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Climate change and heat vulnerabilities of Canadian workers: Focus on the Central and Western provinces of Canada

RESEARCH REPORT

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Climate change and heat vulnerabilities of Canadian workers: Focus on the Central and Western provinces of Canada

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Direction des risques biologiques et de la santé au travail

July 2021

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflicts of interest.

SUGGESTED CITATION

Adam-Poupart A, Nicolakakis N, Anassour Laouan Sidi E, Berry P, Campagna C, Chaumont D, Hamel D, Labrèche F, Sassine M-P, Smargiassi A, Zayed J. *Climate change and heat vulnerabilities of Canadian workers: Focus on the Central and Western provinces of Canada.* Institut national de santé publique du Québec. 2021.

Legal deposit – 3rd quarter 2021
Bibliothèque et Archives nationales du Québec
ISBN: 978-2-550-89712-5 (French PDF)
ISBN: 978-2-550-89720-0 (PDF)

Acknowledgements

This study was made possible with the financial support of the Climate Change and Innovation Bureau, Healthy Environments and Consumer Safety Branch of Health Canada.

Special thanks to Ms Anne Frigon, Team Leader of Climate Science and Climate Services at Ouranos for helpful comments on the report and to the following workers' compensation boards for providing access to their data: the Quebec Commission des normes, de l'équité, de la santé et de la sécurité du travail (CNESST), the Ontario Workplace Safety and Insurance Board (WSIB), the Workers' Compensation Board of Manitoba, the Saskatchewan Workers' Compensation Board and the Workers' Compensation Board of Alberta.

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List of acronyms and abbreviations

CDC	Centers for Disease Control and Prevention
CMIP5	Coupled Model Intercomparison Project Phase 5
CNESST	Commission des normes, de l'équité, de la santé et de la sécurité du travail
CORDEX	Coordinated Regional Climate Downscaling Experiment
CSA	Canadian Standards Association
CSN	Confédération des syndicats nationaux
CSST	Commission de la santé et de la sécurité du travail
Daymet	Daily Surface Weather and Climatological Summaries
EQCOTESST	Enquête québécoise sur des conditions de travail, d'emploi, de santé et de sécurité du travail
GCM	General Climate Model
ILO	International Labour Organization
INSPQ	Institut national de santé publique du Québec
IPCC	Intergovernmental Panel on Climate Change
MSSS	Ministère de la Santé et des Services sociaux
NAICS	North American Industry Classification System
NASA	National Aeronautics and Space Administration
ORNL DAAC	Oak Ridge National Laboratory Distributed Active Archive Center
OSHA	Occupational Safety and Health Administration
EQSP	Enquête québécoise sur la santé de la population
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
WBGT	Wet Bulb Globe Temperature
WSIB	Workplace Safety and Insurance Board

Key facts

- This study on the relationship between summer temperatures and worker health in five Canadian provinces has produced new knowledge that can guide decision-makers and prevention stakeholders. Drawing on workers' compensation claims data from Quebec, Ontario, Manitoba, Saskatchewan and Alberta, as well as meteorological data, the study revealed that:
  - For every 1°C increase in the daily maximum summer temperature for the 2001-2016 period, there was a 28% to 51% increase in the daily number of accepted heat illness claims (e.g. edema, syncope, exhaustion, sunstroke/heatstroke), depending on the province and the heat exposure indicator used; applied to the province of Quebec, a 34% increase (model based on T_{max}) represents seven additional accepted heat illness claims over the five summer months of each year of the 2001-2016 period.
  - No sex- or age-based disparities were observed in relation to the heat illness risk examined. In Quebec and Alberta, where information on industries was analyzed, no difference was found between industries that operate mainly indoors and those that operate mainly outdoors;
  - For traumatic injuries (e.g. fractures, cuts, burns), each 1°C increase in daily summer temperature was associated with a 0.2% to 0.6% increase in the daily number of accepted claims during this period; this increase, though it may appear small, is important because of the large number of workers concerned. Applied to the province of Quebec, a 0.2% increase represents approximately 64 additional traumatic injury claims accepted per year during the 2001-2016 summer period.
  - The risk of traumatic injury per 1°C increase in temperature is higher for men, younger workers (15–24 years) and, in the case of Quebec and Alberta, where information on industries was analyzed, for individuals working in industries that operate primarily outdoors.
- This is the first study to provide projections for the daily number of heat illness claims that could be accepted in workers (e.g. edema, syncope, exhaustion, sunstroke/heatstroke) by 2050, taking into account expected climate warming:
  - It is estimated that the daily number of heat illness claims will rise by a worrying 73% to 113% under an optimistic greenhouse gas emissions scenario (RCP4.5) and by 110% to 165% under a pessimistic scenario (RCP8.5), depending on the province and the heat exposure indicator used;
  - Applied to the province of Quebec, the number of accepted heat illness claims per year during the summer period would increase from 21 in the reference period to 39 by 2050 under an optimistic scenario and to 47 under a pessimistic scenario (models based on T_{max}).
- Our results highlight the need to maintain and strengthen preventive efforts among workers as well as workplace adaptation efforts.
- The study results are of great importance in terms of prevention, as they would enable more targeted awareness and engagement efforts aimed at legislators, the research community and key prevention stakeholders.
- Since heat illness projections are based on current workplace preventive programs and strategies and since these health problems are often preventable, there would no doubt be much to gain from taking action.

