity in Central America, vol. 17; 2011.

56. Kjellstrom T, Freyberg C, Lemke B, Otto M, Briggs D: Estimating population heat exposure and impacts on working people in conjunction with climate change. International Journal of Biometeorology 2018, 62(3):291-306.

57. Kjellstrom T, Holmer I, Lemke B: Workplace heat stress, health and productivity-an increasing challenge for low and middle-income countries during climate change. Global Health Action 2009, 2(1):1-6.

58. Kjellstrom T, Kovats RS, Lloyd SJ, Holt T, Tol RSJ: The direct impact of climate change on regional labor productivity. Archives of Environmental and Occupational Health 2009, 64(4):217-227.

59. Kjellstrom T, Lemke B, Otto M: Mapping occupational heat exposure and effects in South-East Asia: ongoing time trends 1980-2011 and future estimates to 2050. Ind Health 2013, 51(1):56-67.

60. Knapik JJ, Canham-Chervak M, Hauret K, Laurin MJ, Hoedebecke E, Craig S, Montain SJ: Seasonal variations in injury rates during US Army Basic Combat Training. The Annals of occupational hygiene 2002, 46(1):15-23.

61. Knez W, Girard O, Racinais S, Walsh A, Gaoua N, Grantham J: Does living and working in a hot environment induce clinically relevant changes in immune function and voluntary force production capacity? Industrial Health 2014, 52(3):235-239.

62. Knittel N, Jury MW, Bednar-Friedl B, Bachner G, Steiner AK: A global analysis of heat-related labour productivity losses under climate change-implications for Germany's foreign trade. Climatic Change 2020, 160(2):251-269.

63. Kopp R, Rasmussen DJ, Mastrandrea M: American Climate Prospectus: Economic Risks in the United States. Rhodium Group 2014, 1.2(October):1-202.

64. Koteswara Rao K, Lakshmi Kumar TV, Kulkarni A, Ho CH, Mahendranath B, Desamsetti S, Patwardhan S, Dandi AR, Barbosa H, Sabade S: Projections of heat stress and associated work performance over India in response to global warming. Scientific Reports 2020, 10(1):1-14.

65. Krishnamurthy M, Ramalingam P, Perumal K, Kamalakannan LP, Chinnadurai J, Shanmugam R, Srinivasan K, Venugopal V: Occupational Heat Stress Impacts on Health and Productivity in a Steel Industry in Southern India. Saf Health Work 2017, 8(1):99-104.

66. Kuhla K, Willner SN, Otto C, Wenz L, Levermann A: Future heat stress to reduce peopleâ€™s purchasing power. PLoS ONE 2021, 16(6 June):1-17.

67. Lam M, Krenz J, PalmÃndez P, Negrete M, Perla M, Murphy-Robinson H, Spector JT: Identification of barriers to the prevention and treatment of heat-related illness in Latino farmworkers using activity-oriented, participatory rural appraisal focus group methods. BMC public health 2013, 13:1004-1004.

68. Lamb S, Kwok KCS: A longitudinal investigation of work environment stressors on the performance and wellbeing of office workers. Applied Ergonomics 2016, 52:104-111.

69. Langkulsen U, Vichit-Vadakan N, Taptagaporn S: Health impact of climate change on occupational health and productivity in Thailand. Global Health Action 2010, 3(1):5607-5607.

70. Lao J, Hansen A, Nitschke M, Hanson-Easey S, Pisaniello D: Working smart: An exploration of council workers' experiences and perceptions of heat in Adelaide, South Australia. Safety Science 2016, 82:228-235.

71. Lee J, Venugopal V, Latha PK, Alhadad SB, Leow CHW, De Goh NY, Tan E, Kjellstrom T, Morabito M, Lee JKW: Heat stress and thermal perception amongst healthcare workers during the covid-19 pandemic in india and singapore. International Journal of Environmental Research and Public Health 2020, 17(21):1-12.

72. Lee S-W, Lee K, Lim B: Effects of climate change-related heat stress on labor productivity in South Korea. International journal of biometeorology 2018, 62(12):2119-2129.

