

# Air temperatures and occupational injuries in the construction industries: a report from Northern Italy (2000–2013)

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**Abstract:** The aim of this study was to assess the relationship between environmental temperatures and occupational injuries (OIs) in construction workers (CWs) from a subalpine region of North-Eastern Italy. Data about OIs from 2000 to 2013, and daily weather for the specific site of the events were retrieved. Risk for daily OIs was calculated through a Poisson regression model. Estimated daily incidence for OIs was 5.7 (95%CI 5.5–5.8), or 2.8 OIs/10,000 workers/d (95%CI 2.7–2.9), with higher rates for time periods characterized by high temperatures (daily maximum  $\geq 35^{\circ}\text{C}$ ), both in first 2 d (3.57, 95%CI 3.05–4.11) and from the third day onwards (i.e. during Heat Waves: 3.43, 95%CI 3.08–3.77). Higher risk for OIs was reported in days characterized temperatures  $\geq 95$ th percentile (OR 1.145, 95%CI 1.062–1.235), summer days (daily maximum  $\geq 25^{\circ}\text{C}$ , OR 1.093, 95%CI 1.042–1.146). On the contrary, no significant increased risk was found for OIs having a more severe prognosis ( $\geq 40$  d or more; death). In conclusion, presented findings recommend policymakers to develop appropriate procedures and guidelines, in particular aimed to improve the compliance of younger CWs towards severe-hot daily temperatures.

**Key words:** Construction workers, Climate change, Heat exposure, Occupational injuries, Hot weather, Heat wave

## Introduction

During the last decades, climate changes have significantly affected both living and working environments<sup>1–3</sup>.

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) has estimated that between the 1850–1900 period and the 2003–2012 period average global temperatures have increased of  $0.78^{\circ}\text{C}$ <sup>4</sup>, and such transition was associated with a significant surge in both magnitude and frequency of extreme events such as heatwaves (HWs), with an even higher risk for population exposed to Mediterranean-like climates<sup>5</sup>. High environmental temperatures and HWs events have been strongly

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associated with population-level increases in morbidity and mortality for cardiovascular, respiratory and other illnesses, and the climate changes will presumptively increase both the incidence and the severity of these effects<sup>6–17</sup>).

Because of a combination of external thermal environment, heat sources in the workplace, and internal heat generation by physical activity associated with strenuous muscular work, climate changes and eventual heat exposure represent an even greater challenge to workers' health and safety, especially in persons with pre-existing illnesses<sup>2, 7, 18–28</sup>). The risk of heat-related health effects appears significantly increased in outdoors workers, including construction workers, for several reasons<sup>1, 3, 18, 29–36</sup>). First and foremost, even though the mechanization of many tasks has reduced the strenuous physical labour carried out by construction workers, many activities still requires strenuous manual work. Actually, extensive mechanization requires economic resources that are often beyond the financial capacity of many small companies (i.e. <10 employees)<sup>30, 37, 38</sup>). Second, due to the physical nature of construction industry, construction workers usually perform their activities outdoors, being poorly protected against meteorological factors such as extreme heat and solar radiation<sup>30, 39</sup>). Third, health and safety training in the construction industry are frequently inadequate, and again small companies are less likely to implement appropriate procedures and guidelines<sup>30, 32, 37–40</sup>). Hence, many workers may continue to work beyond a safe heat exposure limit as they are unaware of the risks associated with the heat exposure, or have inappropriate knowledge of the preventive measures, as avoiding the hottest hours of the day for most strenuous physical exertion, or increasing the water intake during the HWs<sup>41, 42</sup>).

Available evidence suggests that heat-related health effects include a significantly increased risk of occupational injuries<sup>1, 29, 30, 43, 44</sup>). As high temperatures can affect cognition, hamper concentration, reduce vigilance and increase fatigue, working during warm weather would ultimately increase the risk of mistakes, accidents and injuries<sup>18, 35, 36, 44–46</sup>), especially in subjects who otherwise would spend little time outdoor, such as part-time or seasonal workers<sup>29</sup>). Moreover, higher temperatures may force the workers to reduce the use of personal protective equipment, ultimately increasing the risk for incidents associated with the exposure to dusts and chemicals<sup>1, 3, 18, 29–36, 43</sup>).

As climate change effects gradually progress, the importance of understanding the impact of hot climate on injuries in the construction industry, and preventing them through appropriate preparedness and emergency

response plans in the workplace becomes a growing challenge for occupational health and safety<sup>1, 3, 18, 24, 29, 32, 35, 36, 44, 47–49</sup>). The aim of this study was therefore to assess to what extent Construction workers have been impacted by hot weather in a highly developed settings, i.e. the North-Eastern Italian region of Trentino (Autonomous Province of Trento).