Summary

Background and objectives

Global warming could have particularly severe impacts on Canada. It is estimated that temperatures in Canada increased at roughly twice the global mean rate over the 1948–2016 period, with a mean annual increase of 1.7°C compared to a global increase of 0.8°C. Periods of extreme heat have become more frequent and more intense in most provinces. Without appropriate preventive actions, these changes could lead to an increase in mortality and morbidity rates, affecting, among others, urban populations and the elderly as well as disadvantaged individuals and those with cardiovascular or respiratory diseases. The relationship between mortality and heat waves or high ambient temperatures is well documented. In Quebec, higher rates of ambulance transport, emergency room admissions and deaths have been reported during regional extreme heat waves than during comparison periods.

Although the effects of extreme heat on the health of the general population have been documented, knowledge on heat-induced mortality and morbidity among workers is limited. This study aims to address these knowledge gaps. Drawing on workers' compensation data from five provinces in Central and Western Canada (Quebec, Ontario, Manitoba, Saskatchewan and Alberta) as well as meteorological data, this study aims to:

1) quantify the relationship between summer outdoor temperatures and the daily number of individuals compensated for heat illnesses (e.g. edema, syncope, exhaustion, sunstroke/heatstroke) and traumatic injuries (e.g. fractures, cuts, burns) between 2001 and 2016 in each province;
2) verify whether the effect of temperature on occupational morbidity is more significant for certain groups—classified by sex, age and whether workers are employed in an industry that operates primarily outdoors—in order to identify groups at higher risk for traumatic injuries and heat illness; and
3) estimate the number of accepted claims for heat illness (e.g. edema, syncope, exhaustion, sunstroke/heatstroke) that would arise between now and 2050, given the projected climate warming.

Two heat exposure indicators were calculated for economic regions in the provinces and linked to the claim files of injured workers, using the postal code of their employer's establishment. These indicators are the maximum daily temperature (T_{max}) and the maximum daily Wet Bulb Globe Temperature ($WBGT_{max}$), a heat stress indicator used widely in the field of occupational health. A simplified version of the WBGT was calculated for the purposes of this study. In addition, projected increases in temperature were calculated using two forcing scenarios, called Representative Concentration Pathways (RCP): an optimistic scenario (RCP4.5), in which greenhouse gas emissions peak around 2040 and then decline, and a pessimistic scenario (RCP8.5), in which greenhouse gas emissions continue to increase throughout the 21st century.

Key findings and interpretation

For the 2001–2016 period, the study revealed that for every 1°C increase in the daily maximum summer temperature (T_{max}), there was a 21% to 41% increase (varying by province) in the daily number of heat illness claims accepted by compensation boards. Applied to the province of Quebec, a 34% increase (model based on T_{max}) represents seven additional accepted heat illness claims over the five summer months of each year of the 2001-2016 period. With the $WBGT_{max}$ indicator, the increase ranged from 41% to 51% depending on the province. However, the results did not allow a definitive conclusion to be reached with respect to age-, sex- and industry-based disparities in heat illness risk. For some comparisons, this was partly due to the small number of cases. In Manitoba, the small number of cases for the sex and age strata made it impossible to conduct analyses stratified by these subgroups. Disparities, if any, could be attributed to differences in the workplace heat exposure of individuals in these subgroups. However, laboratory studies on physiological responses to heat stress suggest that when factors such as muscle mass, body surface area, cardiovascular function, or acclimatization are taken into account, sex and age-related disparities tend to disappear. Thus, sex and age could be proxy variables for factors that influence the physiological response to heat stress (or some of its components). Further research is required to better understand how the risk of heat illness varies by sex, age and other subgroups (e.g. jobs, industries. More detailed analyses of heat exposure that take into account specific working conditions and tasks, as well as individual characteristics (chronic disease, medication use, history of sunstroke, body mass index, etc.), should be considered.

The study also showed that every 1°C increase in T_{max} over the 2001–2016 period was associated with a 0.2% to 0.4% increase (varying by province) in the daily number of accepted work-related traumatic injury claims. With the $WBGT_{max}$ indicator, the increase ranged from 0.2% to 0.6%. Although this increase may seem small, it is significant as it affects a large number of people. Applied to the province of Quebec, a 0.2% increase represents approximately 64 additional accepted traumatic injury claims over the five summer months of each year of the 2001-2016 period. The effect of a temperature increase on the risk of traumatic injuries is greater among male workers, younger workers (15–24 years) and workers in industries that operate primarily outdoors (the sectors 'agriculture, forestry, fishing and hunting'; construction; 'mining, quarrying, and oil and gas extraction'; 'transportation and warehousing'). The latter finding is based on data from Quebec and Alberta, where industry information was analyzed—the other provinces studied have their own industry classification systems, and comparisons with the North American Industry Classification System are not readily available.