73. Levi M, Kjellstrom T, Baldasseroni A: Impact of climate change on occupational health and productivity: A systematic literature review focusing on workplace heat. Medicina del Lavoro 2018, 109(3):163-179.

74. Li X, Chow KH, Zhu Y, Lin Y: Evaluating the impacts of high-temperature outdoor working environments on construction labor productivity in China: A case study of rebar workers. Building and Environment 2016, 95:42-52.

75. Licker R, Dahl K, Abatzoglou JT: Quantifying the impact of future extreme heat on the outdoor work sector in the United States. Elementa 2022, 10(1):1-16.

76. Lin RT, Chan CC: Effects of heat on workers' health and productivity in Taiwan. Global Health Action 2009, 2(1).

77. Liu X: Reductions in Labor Capacity from Intensified Heat Stress in China under Future Climate Change. International journal of environmental research and public health 2020, 17(4).

78. Lundgren K, Kuklane K, Gao C, HolmÃ©r I: Effects of heat stress on working populations when facing climate change. Industrial health 2013, 51(1):3-15.

79. Lundgren K, Kuklane K, Venugopal V: Occupational heat stress and associated productivity loss estimation using the PHS model (ISO 7933): a case study from workplaces in Chennai, India. Glob Health Action 2014, 7:25283-25283.

80. Lundgren-Kownacki K, Dahl M, Gao C, Jakobsson K, Linninge C, Song D, Kuklane K: Exploring how a traditional diluted yoghurt drink may mitigate heat strain during medium-intensity intermittent work: A multidisciplinary study of occupational heat strain. Industrial Health 2018, 56(2):106-121.

81. Lundgren-Kownacki K, Kjellberg SM, Gooch P, Dabaieh M, Anandh L, Venugopal V: Climate change-induced heat risks for migrant populations working at brick kilns in India: a transdisciplinary approach. International journal of biometeorology 2018, 62(3):347-358.

82. Ma R, Zhong S, Morabito M, Hajat S, Xu Z, He Y, Bao J, Sheng R, Li C, Fu C et al: Estimation of work-related injury and economic burden attributable to heat stress in Guangzhou, China. Science of the Total Environment 2019, 666:147-154.

83. Marchetti E, Capone P, Freda D: Climate change impact on microclimate of work environment related to occupational health and productivity. Annali dell'Istituto superiore di sanita 2016, 52(3):338-342.

84. MartÃ-nez-Solanas Ãˆ, LÃ³pez-Ruiz M, Wellenius GA, Gasparrini A, Sunyer J, Benavides FG, BasagaÃ±a X: Evaluation of the impact of ambient temperatures on occupational injuries in Spain. Environmental Health Perspectives 2018, 126(6):1-10.

85. Martinich J, Crimmins A: Climate damages and adaptation potential across diverse sectors of the United States. Nature Climate Change 2019, 9(5):397-404.

86. Mathee A, Oba J, Rose A: Climate change impacts on working people (the HOTHAPS initiative): findings of the South African pilot study. Global Health Action 2010, 3(1):5612-5612.

87. Matsuzuki H, Ito A, Ayabe M, Haruyama Y, Tomita S, Katamoto S, Muto T: The effects of work environments on thermal strain on workers in commercial kitchens. Industrial health 2011, 49(5):605-613.

88. Mazlomi A, Golbabaei F, Farhang Dehghan S, Abbasinia M, Mahmoud Khani S, Ansari M, Hosseini M: The influence of occupational heat exposure on cognitive performance and blood level of stress hormones: a field study report. International Journal of Occupational Safety and Ergonomics 2017, 23(3):431-439.

89. Messeri A, Bonafede M, Pietrafesa E, Pinto I, Deâ€™donato F, Crisci A, Lee JKW, Marinaccio A, Levi M, Morabito M: A web survey to evaluate the thermal stress associated with personal protective equipment among healthcare workers during the covid-19 pandemic in Italy. International Journal of Environmental Research and Public Health 2021, 18(8):1-21.