## Methods

### *Settings*

Autonomous Province of Trento is located in the Italy's North East, covers a total area of 6,214 km<sup>2</sup> (2,399 sq mi) and has a population of 537,416 habitants (2015 census). According to available data and labor force statistics from the Statistical Institute of the Autonomous Province of Trento (ISPAT) in the last decade workforce encompassed around 250,000 adult age subjects per year, and construction industry employed around 9.2% of total (i.e. around 20,000 adult age subjects/year, 14.8% of total male workforce)<sup>50</sup>).

### *Meteorological data*

Meteorological data, including daily average (Tday), minimum (Tmin), maximum (Tmax) temperatures, air relative humidity, atmospheric pressure, wind speed and solar irradiation for the study period were obtained from the Meteotrentino Service (<http://www.meteotrentino.it/dati-meteo/info-dati.aspx?ID=3>) of the APT. Meteotrentino Archive includes data from a total of 214 meteorological stations scattered over the provincial area, allowing to direct link geographical site of injury with air temperature at the time of the accident. As data about air relative humidity, wind speed and solar irradiation were not available for all meteorological stations, data from the nearest station at the time of the index injury were ultimately retrieved. Exposure groups were defined as follows. As otherwise suggested<sup>49</sup>), calendar days were initially categorized by Tmin and Tmax as follows: Frost days (i.e. days with Tmin <0°C), Summer days (i.e. days with Tmax >25°C), Summer days/Tropical Nights (i.e. days with Tmax >25°C and Tmin >20°C). Days not included in the aforementioned definition were classified as "Neutral days". Currently, there is no universal definition of a HW, although most studies have defined HW as a combination of duration (e.g. 3 or more days) and intensity (either as Tmax or average daily temperatures)<sup>52, 53</sup>). In order to more easily compare our estimated with previous studies on HWs, an HW event was defined by 3 or more consecutive days having Tmax

$\geq 35^{\circ}\text{C}$ <sup>30, 35, 36, 43</sup>). Eventually, in order to assess the effect of average daily temperature,  $T_{\text{day}}$  were arbitrarily categorized into the following <5th, 5–24th, 25–74th, 75–94th and  $\geq 95$ th percentiles.

### *Occupational injuries*

Data on occupational injuries for all of Autonomous Province of Trento from 2000 to 2013 were retrieved from the archive of the Operative Unit for Health and Safety in the Workplaces (UOPSAL, Italian acronym), the institutional service representing the local governmental structure for the management and prevention of occupational injuries, occupational diseases, and work-related diseases in the workplaces. Available data were anonymized in order to include only age at the time of the event, sex, and country of birth, and incorporated reference to the geographical site (municipality-level detail) and calendar date of the events, the nature of injury, bodily location, mechanism, and agency of injury/disease. As activities of construction industry are clustered during the warm season, but diffusely performed across the calendar year, we retrieved all available injuries, and excluded all cases that occurred: (a) on to way to/from the workplace (in Italian, “*in itinere*”); (b) clearly occurred indoors; (c) during weekend and holidays; (d) in days characterized by rain or snow (arbitrary cut-off: 5 mm). Similarly, (e) injuries without information on the place of event, and (f) those in the validation phase, were excluded from the analyses.

### *Ethics*

The study included only a retrospective assessment of data available through an Institutional Database, and the analysis was performed as a part of official duties. Personal data were restricted to information about the occupational injury, and were treated in order to guarantee the respect of privacy of the involved workers, as specifically stated by Italian Law n. 675 of 1996 about personal data protection. Therefore, the study did not require preliminary evaluation by the local Ethical Committee.

### *Statistical analysis*

Continuous variables were tested for normal distribution (D’Agostino and Pearson omnibus normality test): where the corresponding  $p$  value was  $< 0.10$ , normality distribution was assumed as rejected and variables were compared through Mann-Whitney or Kruskal-Wallis test for multiple independent samples. On the other hand, variables passing the normality check (D’Agostino and Pearson  $p \geq 0.10$ ) were compared using the Student’s  $t$ -test or ANOVA,