Disparities among industries could reflect differences in exposures—for instance, the risk of traumatic injury is higher in agriculture and construction than in education—as well as differences in companies' preventive measures and health and safety culture. Sex-related disparities may be explained by a male-dominated workforce in industries with higher risk for injury, e.g. forestry, construction and mining. Age-related differences could reflect a disproportionate distribution of younger individuals in some industries that have a higher risk of injury. They could also represent gaps in health and safety training among less experienced workers or a lower perception of risk and suboptimal compliance with health and safety regulations among younger workers.

Finally, taking into account projected global warming by 2050, this study has estimated a worrying future increase in the daily number of heat illness claims that could be accepted by workers' compensation boards in relation to exposure to high temperatures. Under the optimistic scenario (RCP4.5), projected increases in the summer T_{max} between the reference and future periods would be accompanied by a 73% to 95% increase in the number of accepted heat illness claims, depending on the province. With the $WBGT_{max}$ indicator, the increase is estimated to be between 83% and 113%. Under the pessimistic scenario (RCP8.5), the increase in the daily number of accepted heat illness claims would range from 110% to 139% (T_{max}) and from 121% to 165% ($WBGT_{max}$), depending on the province. Applied to the province of Quebec, the number of accepted heat illness claims per year during the summer period would increase from 21 in the reference period to 39 by 2050 under an optimistic scenario and to 47 under a pessimistic scenario (models based on T_{max}).

It is important to note that interprovincial comparisons could not be made due to legislative and administrative differences between provincial health and safety regimes. Nonetheless, the main findings from the study are similar across provinces.

Considerations and outlook

The results of this study should be interpreted in light of certain considerations. Firstly, the use of compensation data may result in an underestimation of the incidence and magnitude of occupational injuries, because of documented under-reporting of injuries by workers to compensation boards. Heat illness in particular could be misdiagnosed or workers could fail to see the connection between their illness and their work. This lack of recognition could contribute to under-reporting and, therefore, underestimation.

Heat exposure was estimated on a regional scale. The specific circumstances of the injury or illness are unknown, including whether the workplace was air conditioned, where the individual was located (inside or outside the establishment), whether personal protective equipment was worn and how much exertion was involved in performing the tasks that gave rise to the injury or illness. Moreover, the administrative databases that were used do not provide information on aforementioned personal factors that may influence heat illness, hence they could not be considered in the analyses.

The heat illness projections assume that the populations under study will not change between the reference and future periods, which is an obvious simplification of reality. Additionally, as was the case for the 2001–2016 analyses, a number of conjectural, contextual and personal factors that could influence the occurrence of heat illness between now and 2050 were not considered in the projections. Legislative changes (e.g. modernization of the current occupational health and safety regime in Quebec) and changes in practices for recognizing occupational injuries as well as labour market changes could have a significant impact on these projections.

Nevertheless, the overall results of this study underscore the need to maintain, as well as strengthen, preventive efforts and adaptive measures. For example, adequate occupational health and safety training must be provided to workers, including younger workers. Workplaces should receive support and guidance to develop and implement action plans to assess and limit employee heat stress on hot days, for example, through appropriate use of work-rest schedules and adequate hydration. Studies in real work settings are also needed in order to identify interventions found to be effective against heat strain in the workplace, given that current knowledge stems primarily from laboratory studies on athletic performance and from studies focusing on only a few occupations (e.g. firefighting).

Improved monitoring of heat-related occupational injuries is also necessary to inform needs in this area, such as by documenting these health problems in population health surveys commissioned by government authorities. This would make it possible to more accurately gauge the extent of these health problems among the general working population and to more clearly define the scope of occupational health and safety needs, which would complement the information from workers' compensation occupational injury files.

According to the Intergovernmental Panel on Climate Change (IPCC), if global warming continues at the current rate, global temperature will rise 1.5°C (above pre-industrial [1850–1900] levels) by 2040. This increase would have adverse effects on ecosystems, natural resources and human health. Various impacts on worker health and safety can be anticipated. Beyond effects on heat-related mortality and morbidity, some repercussions may include increased risks of certain zoonotic diseases and illnesses with the spread of their vectors to higher latitudes; impacts on the mental health of farmers and other workers who have to cope with heat stress and drought; and possible psychological effects on first responders and other intervention specialists involved in the management of increasingly frequent disasters (e.g. forest fires, floods).

Our projections are of great importance in terms of prevention, as they would enable more targeted awareness raising and engagement efforts aimed at legislators, the research community and key actors. Clearly, climate change is a major public health issue that calls for concerted action in order to reduce, if not eliminate, many potential risks. Since the heat illness projections are based on current preventive programs and strategies and since these health problems are often preventable, much is to be gained from taking action.

1 Introduction

Global warming could have particularly severe impacts on Canada (Martin et al., 2012). It is estimated that temperatures in Canada increased at roughly twice the global mean rate over the 1948–2016 period, with a mean annual increase of 1.7°C compared to a global increase of 0.8°C. Periods of extreme heat have become more frequent and more intense in most provinces (Zhang et al., 2019; Intergovernmental Panel on Climate Change [IPCC], 2013). Without appropriate preventive actions, these changes could lead to an increase in mortality (Gasparrini et al., 2015; Martin et al., 2012) and morbidity rates, affecting, among others, urban populations and the elderly, as well as disadvantaged individuals and those with cardiovascular or respiratory diseases (Hajat et al., 2010; Basu and Samet, 2002). In a review of 49 studies published as of 1970, Basu and Samet (2002) highlight the existence of a relationship between mortality and heat waves or high ambient temperatures. In Quebec, higher rates of ambulance transport, emergency room admissions and deaths were reported during regional extreme heat waves, including the heat wave of July 2010, than during comparison periods (Lebel et al., 2017).