90. Messeri A, Morabito M, Bonafede M, Bugani M, Levi M, Baldasseroni A, Binazzi A, Gozzini B, Orlandini S, Nybo L et al: Heat stress perception among native and migrant workers in italian industriesâ€"case studies from the construction and agricultural sectors. International Journal of Environmental Research and Public Health 2019, 16(7).

91. Mirabelli MC, Quandt SA, Crain R, Grzywacz JG, Robinson EN, Vallejos QM, Arcury TA: Symptoms of heat illness among Latino farm workers in North Carolina. American Journal of Preventive Medicine 2010, 39(5):468-471.

92. Mohamed S, Srinavin K: Forecasting labor productivity changes in construction using the PMV index. International Journal of Industrial Ergonomics 2005, 35(4):345-351.

93. Morabito M, Messeri A, Crisci A, Bao JZ, Ma R, Orlandini S, Huang CR, Kjellstrom T: Heat-related productivity loss: benefits derived by working in the shade or work-time shifting. International Journal of Productivity and Performance Management:19-19.

94. Morrissey MC, Brewer GJ, Williams WJ, Quinn T, Casa DJ: Impact of occupational heat stress on worker productivity and economic cost. American Journal of Industrial Medicine 2021, 64(12):981-988.

95. Mostafa M: Constructed Environment. 2016, 3(1).

96. Moyce SC, Schenker M: Occupational Exposures and Health Outcomes Among Immigrants in the USA. Current environmental health reports 2017, 4(3):349-354.

97. Muth CM: Heat-related illnesses. Notfall und Rettungsmedizin 2020, 23(4):299-312.

98. Nag A, Kumar Nag P: Heat Stress of Women Doing Manipulative Work. American Industrial Hygiene Association Journal 1992, 53(12):751-756.

99. National Climate Change Adaptation Research F: What are the RCPs? Coast Adapt 2017.

100. Niemela R, Hannula M, Rautio S, Reijula K, Railio J: The effect of air temperature on labour productivity in call centres - A case study. Energy and Buildings 2002, 34(8):759-764.

101. No IZADP, Park RJ, Pankratz N, Behrer AP, Park RJ, Pankratz N: DISCUSSION PAPER SERIES Temperature , Workplace Safety , and Labor Market Inequality Temperature , Workplace Safety , and Labor Market Inequality. 2021(14560).

102. Nunfam VF, Adusei-Asante K, Van Etten EJ, Oosthuizen J, Frimpong K: Social impacts of occupational heat stress and adaptation strategies of workers: A narrative synthesis of the literature. Science of the Total Environment 2018, 643:1542-1552.

103. Nunfam VF, Afrifa-Yamoah E: Heat exposure effect on Ghanaian mining workers: A mediated-moderation approach. Science of the Total Environment 2021, 788:147843-147843.

104. Orlov A, Sillmann J, Aaheim A, Aunan K, de Bruin K: Economic Losses of Heat-Induced Reductions in Outdoor Worker Productivity: a Case Study of Europe. Economics of Disasters and Climate Change 2019, 3(3):191-211.

105. Orlov A, Sillmann J, Aunan K, Kjellstrom T, Aaheim A: Economic costs of heat-induced reductions in worker productivity due to global warming. Global Environmental Change-Human and Policy Dimensions 2020, 63:13-13.

106. Oyekale AS: Climate change induced occupational stress and reported morbidity among cocoa farmers in South-Western Nigeria. Annals of Agricultural and Environmental Medicine 2015, 22(2):357-361.

107. Page L, Sheppard S: Heat Stress: the impact of ambient temperature on occupational injuries in the US. Department of Economics Working Papers 2016:1-47.

108. Parks D, Xu M: An Economic Assessment of Extreme Heat Events on Labor Productivity in the Table of Contents.

109. Parsons LA, Masuda YJ, Kroeger T, Shindell D, Wolff NH, Spector JT: Global labor loss due to humid heat exposure underestimated for outdoor workers. Environmental Research Letters 2022, 17(1).

110. Patz JA, Frumkin H, Holloway T, Vimont DJ, Haines A: Climate change: Challenges and opportunities for global health. JAMA - Journal of the American Medical Association 2014, 312(15):1565-1580.