where appropriate. Daily rates of occupational injuries were calculated for the study period, by year, by season, by calendar month, and eventually for the exposure groups as previously described. We assumed that the recorded events (i.e., occupational injuries) were mutually independent, and although influenced by demographic factors and by the extent of the activities performed in that time period, eventually related to air temperatures. In order to adjust crude rates for factors having a presumptive effect on the outcome variable injury rate, Odds Ratios (ORs) with their respective 95% Confidence Intervals (95%CI) were calculated for all cases, for cases having a prognosis  $\geq 40$  d and with any long-term sequela, as well as by age groups (i.e.  $< 20$  yr, 20–29 yr, 30–39 yr, 40–49 yr,  $\geq 50$  yr) and by settings of the injury, through 3 Poisson regression models that included the aforementioned exposure categories as the effector variables, and meteorological data (i.e. air relative humidity, atmospheric pressure, wind speed and solar irradiation) as covariates. In the analyses, we assumed as reference categories: (1) “neutral days” compared to “frost days”, “summer days”, and “summer days/tropical nights”; (2) days having  $T_{\text{max}} < 35^{\circ}\text{C}$  compared to days characterized by  $T_{\text{max}} \geq 35^{\circ}\text{C}$ , either as an isolate exposure, or following 3 or more consecutive days with  $T_{\text{max}} \geq 35^{\circ}\text{C}$  (i.e. HW events); (3) 25–74th  $T_{\text{day}}$  percentile vs. all other percentiles. All the analyses were controlled for the number of Construction workers actually active in the construction industry at the time of the reported injury. The models did not include factors such as heat sources in the workplace, noise exposure, type of employment, etc., as not universally available from the reports. All the analyses were performed in SPSS 25 (IBM Corp. Armonk, NY, USA).

## **Results**

Meteorological data for time period 01/01/2000–31/12/2013 are presented in Table 1. Briefly, average  $T_{\text{day}}$  was  $12.7^{\circ}\text{C}$  (range  $-6.2^{\circ}\text{C}$  to  $29.9^{\circ}\text{C}$ , median  $13.1^{\circ}\text{C}$ ), and average values for  $T_{\text{min}}$  and  $T_{\text{max}}$  were  $6.5^{\circ}\text{C}$  ( $-10.5^{\circ}\text{C}$  to  $21.0^{\circ}\text{C}$ ) and  $20.5^{\circ}\text{C}$  ( $0.1^{\circ}\text{C}$  to  $41.2^{\circ}\text{C}$ ), respectively. A total of 246 d (10.9%) fulfilled the working definition of “Frost day”, whereas 1,161 (51.4%) were classified as “Summer days” and 15 (0.7%) as “Summer days/Tropical nights”. Of them, 161 d were characterized by  $T_{\text{max}} > 35^{\circ}\text{C}$  (5.3%), with 112 occurring as the third or later during a HW event.

As shown in Table 2, a total of 20,724 occupational injuries were initially retrieved: after exclusion criteria were applied, a total of 14,072 episodes were analysed:

**Table 1. Descriptive summary of daily meteorological data, Autonomous Province of Trento, 2000 to 2013**

Meteorological measure (unit)	Min.	Max.	Mean	Percentiles						
				5%	10%	25%	50%	75%	90%	95%
Maximum daily temperature (°C)	0.1	41.2	20.5	5.7	7.5	12.1	21.4	28.6	32.3	33.9
Minimum daily temperature (°C)	-10.5	21	6.5	-5.6	-3.6	-0.4	6.8	13.1	16.7	17.9
Average daily temperature (°C)	-6.2	29.9	12.7	-0.6	1.2	4.9	13.1	20.1	24	25.3
Difference with average temperatures (°C)	-11.8	11.7	1.2	-3.9	-2.7	-0.7	1.3	3.3	5.1	6.1
Relative humidity (%)	14.8	100	65.5	38.4	44.8	55.1	64.6	73.3	83.1	88.4
Solar radiation (kJ/m <sup>2</sup> )	60	245,443	13,867	1,179	2,064	3,373	7,177	12,506	19,854	23,789
Atmospheric pressure (hPa)	911.2	1,021.7	985.1	967.6	974.1	981.8	987.1	992.3	998.5	1002.9
Wind Speed (m*s-1)	0.1	7.6	1.5	0.6	0.7	0.9	1.4	1.9	2.3	2.6

**Table 2. Number and characteristics of acute work-related injuries in the construction industries, Autonomous Province of Trento (2000–2013)**

	Variable	No.	%
Occupational injuries	All recorded events, 2000 to 2013	20,724	100
	Included in the final analysis	14,072	67.9
Gender	Male	13,931	99
	Female	141	1
Migration background	No (Italian-born People)	10,878	77.3
	Yes (Foreign-born People)	3,194	22.7
Age group (yr)	≤20	743	5.3
	20–29	3,632	32.5
	30–39	4,156	23.2
	40–49	3,378	12
	≥50	2,163	15.4
Prognosis (d)	≥40 d	2,396	17
	Any long-term sequela	1,814	12.9
Characteristics of the injury	Falls, in general	2,973	21.1
	Falls from height >2 m	929	6.6
	Distraction/carelessness during usual tasks	2,448	17.4
	Use of tools/machineries	2,481	17.6
	Manual handling	865	6.1