Although the effects of extreme heat on the health of the general population have been documented, knowledge on heat-induced mortality and morbidity among workers is limited (Adam-Poupart et al., 2013). In the United States, 423 heat-related deaths were recorded over the 15-year period from 1992 to 2006, representing an annual average of 0.02 deaths per 100,000 workers. Nearly a quarter of these deaths occurred in the agriculture, forestry, hunting and fisheries sectors (Centers for Disease Control and Prevention [CDC], 2008). In 2012–2013, 13 heat-related deaths were reported to the U.S. Occupational Safety and Health Administration (OSHA). The fact that all of these deaths occurred within the first three days of work (four occurred on the first day) underscores the lack of acclimatization measures in the workplaces concerned (CDC, 2014). In Australia, increases in outdoor temperatures were associated with an increase in workplace accidents and heat-related occupational illnesses from 2001 to 2010 (Xiang et al., 2014a; 2015). Very little research has been conducted on heat-related occupational morbidity in Canada (Adam-Poupart et al., 2014; 2015a, b; Fortune et al., 2013; 2014). Studies conducted in Quebec estimated a 42% increase in the daily number of individuals compensated by the Quebec Commission de la santé et de la sécurité du travail (now known as the CNESST, Commission des normes, de l'équité, de la santé et de la sécurité du travail) for heat illness, e.g. sunstroke/heatstroke, per 1°C increase in maximum summer temperature from 1998 to 2010. A 0.2% increase in work-related traumatic injuries, e.g. falls, between 2003 and 2010 was reported (Adam-Poupart et al., 2014; 2015a, b).

Adam-Poupart et al. also identified groups of workers at increased risk for traumatic injuries: workers aged 15–24 years, compared to older workers; workers in industries that operate mainly outdoors; as well as individuals working in textile mills, smelters and kitchens, whose activities take place indoors. These findings are reflected in two scientific literature reviews (International Labour Organization [ILO], 2016; Xiang et al., 2014b), which reported that workers are most likely to be exposed to excessive heat when their tasks are performed outdoors and require a high level of physical exertion, as is the case in farming, construction, mining, transportation, firefighting and the armed forces. Indoor workers could also be exposed to heat and humidity generated by work processes and equipment.

To our knowledge, apart from the few Canadian studies referenced above, heat-related occupational morbidity has not been studied elsewhere in Canada. This study aims to address these knowledge gaps. Drawing on workers' compensation data from five provinces in Central and Western Canada (Quebec, Ontario, Manitoba, Saskatchewan and Alberta) as well as meteorological data, this study aims to: 1) quantify the relationship between summer outdoor temperatures and the daily number of individuals compensated for heat illness and work-related traumatic injuries between 2001 and 2016 in each province; 2) verify whether the impact of temperature on occupational morbidity is more significant for certain groups, classified by sex, age and employment in an industry where work is mainly performed indoors or outdoors. This approach makes it possible to identify groups that are at higher risk for heat illness claims and traumatic injuries; and 3) estimate the number of individuals who could be compensated for heat illness and traumatic injuries by 2050, given expected climate warming. Ultimately, the goal of this research is to generate knowledge that can help support decision making and guide preventive efforts.

2 Methodology

2.1 Health data

2.1.1 STUDY POPULATION AND DATA SOURCES

The study focuses on workers[1] who submitted a compensation claim for an employment injury occurring between May 1 and September 30 of each year from 2001 to 2016 which was accepted by their respective province's compensation board.[2] These months were chosen because they correspond to the period during which hot days can occur in Canada. The years of study were chosen according to the availability of data.

The data were drawn from the annual occupational injury files of the Workers' Compensation Board of Alberta, the Workers' Compensation Board of Manitoba, the Saskatchewan Workers' Compensation Board, the Ontario Workplace Safety and Insurance Board (WSIB) and the Quebec CNESST. These files contain information on the claimant (sex, age), injury (date of occurrence, diagnosis, area of the body affected, etc.) and the employer's establishment (three- or six-digit postal code [depending on the province], industry corresponding to the economic activity associated with the employer's rate file, etc.).