111. Picciariello A, Id SC, Bazaz A, Roy R: Literature review - The costs of climate change in India. 2021.

112. Pradhan B, Shrestha S, Shrestha R, Pradhanang S, Kayastha B, Pradhan P: Assessing climate change and heat stress responses in the Tarai region of Nepal. Industrial health 2013, 51(1):101-112.

113. Quiller G, Krenz J, Ebi K, Hess JJ, Fenske RA, Sampson PD, Pan M, Spector JT: Heat exposure and productivity in orchards: Implications for climate change research. Archives of Environmental and Occupational Health 2017, 72(6):313-316.

114. Rameezdeen R, Elmualim A: The Impact of Heat Waves on Occurrence and Severity of Construction Accidents. Int J Environ Res Public Health 2017, 14(1).

115. Risks E, States U: Economic risks of climate change: an American prospectus. Choice Reviews Online 2016, 53(06):53-2694-2653-2694.

116. Roson R, Mensbrugghe DVd: Climate change and economic growth: impacts and interactions. International Journal of Sustainable Economy 2012, 4(3):270-270.

117. Roson R, Sartori M: Estimation of Climate Change Damage Functions for 140 Regions in the GTAP 9 Database (Supplementary files). Journal of Global Economic Analysis 2016, 1(2):78-115.

118. Sadiq LS, Hashim Z, Osman M: The Impact of Heat on Health and Productivity among Maize Farmers in a Tropical Climate Area. Journal of environmental and public health 2019, 2019:9896410-9896410.

119. Sahu S, Sett M, Kjellstrom T: Heat exposure, cardiovascular stress and work productivity in rice harvesters in India: implications for a climate change future. Industrial health 2013, 51(4):424-431.

120. Sancho-GarcÃ-a I, PiÃ±ero-Zapata M: Aumento de eventos cardiovasculares en pacientes tratados con clopidogrel y omeprazol simultÃ¡neamente: una revisiÃ³n sistemÃ¡tica. Evidentia 2021, 18:e12814-e12814.

121. Sett M, Sahu S: Effects of occupational heat exposure on female brick workers in West Bengal, India. Glob Health Action 2014, 7:21923-21923.

122. Sheffield PE, Herrera JGR, Lemke B, Kjellstrom T, Romero LEB: Current and future heat stress in Nicaraguan work places under a changing climate. Industrial health 2013, 51(1):123-127.

123. Singh S, Hanna EG, Kjellstrom T: Working in Australia's heat: Health promotion concerns for health and productivity. Health Promotion International 2015, 30(2):239-250.

124. Somanathan E, Somanathan R, Sudarshan A, Tewari M: The impact of temperature on productivity and labor supply: Evidence from indian manufacturing. Journal of Political Economy 2021, 129(6):1797-1827.

125. Spector JT, Masuda YJ, Wolff NH, Calkins M, Seixas N: Heat Exposure and Occupational Injuries: Review of the Literature and Implications. Current environmental health reports 2019, 6(4):286-296.

126. Suzuki-Parker A, Kusaka H: Future projections of labor hours based on WBGT for Tokyo and Osaka, Japan, using multi-period ensemble dynamical downscale simulations. International Journal of Biometeorology 2016, 60(2):307-310.

127. Szewczyk W, Mongelli I, Ciscar JC: Heat stress, labour productivity and adaptation in Europe - A regional and occupational analysis. Environmental Research Letters 2021, 16(10).

128. Table S, Lowering P, Comparing T, Intervention A, Cad MI: Supplementary appendix Supplementary Appendix. 2015, 6736(15):1-24.

129. Takakura Jy, Fujimori S, Takahashi K, Hijioka Y, Hasegawa T, Honda Y, Masui T: Cost of preventing workplace heat-related illness through worker breaks and the benefit of climate-change mitigation. Environmental Research Letters 2017, 12(6).

130. Tewari M, Sudarshan A: Working Paper 278 The Economic Impacts of Temperature on Industrial Productivity : Evidence from Indian Manufacturing Anant Sudarshan Meenu Tewari. 2014(278).