the majority of them occurred in construction workers that were <40 yr-old at the time of the injury (61%; mean age 36.7 ± 11.4 yr), and in subjects of Italian origin (77.3%). The final sample included 13,931 males (99.0%; mean age: 36.7 ± 11.4 yr), and 141 females (1.0%; mean age: 36.6 ± 10.9 yr), of similar age ( $p > 0.05$ ). In 2,396 cases (17.0%), the occupational injury had a prognosis ≥40 d, with long-term sequelae in 12.9% of all cases. The majority of occupational injuries included in the analyses occurred as falls (21.1%), with a third of them (6.6% of total sample) from height >2 m, followed by injuries involving the use of tools and/or machineries (17.6%), inattention (i.e. distraction and/or carelessness) during usual tasks (17.4%), and tasks requiring manual handling (6.1%).

Estimated incidence of occupational injuries during the

study period was 5.7 events by day (95%CI 5.5–5.8), with an estimated cumulative incidence of 2.8 episodes/10,000 workers/d (95%CI 2.7–2.9). As shown in Table 3, daily incidence of work accidents significantly decreased between 2000 and 2013 (ANOVA test for trend <0.001), whereas the ratio between injuries with prognosis ≥40 d and total injuries ranged from a minimum of 14.9% (95%CI 12.7–17.2) in 2000, to the maximum of 20.3% (95%CI 17.5–23.0) in 2004 without a clear time trend. On the contrary, a time trend was identified across the calendar year, with higher shares for the winter months of November (20.0%, 95%CI 17.4–22.5) and December (22.8%, 95%CI 19.1–26.5). Overall (Table 4), daily rates of injuries were significantly higher in Summer days than in reference to Neutral ones (3.20, 95%CI 3.11–3.30 vs. 3.02, 95%CI

**Table 3. Rates of occupational injuries (OIs) in the construction industries, for all cases and for cases having prognosis  $\geq 40$  d, and their ratio, by year and month of occurrence**

	All OIs (No./10,000 person-day)	OIs with prognosis $\geq 40$ d (No./10,000 person-day)	Ratio OIs with prognosis $\geq 40$ d/ all OIs (%)
Year of Occurrence			
2000	3.78 (3.56; 4.01)	0.60 (0.53; 0.68)	16.4 (14.2; 18.7)
2001	3.42 (3.21; 3.63)	0.50 (0.43; 0.57)	14.9 (12.7; 17.2)
2002	3.16 (2.97; 3.36)	0.52 (0.45; 0.60)	15.7 (13.4; 18.0)
2003	3.33 (3.13; 3.52)	0.59 (0.52; 0.65)	17.8 (15.6; 20.0)
2004	3.43 (3.21; 3.65)	0.62 (0.56; 0.69)	20.3 (17.5; 23.0)
2005	3.49 (3.28; 3.70)	0.56 (0.49; 0.63)	16.4 (14.2; 18.5)
2006	3.35 (3.13; 3.56)	0.58 (0.51; 0.65)	17.8 (15.3; 20.2)
2007	2.97 (2.79; 3.16)	0.56 (0.49; 0.62)	19.7 (17.1; 22.3)
2008	2.55 (2.38; 2.73)	0.45 (0.39; 0.50)	18.4 (15.6; 21.3)
2009	2.25 (2.09; 2.42)	0.40 (0.34; 0.45)	17.7 (15.0; 20.4)
2010	2.48 (2.30; 2.66)	0.49 (0.42; 0.56)	19.7 (16.6; 22.9)
2011	1.91 (1.77; 2.05)	0.38 (0.33; 0.44)	18.9 (16.0; 21.8)
2012	1.59 (1.46; 1.72)	0.27 (0.22; 0.32)	16.0 (12.8; 19.2)
2013	1.39 (1.25; 1.52)	0.29 (0.23; 0.36)	18.4 (14.2; 22.6)
Month of Occurrence			
Jan.	1.65 (1.52; 1.79)	0.32 (0.27; 0.36)	17.2 (14.4; 20.1)
Feb.	2.18 (2.03; 2.33)	0.41 (0.27; 0.47)	19.5 (16.4; 22.5)
Mar.	2.74 (2.58; 2.91)	0.50 (0.44; 0.56)	17.6 (15.3; 19.8)
Apr.	2.86 (2.69; 3.04)	0.48 (0.42; 0.54)	16.9 (14.7; 19.2)
May	3.36 (3.16; 3.56)	0.52 (0.45; 0.59)	14.7 (12.8; 16.7)
Jun.	3.53 (3.34; 3.73)	0.57 (0.51; 0.63)	16.7 (14.6; 18.8)
Jul.	3.61 (3.40; 3.82)	0.55 (0.49; 0.61)	16.1 (14.0; 18.1)
Aug.	2.23 (2.05; 2.42)	0.34 (0.28; 0.39)	14.8 (12.1; 17.6)
Sep.	3.32 (3.14; 3.50)	0.59 (0.52; 0.65)	18.4 (16.3; 20.6)
Oct.	3.08 (2.90; 3.25)	0.54 (0.48; 0.61)	18.2 (16.1; 20.3)
Nov.	3.04 (2.83; 3.25)	0.60 (0.53; 0.67)	20.0 (17.4; 22.5)
Dec.	2.12 (1.93; 2.31)	0.47 (0.40; 0.53)	22.8 (19.1; 26.5)