Only employment injuries[3] recognized as work accidents for the purposes of compensation were considered (for Quebec, Alberta and Manitoba). For injuries compensated as an occupational disease, the date of occurrence recorded in the file is the day of diagnosis, not the day on which the injury occurred. The inclusion of such injuries could lead to errors in classifying the exposure of individuals. However, in the case of Saskatchewan and Ontario, both types of injuries had to be used, i.e. those classified as workplace accidents as well as those classified as occupational diseases. On the one hand, the Saskatchewan Workers' Compensation Board does not make the above-mentioned distinction for the purposes of compensation. On the other hand, the Ontario WSIB classifies most injuries as occupational diseases. Moreover, the data from the WSIB include only time-loss injuries; injuries that did not result in time off were not coded by the nature (diagnosis) of the injury and the area of the body affected. For other provinces such as Quebec, Alberta and Manitoba, the data cover both time-loss and non-time-loss injuries (e.g. those incurring medical costs only). Because of differences in the practices of compensation boards as well as the extent to which health and safety plans cover the workforce, industries and jobs (Association of Workers' Compensation Boards of Canada, 2016), the data were analyzed separately for each province, without comparing provinces. Finally, although compensation boards use the term "work accident," it should be noted that this could refer to traumatic injuries as well as illnesses and non-traumatic health problems.

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1 Recurring claims for the same injury were removed by the compensation boards before data transfer.

2 The years 2002–2017 were used for Ontario, since data for 2001 were not available.

3 An employment injury is defined as "an injury or a disease arising out of or in the course of an industrial accident, or an occupational disease, including a recurrence, relapse or aggravation" (LégisQuébec, *Act respecting industrial accidents and occupational diseases*, chapter A-3.001). The corresponding term in Alberta and Manitoba is "work injury," meaning an injury to a worker resulting from an "accident," which is defined as "any event arising out of, and in the course of, employment" and includes occupational diseases (Manitoba Laws, *The Workers Compensation Act*, C.C.S.M. c. W200, section 1; Alberta Queen's Printer, Workers' Compensation Act, Chapter W-15, sections 1, 24.1, 24.2).

2.1.2 CASE DEFINITION OF HEAT ILLNESS

Heat illness is defined as a medical condition resulting from a disruption of thermoregulation in an individual exposed to excessive heat, and presents as symptoms ranging from relatively mild, e.g. cramps, edema, exhaustion, to severe problems, e.g. potentially fatal heatstroke (Gauer and Meyers, 2019). The following codes were used to identify these health problems in the occupational injury files (classification according to the CSA Z795-03 (R2013) standard of the Canadian Standards Association):

- 07200 - Effects of heat and light, unspecified
- 07210 - Heatstroke
- 07220 - Heat syncope
- 07280 - Multiple effects of heat and light
- 07290 - Effects of heat and light, n.e.c. (including heat fatigue and heat edema)

2.1.3 CASE DEFINITION OF WORK-RELATED TRAUMATIC INJURY

Excessive exposure to heat could exacerbate discomfort and fatigue as well as decrease alertness and manual dexterity. Surfaces made slippery by perspiration from the hands and reduced visibility caused by condensation forming on protective equipment (e.g. visors) could increase the likelihood of work-related injuries (reviewed in Spector et al., 2019). Hence, all work-related traumatic injuries were considered. They were identified on the basis of the following nature of injury codes (classification according to the CSA Z795-03 (R2013)):

- 00 - Traumatic injuries disorders, unspecified
- 01 - Traumatic injuries to bones, nerves, spinal cord
- 02 - Traumatic injuries to muscles, tendons, ligaments, joints, etc.
- 03 - Open wounds
- 04 - Surface wounds and bruises
- 05 - Burns
- 06 - Intracranial injuries
- 07 - Effects of environmental conditions
- 08 - Multiple traumatic injuries and disorders
- 09 - Other injuries and multiple traumatic injuries and disorders

2.1.4 INDUSTRIES

In Quebec and Alberta's occupational injury files, industries are classified using the North American Industry Classification System (NAICS). Saskatchewan, Manitoba and Ontario use their own systems, which differ from the NAICS and for which comparisons are not readily available. For Alberta and Quebec, industries were grouped based on whether they operate mainly indoors or outdoors (as in Adam-Poupart et al., 2015a). The groupings are based on two-digit NAICS codes that refer to major economic sectors (Statistics Canada, 2018a). "Outdoor" industries include:

- 11 - Agriculture, forestry, fishing and hunting
- 21 - Mining, quarrying, and oil and gas extraction
- 23 – Construction
- 48-49 – Transportation and warehousing

"Indoor" industries include:

- 22 – Utilities
- 31-33 – Manufacturing
- 41 – Wholesale trade
- 44-45 – Retail trade
- 51 – Information and cultural industries
- 52 – Finance and insurance
- 53 – Real estate and rental and leasing
- 54 – Professional, scientific and technical services
- 55 – Management of companies and enterprises
- 56 – Administrative and support, waste management and remediation services
- 61 – Educational services
- 62 – Health care and social assistance
- 71 – Arts, entertainment and recreation
- 72 – Accommodation and food services
- 81 – Other services (except public administration)
- 91 – Public administration

2.2 Meteorological data

2.2.1 Daymet data

The daily meteorological data come from Daymet (Daily Surface Weather and Climatological Summaries).[4] This file provides gridded estimates of daily meteorological variables in North America at a 1 km^2 resolution for the period 1980 to 2017 (Oak Ridge National Laboratory Distributed Active Archive Center [ORNL DAAC], 2019). These data are hosted at one of NASA's data centres and are available online free of charge (https://daymet.ornl.gov/). We downloaded the minimum and maximum daily values for air temperature at 2 m above the land surface (°C), average partial pressure of water vapour (Pa) and total precipitation (mm/day).