131. Tompa E, Mofidi A, van den Heuvel S, van Bree T, Michaelsen F, Jung Y, Porsch L, van Emmerik M: Economic burden of work injuries and diseases: a framework and application in five European Union countries. BMC Public Health 2021, 21(1):1-10.

132. United Nations Development P: Climate Change and Labour: Impacts of Heat in the Workplace. Climate Vulnerable Forum Secretariat 2016:36-36.

133. Vanos J, Vecellio DJ, Kjellstrom T: Workplace heat exposure, health protection, and economic impacts: A case study in Canada. American journal of industrial medicine 2019, 62(12):1024-1037.

134. Varghese BM: Understanding the Heat-Work Injury Phenomenon in Australia: An Evaluation of Risk, Susceptibility and Attributable Burden. 2019(December).

135. 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 2018, 110:380-392.

136. Venugopal V, Chinnadurai JS, Lucas RAI, Kjellstrom T: Occupational Heat Stress Profiles in Selected Workplaces in India. International journal of environmental research and public health 2015, 13(1).

137. Venugopal V, Latha PK, Shanmugam R, Krishnamoorthy M, Omprashanth R, Lennqvist R, Johnson P: Epidemiological evidence from south Indian working populationâ€"the heat exposures and health linkage. Journal of Exposure Science and Environmental Epidemiology 2021, 31(1):177-186.

138. Venugopal V, Shanmugam R, Kamalakkannan LP: Heat-health vulnerabilities in the climate change context-comparing risk profiles between indoor and outdoor workers in developing country settings. Environmental Research Letters 2021, 16(8).

139. Vivid E: Impacts of higher temperatures on labour productivity and value for money adaptation: Lessons from five DFID priority country case studies. 2017(August).

140. Wyndham CH: Adaptation to heat and cold. Environmental Research 1969, 2(5-6):442-469.

141. Xia Y, Li Y, Guan D, Tinoco DM, Xia J, Yan Z, Yang J, Liu Q, Huo H: Assessment of the economic impacts of heat waves: A case study of Nanjing, China. Journal of Cleaner Production 2018, 171:811-819.

142. Xiang J, Bi P, Pisaniello D, Hansen A: The impact of heatwaves on workers[U+05F3] health and safety in Adelaide, South Australia. Environmental Research 2014, 133:90-95.

143. Xiang J, Bi P, Pisaniello D, Hansen A: Health impacts of workplace heat exposure: An epidemiological review. Industrial Health 2014, 52(2):91-101.

144. 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 2019, 60(9):E463-E469.

145. Yi W, Chan APC: Effects of Heat Stress on Construction Labor Productivity in Hong Kong: A Case Study of Rebar Workers. International journal of environmental research and public health 2017, 14(9).

146. Zander KK, Botzen WJW, Oppermann E, Kjellstrom T, Garnett ST: Heat stress causes substantial labour productivity loss in Australia. Nature Climate Change 2015, 5(7):647-+.

147. Zander KK, Mathew S: Estimating economic losses from perceived heat stress in urban Malaysia. Ecological Economics 2019, 159(June 2018):84-90.

148. Zealand N: The influence of skill and low back pain on peak and cumulative spine loads during wool harvesting . Poonam Pal A thesis submitted for the degree of Doctor of Philosophy at the University of Otago , Dunedin. 2010.

149. Zhang Y, Shindell DT: Costs from labor losses due to extreme heat in the USA attributable to climate change. Climatic Change 2021, 164(3-4):1-18.

150. Zhao Y, Sultan B, Vautard R, Braconnot P, Wang HJ, Ducharne A: Potential escalation of heat-related working costs with climate and socioeconomic changes in China. Proceedings of the National Academy of Sciences of the United States of America 2016, 113(17):4640-4645.

151. Zivin JG, Neidell MJ, Berman E, Currie J, Deb P, Glied S, Hanson G, Kellogg R, Mendelsohn R, Roberts M et al: Temperature and the Allocation of Time. Health (San Francisco) 2010.