All data are presented with their respective 95% Confidence Intervals.

2.92–3.12), whereas a significantly lower rate was identified for Frost days (2.78, 95%CI 2.59–2.96). Similarly, when compared with days having  $T_{max} < 35^{\circ}\text{C}$  (2.77, 95%CI 2.71–2.83), days characterized by a  $T_{max} \geq 35^{\circ}\text{C}$  were associated with higher rates for occupational injuries, both for exposures  $< 3$  days (3.57, 95%CI 3.05–4.11), and from the third day onwards (i.e. HW time periods, 3.43, 95%CI 3.08–3.77).

In regression analysis, a significantly higher risk for occupational injuries was associated to the Summer days (OR 1.093, 95%CI 1.042–1.146) and to days having a  $T_{max} \geq 35^{\circ}\text{C}$ , both for exposures shorter than 3 consecutive days (OR 1.276, 95%CI 1.147–1.418) or equals to/longer than 3 consecutive days (OR 1.230, 95%CI 1.144–1.322). More specifically, higher risks for occupational injuries in subjects  $< 20$  yr-old at the time of the event were reported

in days fulfilling Summer day and Summer day/Tropical night definition (OR 1.302, 95%CI 1.040–1.630, and OR 3.493, 1.417–8.612, respectively). Similarly, days having a  $T_{max} \geq 35^{\circ}\text{C}$  were characterized by an increased risk for injuries in all subjects  $< 50$  yr-old, while no significant differences were reported in older age groups (OR 0.935 95%CI 0.684–1.278 for exposure lags  $< 3$  consecutive days, and 1.156, 95%CI 0.958–1.396 for exposure lags  $\geq 3$  consecutive days).

Focusing on low temperatures, Frost days were associated with a significantly reduced risk (OR 0.892, 95%CI 0.831–0.957), in particular for subjects 20–29 yr-old (OR 0.822, 95%CI 0.712–0.951) and 30–39 yr-old (0.779, 95%CI 0.680–0.891) (Table 5). However, when focusing on the severity of the injuries (i.e. prognosis  $\geq 40$  d, evidence of long-term sequelae), no significant difference was found.

**Table 4. Rates of occupational injuries (OIs) in the construction industries throughout the classification of reported days by meteorological data**

	OIs (No./10,000 person-day)	<i>p</i> value
Neutral day (Tmin >0.0°C, Tmax <25.0°C)	3.02 (2.92; 3.12)	-
Frost days (Tmin <0.0°C)	2.78 (2.59; 2.96)	<0.001
Summer days (Tmax ≥25.0°C)	3.20 (3.11; 3.30)	<0.001
Summer days, tropical nights (Tmax >25.0°C, Tmin >20.0°C)	3.11 (2.02; 4.20)	0.917
Classification by Heat Waves Event		
Days with Tmax <35°C	2.77 (2.71; 2.83)	-
Heat Wave, First 2 d	3.57 (3.05; 4.11)	<0.001
Heat Wave, from 3rd day onwards	3.43 (3.08; 3.77)	0.001

All data are presented with their respective 95% Confidence Intervals.

**Table 5. Risk of occupational injuries (OIs) in the construction industries, throughout the classification of calendar day by meteorological data**