The meteorological values for the Daymet grid-cell (centroid of each 1 km^2 cell) closest to a six-digit postal code were assigned to the surface area covered by that postal code. [5] Data by postal code were then aggregated by economic region, as defined by Statistics Canada (Statistics Canada, 2018b), by calculating a weighted average based on the population size associated with each three-digit postal code. This made it possible to give greater weight to temperatures from postal codes with the largest populations, thus more accurately representing heat exposure. Daily exposure was considered constant for all individuals in the same economic region. The same weighting was applied to the water vapour and precipitation data (taking the mean values of these variables).

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4 The Daymet file is derived from various ground-based observations, which are processed by the Daymet model developed by Thornton in 1997 and updated in 2016 (Thornton, 2016).

5 For postal codes covering scattered areas, the Daymet values closest to the centroid of the surface area covered by each postal code area were assigned to each area and the average was calculated.

2.2.2 HEAT EXPOSURE INDICATORS

Two heat exposure indicators were calculated for each economic region: the maximum daily temperature (T_{max}) and the maximum daily Wet Bulb Globe Temperature ($WBGT_{max}$), an indicator of heat stress used widely in the field of occupational health (Parsons, 2003). A simplified version of the WBGT was calculated for the purposes of this study (American College of Sports Medicine, 1984; Australian Government Bureau of Meteorology, 2010), taking T_{max} as the ambient temperature (T):

$$WBGT = 0.567 \times T + 0.393 \times VP + 3.94$$

where VP is the partial pressure of water vapour (Pa). This formula assumes that winds are light and solar radiation is moderately high and constant over time—conditions that are representative of a workday in summer (Australian Government Bureau of Meteorology, 2010).

2.3 Climate scenarios

Two 20-year periods (minimum duration used by the Intergovernmental Panel on Climate Change, Collins et al., 2013) were chosen for the temperature scenarios: the reference period 1997–2016, which corresponds approximately to the period for which health data are available, and the future period 2041–2060, centered on the decade of 2050. The length of time between the two periods (44 years) is long enough to enable accurate detection of the general trend of temperature data (Liebmann et al., 2010).

T_{max} and $WBGT_{max}$ temperatures were calculated for all summer days[6] for both the reference and future periods. Five global models[7] (Taylor et al., 2012; Knutti et al., 2013) and three regional models[8] (Giorgi et al., 2009) were used in the calculations under two forcing scenarios, known as Representative Concentration Pathways (RCP): an optimistic scenario (RCP4.5), in which greenhouse gas emissions peak around 2040 and then decline, and a pessimistic scenario (RCP8.5), in which emissions continue to increase throughout the 21st century (Van Vuuren et al., 2011). To adjust for inherent biases in the climate models (i.e. systematic differences between simulated and actual data), and for the scale difference between the climate model and the observations, the climate simulations were corrected using the quantile mapping bias correction method.

Temperatures were calculated for each 1 km^2 cell of the area under study, for both the reference and future periods, and aggregated by postal code, then by economic region, as described in section 2.2.1. The difference between the multi-model temperature means of the reference and future periods represents the projected increase in temperature by 2050. This difference was divided by the inter-model spread with respect to the reference period, to obtain a signal-to-noise ratio, i.e. the magnitude of climate change (signal) in relation to natural climate variability (noise) (Sansom et al., 2013). All of the calculations were performed with Julia 0.6.3. Most of the algorithms, including those designed to handle and correct biases, were drawn from or included in the ClimateTools package.

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6 Due to an error, the period covered is from April 1 to October 31, instead of May 1 to September 30. However, verifications showed that this did not affect projected temperature increases between the reference and future periods or the projected number of injuries.

7 Global models (General Climate Models, GCM) belonging to the suite of Coupled Model Intercomparison Project Phase 5 (CMIP5) models: CanESM2, GFDL-ESM2M, IPSL-CM5A-MR, MIROC-ESM, NorESM1-M.

8 Regional models (Regional Climate Models, RCM) belonging to the suite of Coordinated Regional Climate Downscaling Experiment – North America (CORDEX-NA) models: CCCma-CanRCM4; DMI-HIRHAM5; UQAM-CRCM5.

2.4 Association between summer temperatures and occupational injuries, 2001–2016

An ecological, time series-based approach was used to analyze the associations between outdoor summer temperatures and the daily number of accepted claims for occupational injuries from 2001 to 2016 (or 2002 to 2017 for Ontario). These associations were estimated using generalized linear modeling, namely negative binomial regression to account for overdispersion. Otherwise, Poisson regression was used (variance was adjusted by a Pearson factor, PSCALE). We verified the non-linearity of the models using splines and quadratic transformations, but these models did not provide a better fit to the data. Relationships were estimated at the regional level, using the postal code of the employer's establishment to associate claim files with an economic region.[9] Relationships were also estimated at the provincial level, using generalized estimating equation models, with economic regions as clusters.