	T max ≥35°C	T max ≥35°C	Frost days	Summer days	Summer days, Tropical nights
	Less than 3 consecutive days	3rd consecutive day and onwards			
All cases	1.276 (1.147; 1.418)	1.230 (1.144; 1.322)	0.892 (0.831; 0.957)	1.093 (1.042; 1.146)	1.063 (0.778; 1.454)
prognosis ≥40 d	0.995 (0.748; 1.324)	1.080 (0.899; 1.297)	1.121 (0.961; 1.307)	0.997 (0.891; 1.116)	0.585 (0.218; 1.568)
long-term sequelae	0.881 (0.622; 1.249)	1.181 (0.964; 1.446)	0.959 (0.800; 1.150)	1.005 (0.887; 1.139)	0.729 (0.272; 1.955)
Age groups					
<20 yr	1.640 (1.074; 2.505)	1.892 (1.449; 2.470)	0.815 (0.575; 1.155)	1.302 (1.040; 1.630)	3.493 (1.417; 8.612)
20–29 yr	1.462 (1.203; 1.776)	1.125 (1.971; 1.305)	0.822 (0.712; 0.951)	1.048 (0.953; 1.152)	1.043 (0.558; 1.950)
30–39 yr	1.219 (1.000; 1.486)	1.168 (1.020; 1.337)	0.779 (0.680; 0.891)	1.065 (0.976; 1.162)	1.185 (0.684; 2.053)
40–49 yr	1.280 (1.030; 1.591)	1.323 (1.146; 1.527)	0.952 (0.829; 1.094)	1.134 (1.032; 1.246)	0.938 (0.485; 1.813)
≥50 yr	0.935 (0.684; 1.278)	1.156 (0.958; 1.396)	1.167 (0.986; 1.381)	1.107 (0.981; 1.249)	0.502 (0.161; 1.565)
Injuries					
Falls	1.087 (0.847; 1.395)	1.276 (1.093; 1.489)	1.010 (0.885; 1.152)	1.046 (0.950; 1.152)	1.074 (0.591; 1.952)
Falls from height	1.169 (0.759; 1.800)	1.339 (1.021; 1.756)	0.899 (0.704; 1.147)	1.080 (0.910; 1.283)	0.649 (0.161; 2.617)
Inattention	1.001 (0.753; 1.332)	1.077 (0.896; 1.295)	1.178 (1.020; 1.359)	1.041 (0.939; 1.154)	1.030 (0.533; 1.993)
Use of tools/machineries	1.090 (0.831; 1.431)	1.170 (0.981; 1.395)	0.756 (0.638; 0.896)	1.158 (1.037; 1.293)	1.534 (0.842; 2.794)
Manual handling	1.398 (0.932; 2.095)	1.045 (0.764; 1.427)	0.876 (0.687; 1.116)	0.942 (0.796; 1.115)	1.588 (0.652; 3.866)

All data are presented as Odds Ratios with their respective 95% Confidence Intervals.

Frost days: days having minimum daily temperature <0°C.

Summer days: days having maximum daily temperature >25°C.

Summer days, tropical nights: days having maximum daily temperature >25°C, and minimum daily temperature >20°C.

Regarding the mechanism of the injuries, an increased risk was reported for inattention during usual tasks performed in Frost days (OR 1.178, 95%CI 1.020–1.359), and for the use of tools/machineries in Summer days (OR 1.158, 95%CI 1.037–1.293), whereas a significantly reduced risk was identified for injuries associated with the handling of tools/machineries during Frost days (OR 0.756, 95%CI 0.638–0.896). Interestingly enough, exposures to Tmax ≥35°C for 3 consecutive days or more during HW were associated with increased risks of falls (OR 1.276, 95%CI 1.093–1.489), and falls from height (OR 1.339, 95%CI 1.021–1.756), and such effect was not reported for shorter exposures.

Table 6 shows the risk for injuries broken down by daily exposure groups, for the whole study period. A more complex patter was identified. More specifically, the risk was significantly higher for exposures >95th percentile (OR 1.145, 95%CI 1.062–1.235), particularly among workers aged <20 yr (OR 1.902, 95% 1.393–2.599) and 40 to 49 yr (OR 1.177, 95%CI 1.016–1.365). On the contrary, a somehow protective effect towards injuries was found for Tday 10th to 24th percentile (OR 0.851, 95%CI 0.782–0.927), particularly in age groups 20 to 49 yr, while a seemingly increased risk was identified for Construction workers aged 50 yr or more (OR 1.232, 95%CI 1.017–1.494). Similarly, a reduced risk for occupational injuries was

**Table 6. Risk of occupational injuries (OIs) in the construction industries, throughout the classification of calendar day by Tday percentiles**