The models were adjusted for day of the week, month, year, holidays (for Quebec, the two weeks of construction holidays were included) to take into account the effects of temporal trends. The daily average precipitation and the daily average partial pressure of water vapour were also included in the T_{max} models (these variables were not included in the models based on the $WBGT_{max}$ indicator, which already takes humidity into account). The partial pressure of water vapour was not included in the T_{max} models of traumatic injuries, since it did not improve model fit. Temperature, precipitation, vapour pressure and year were included in the simple linear form.[10] The month, holiday and economic region variables were included in categories. The provincial models also incorporated an interaction term between region and temperature. Finally, all of the models were adjusted for monthly regional workforce data (offset term) taken from the Labour Force Survey (Statistics Canada, 2019).

The regional models are expressed as:

Ln [E(Yt)] = ln (Monthly estimate of workforce at risk)

$+ \beta_0 + \beta_{1\text{-}6}$ Day of the week $+ \beta_{7\text{-}10}$ Month

$+ \beta_{11}$ Year $+ \beta_{12}$ Holidays

$+ \beta_{13}$ Precipitation over 24 h

$+ \beta_{14}$ Partial pressure of vapour over 24 h

$+ \beta_{15}$ T_{max} or $WBGT_{max}$ over 24 h

$+ \beta_{16,i}$ Economic region i

$+\ldots+ \beta_{16,j}$ Economic region j

$+ \beta_{17,i}$ T_{max} (or $WBGT_{max}$).economic region i

$+\ldots+ \beta_{17,j}$ T_{max} (or $WBGT_{max}$). economic region j $+ \varepsilon$

where E(Yt) is the expected value, i.e. estimated daily number of injuries. The number of β_{16} and β_{17} coefficients varies by province (there are as many β_{16} and β_{17} coefficients as economic regions).

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9 In situations where the postal code was missing or located outside one of the provinces under study, the injuries were excluded from further analysis. In cases where the postal code covered more than one economic region, the region was randomly assigned. This random assignment was done in proportion to the population covered by the postal code in the economic region. This method has been used in several INSPQ studies on the material and social deprivation index.

10 The temperature and year variables were tested in categories when developing the method with Ontario data.

The provincial models are expressed as:

Ln [E(Yt)] = ln (Monthly estimate of workforce at risk)

$+ \beta_0 + \beta_{1\text{-}6}$ Day of the week $+ \beta_{7\text{-}10}$ Month

$+ \beta_{11}$ Year $+ \beta_{12}$ Holidays

$+ \beta_{13}$ Precipitation over 24 h

$+ \beta_{14}$ Partial pressure of vapour over 24 h

$+ \beta_{15}$ T_{max} or $WBGT_{max}$ over 24 h $+ \varepsilon$

It should be noted that, where the $WBGT_{max}$ indicator is used, both models exclude the β_{13} and β_{14} coefficients.

The associations were expressed using incidence rate ratios (IRR) and their 95% confidence intervals (CI) for each 1°C increase in the daily maximum temperature (linear effect). For ease of understanding, the results are reported in terms of percentage increase.

Where a sufficient number of injuries existed (at least two cases per economic region and stratification factor), stratified analyses were conducted based on sex and age (15–24 years, 25–44 years and 45 years and over) and, for Alberta and Quebec, according to whether the industry concerned operates mainly indoors or outdoors. Cochran's Q test (Kaufman and MacLehose, 2013) was used to verify statistical heterogeneity within these strata—in other words, it assessed whether the impact of temperature on the daily number of injuries varied beyond what would be expected by chance within the strata (statistical significance was set at $P < 0.05$). Analyses were conducted using SAS software, version 9.4.

2.5 Injuries projected for the 2050 horizon

Projections were only calculated for heat illness. The estimated IRR values for traumatic injuries were around "one." Therefore, it would be difficult to interpret any relative increase in the number of traumatic injuries by 2050 as being associated with global warming.

For heat illness, the number of injuries was projected onto the estimated differences in temperature between the reference and future periods, while keeping the influence of other variables equal (Erdman et al., 2008). This was done for each economic region and both forcing scenarios. The increase in the daily number of injuries across the province was obtained by tallying the increases in the province's economic regions. It is assumed that there is no change in the working population between the two 20-year periods in terms of size, age composition and types of jobs. Thus, based on the first model presented in section 2.4, the average daily number of accepted heat illness claims for the 2001–2016 period, for the economic region i (ERi), is calculated as follows:

$$\mu_{2001\text{-}2016} = \exp(\beta_0 + \beta_{15}\, T_{current} + \beta_{17,i}\, T_{current}.ER_i)$$

$$= \exp(\beta_0)^{*}\exp(\beta_{15} + \beta_{17,i}\, ER_i)(T_{current})$$

where $T_{current}$ is the maximum temperature calculated for 2001–2016.

The average daily number of accepted heat illness claims for the 2041–2060 future period for ERi is estimated as follows:

$$\mu_{2041\text{-}2060} = \exp(\beta_0 + (\beta_{15} + \beta_{17.I}\, ER_i)(T_{current} + б_{proj}))$$

$$= \exp(\beta_0)*\exp((\beta_{15} + \beta_{17.I}\ ER_i)(T_{current}))*\exp((\beta_{15} + \beta_{17.I}\ ER_i)(б_{proj}))$$

$$= \mu_{2001\text{-}2016}*\exp((\beta_{15} + \beta_{1.I}\ ER_i)(б_{proj}))$$

where $б_{proj}$ is the difference in the mean temperatures estimated between 1997–2016 and 2041–2060.