	Percentiles of Tday					
	<5%	5–9%	10–24%	75–89%	90–95%	>95%
All cases	0.854 (0.746; 0.978)	0.972 (0.820; 1.152)	0.851 (0.782; 0.927)	1.050 (0.995; 1.109)	1.074 (0.992; 1.162)	1.145 (1.062; 1.235)
prognosis $\geq$ 40 d	0.930 (0.683; 1.267)	1.448 (1.035; 2.026)	1.129 (0.944; 1.350)	1.006 (0.884; 1.145)	0.863 (0.703; 1.058)	0.985 (0.816; 1.190)
long-term sequelae	0.805 (0.557; 1.164)	1.168 (0.769; 1.773)	1.021 (0.829; 1.258)	1.073 (0.932; 1.235)	0.846 (0.672; 1.063)	0.970 (0.785; 1.199)
Age groups						
<20 yr	0.838 (0.442; 1.589)	1.520 (0.776; 2.975)	0.730 (0.476; 1.120)	1.172 (0.907; 1.515)	1.696 (1.222; 2.235)	1.902 (1.393; 2.599)
20–29 yr	0.603 (0.439; 0.827)	0.744 (0.508; 1.091)	0.815 (0.687; 0.966)	0.996 (0.892; 1.111)	1.059 (0.903; 1.241)	1.120 (0.962; 1.303)
30–39 yr	0.866 (0.679; 1.104)	0.924 (0.674; 1.267)	0.734 (0.624; 0.863)	1.033 (0.935; 1.142)	1.037 (0.894; 1.202)	1.021 (0.882; 1.182)
40–49 yr	1.036 (0.810; 1.326)	0.857 (0.599; 1.226)	0.837 (0.706; 0.992)	1.102 (0.992; 1.225)	1.034 (0.882; 1.212)	1.177 (1.016; 1.365)
$\geq$ 50 yr	0.960 (0.685; 1.345)	1.519 (1.057; 2.181)	1.232 (1.017; 1.494)	1.061 (0.925; 1.218)	1.084 (0.888; 1.323)	1.187 (0.984; 1.432)
Injuries						
Falls	1.135 (0.898; 1.435)	1.176 (0.889; 1.556)	0.891 (0.761; 1.044)	1.007 (0.901; 1.126)	0.855 (0.715; 1.022)	1.056 (0.902; 1.236)
Falls from height	0.522 (0.286; 0.951)	0.865 (0.485; 1.543)	0.897 (0.681; 1.182)	0.922 (0.751; 1.132)	1.085 (0.812; 1.448)	1.118 (0.849; 1.472)
Inattention	1.325 (1.039; 1.688)	1.201 (0.856; 1.685)	1.033 (0.866; 1.233)	0.970 (0.862; 1.091)	0.920 (0.773; 1.096)	1.047 (0.891; 1.231)
Use of tool/machineries	0.559 (0.383; 0.815)	0.776 (0.516; 1.167)	0.772 (0.635; 0.938)	1.109 (0.979; 1.257)	1.207 (1.009; 1.445)	1.154 (0.966; 1.378)
Manual handling	0.781 (0.473; 1.291)	0.752 (0.387; 1.461)	0.987 (0.752; 1.295)	0.876 (0.714; 1.076)	1.000 (0.746; 1.340)	1.093 (0.831; 1.438)

All data are presented as Odds Ratios with their respective 95% Confidence Intervals.

also identified for exposures <5th percentile (OR 0.854, 95%CI 0.746–0.978), but only for age group 20 to 29 yr (0.603; 95%CI 0.439–0.827), and for accidents resulting from falls from height (OR 0.522, 95%CI 0.286–0.951), and use of tools (OR 0.559, 95%CI 0.383–0.815), while the occurrence injuries associated with inattention was somehow increased (OR 1.325, 95%CI 1.039–1.688).

## Conclusions

Our results reaffirm that weather conditions and the incidence of occupational accidents in the construction industry are associated in a “J-shaped” curve relationship, in which lower risk is found for colder days, while higher rates are reported in hottest calendar days and during HW events, in particular at its beginning, and for injuries associated with falls and falls from height.

Our report is therefore consistent with previous reports suggesting that hot weather conditions might represent a significant risk factors for work-related injuries<sup>3, 29, 30, 35, 36, 43–45</sup>. As previously reported, higher risk for work related accidents is reported in days characterized by severe but not extreme thermal conditions (i.e. “inverted U-shaped curve”), while either extreme hot or cold weather have lower incidence rates<sup>29, 41, 43, 44</sup>. Usually, such trends are explained as a behavioral adaptation: i.e. workers would avoid most strenuous activities during the hottest days and/or the hottest hours of the working day during the warm season and, similarly, coldest days of the cold

season would be perceived as inappropriate to perform outdoor activities<sup>29, 45</sup>. In this regard, it should be recalled that in most high-income countries, hottest months of the warm season are usually associated with holidays, and vacations may further contribute to the reduced number of reported events<sup>3, 29, 36, 44, 45</sup>. Not coincidentally, also in our study lower incidence rates were reported for the month of August. These inconsistencies may be explained recalling some specificities of the Italian construction industry during the last decades. The construction industry has been severely hit by the economic crisis kicked off in 2008 by the problems in the US subprime housing market: also in Italy, around 20% of total workforce was lost in the time period 2008–2013, and a more severe decrease was reported for the total economic turnover (–21.1%). It is possible that resilient companies may have increasingly endured available orders, extending working activities also in uncomfortable weather conditions, exposing construction workers to extreme daily temperatures<sup>53, 54</sup>.

However, we also possibly identified a sort of behavioral adaptation to severe climates. First at all, higher rates for occupational injuries occurred in very hot (Tmax  $\geq$ 35°C) calendar days unrelated with or at the beginning of a HW period. It is reasonable that workers may initially overlook uncomfortable weather condition as a rather common event, particularly during the hot season, while the persistent exposure to high environmental temperature would elicit a more cautious conduct<sup>43</sup>. Similarly, it is reasonable that our results may have been affected by

the “harvesting” effect that has been usually associated with HW in the general population: i.e. people bearing specific individual risk factors are massively affected by environmental heat in the first days of the HW event, with subsequently higher but transient incidence rates for the assessed outcome (i.e. occupational injuries, in our study)<sup>6, 13, 16, 17</sup>.

Second, as the increased risk mainly involved accidents having a prognosis <40 d, i.e. minor trauma, or followed falls and falls from height, some kind of adaptation towards uncomfortable temperatures may be supposed<sup>18, 35, 36, 43–46</sup>. In other words, being exposed workers unable to restrain from all daily tasks, they would avoid those perceived as more dangerous or less compatible with weather conditions as requiring a more strenuous physical effort, or the wearing of insulating personal protective equipment<sup>53, 55</sup>.

Third, the majority of recorded occupational injuries occurred in subjects who were <40 yr-old at the time of the event (63.2%), while a greater risk was reported for all age groups younger of 50 yr at the time of a HW event. As younger age groups in the Autonomous Province of Trento would represent only the 47.0% of total workforce, it is reasonable that our results may have been extensively affected by the experience of the Construction workers towards extreme climates<sup>30, 31, 39, 49</sup>.

Generalization of our results is impaired by several significant limitations. Firstly, it should be stressed that weather conditions such as radiant heat, air humidity, wind speed and solar irradiation, in a mountainous region such as the Autonomous Province of Trento, air humidity and solar irradiation may strikingly fluctuate over a restricted area because of the altitude<sup>3, 29, 43–45</sup>. In other terms, whereas an assessment at municipality level may guarantee a sufficient detail for air temperature, in the settings of our survey it might be not so accurate for other factors<sup>41, 51–53, 55, 56</sup>. Moreover, as available data about air humidity, wind speed and solar irradiation are more diffusely scattered over the area of APT, their inclusion in the exposure assessment may have increased its inaccuracy.

Second, also the data regarding the work-related accidents are affected by some inaccuracies. Available information about occupational injuries were retrieved from an institutional database, whose content did include neither clinical data nor an accurate description of the level of physical activity performed at the time of the event, the type of clothing, and hydration status, and these factors significantly affect the risk for heat related health effects<sup>29, 43, 44, 57</sup>. For instance, a recent study performed

on the same geographical region hinted towards a possible increased risk for occupational injuries during the Ramadan time period for migrant workers of North-African and Middle-Eastern descent<sup>57</sup>. Even our settings classification is rather coarse. For example, falls may occur while performing other tasks, both manual handling and the use of tools and/or machinery include very heterogeneous tasks, in particular in the construction industry, not necessarily associated with risk factors for heat, and labelling an accident as following “*inattention*” may only represent a sort of umbrella definition for injuries lacking a more accurate description. Moreover, all classifications we reported may have been somehow interconnected, eventually inflating the inaccuracy of our estimates<sup>41, 57</sup>.

Third, our data are affected by implicit incompleteness about the total number of subjects actually employed in construction industry at the time of the event. As we included in our analyses the number of workers employed by calendar year, both underestimation of actual rates of occupational injuries during hottest days and their overestimation during intermediate days are possible<sup>41, 43</sup>.

In conclusion, our data confirm previous reports from the construction industries that extreme weather may be associated with increased risk of occupational injuries, particularly at the beginning of HW events. Collectively, such results stress the importance and the urgent need for the active implementation of appropriate procedures and guidelines even in highly developed settings. On the one hand, policymakers should generally improve the compliance of younger workers towards severe-hot daily temperatures, promoting appropriate habits such as restraining from more dangerous and effort-demanding tasks. On the other hand, competent authorities must be aware that even first days of HWs are associated with unfavourable outcomes, therefore promoting timely countermeasures, that ranges from an early warning to the partial suspension of activities in the construction sites.

## Disclosures

The facts, conclusions, and opinions stated in the article represent the authors’ research, conclusions, and opinions and are believed to be substantiated, accurate, valid, and reliable. However, as this article includes the results of personal researches of the Authors, presenting correspondent, personal conclusions and opinions, parent employers are not forced in any way to endorse or share its content and its potential implications.



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