2.6 Ethics approval

This project was approved by the Health Canada Research Ethics Board and the Public Health Agency of Canada (CER 2018-004H). It was also approved by the Comité d'éthique de la recherche en Dépendances, inégalités sociales et santé publique (CÉR-DIS) of the Centre intégré universitaire de santé et de services sociaux du Centre-Sud-de-l'Ile-de-Montréal (DIS-1718-46).

3 Results

3.1 Association between summer temperatures and occupational injuries, 2001-2016

3.1.1 HEAT ILLNESS

Tables 1 to 5 show the number of heat illness claims accepted by the workers' compensation boards of Quebec, Ontario, Manitoba, Saskatchewan and Alberta, respectively, from 2001 to 2016.[11] They also show an estimate of the daily number of such claims per 1°C increase in outdoor summer temperatures (IRR and 95% CI) for the province as a whole and by economic region, sex and age. For Alberta and Quebec, IRRs for working in an industry that operates mainly outdoors or indoors are also presented. Daily average T_{max} and $WBGT_{max}$ temperatures by economic region are presented in tables 12 to 16 in the appendix.

In Quebec, a total of 343 heat illness claims were approved by the CNESST from 2001 to 2016 (Table 1). The majority of claims involved men (80%) and individuals aged 25 to 44 (57%), and were filed chiefly in the regions of Montreal (23%) and Montérégie (17%), by workers in primarily indoor industries (raw frequencies that partly reflect the size of these subgroups). For the province as a whole, an increase of approximately 34% (95% CI: 24–45%) in the daily number of accepted claims was estimated for each 1°C increase in daily T_{max} temperature. This increase represents seven additional accepted heat illness claims over the five summer months of each year of the 2001-2016 period (343 claims between May and September from 2001 to 2016 is equivalent to 0.143 claims per day. Applying an increase of 34% translates to 0.049 additional claims per day and seven additional claims over the five summer months of the year). With the $WBGT_{max}$ indicator, the increase is approximately 41% (95% CI: 35–48%). Increases at the regional level are broadly comparable to those observed at the provincial level. The IRR for women tends to be higher than that for men with the T_{max} indicator (p = 0.076), but heterogeneity associated with the sex stratum is lower with $WBGT_{max}$ and is not statistically significant (Cochran's Q test p = 0.136). The effect of temperature on IRR is comparable across the age and industry strata.

In Ontario, 1,014 claims were accepted by the WSIB from 2002 to 2017 for heat illness (Table 2). The frequency of these claims is higher in the Toronto region (40%), among men (68%) and among those 25 to 44 years of age (46%). For each 1°C increase in maximum daily temperature, an increase in the number of accepted heat illness claims of approximately 41% (95% CI: 39–44%) was estimated with T_{max} and an increase of approximately 48% (95% CI: 45–51%) was estimated with $WBGT_{max}$ at the provincial level (increases were comparable to the regional level), with no disparity by sex. The 25–44 age group has a higher IRR than the 15–24 age group, a difference that is statistically significant in the $WBGT_{max}$ model only.

In Manitoba, from 2001 to 2016, 130 compensation claims for heat illness were approved by that province's board (Table 3). The region with the highest injury frequency was Winnipeg (67%). Heat injuries were most frequent among men (82%) and those aged 25 to 44 (45%). There was an estimated increase of 36% (95% CI: 32–41%) in the daily number of such injuries for every 1°C increase in the T_{max} and approximately 41% (95% CI: 38–44%) for the $WBGT_{max}$ (increases in the economic regions were similar). Associations could not be estimated by age and sex owing to the small number of cases of heat illness in those subgroups.

[11] For Ontario, the results cover the period from 2002 to 2017.

The Saskatchewan Workers' Compensation Board accepted a total of 248 cases of heat illness from 2001 to 2016 (Table 4). Injury distribution by age and sex was similar to that of the other provinces under study. The regions of Regina-Moose Mountain (48%) and Saskatoon-Biggar (32%) had the highest injury frequencies. Increases of approximately 28% (95% CI: 25–32%) in the daily number of accepted heat illness claims were estimated for each 1°C increase in T_{max} and approximately 42% (95% CI: 38–47%) for the $WBGT_{max}$ at the provincial level (increases were comparable at the regional level), with no disparity by sex or age.

Table 5 shows the results for Alberta. From 2001 to 2016, 370 claims for heat illness were approved by that province's compensation board. The highest injury frequencies were observed in the Edmonton (44%) and Calgary (32%) regions, among men (76%) and those aged 25 to 44 (48%), with a similar injury distribution in indoor and outdoor industry groups (these raw frequencies do not take into account the number of workers in each subgroup). For the province as a whole, a 32% increase (95% CI: 29–36%) in the number of accepted heat illness claims was estimated for each 1°C increase in T_{max} and approximately 51% (95% CI: 46–57%) for the $WBGT_{max}$. Increases in the economic regions were comparable to those for the province. No disparities related to sex, age or indoor or outdoor industry were observed in relation to the effects of temperature on heat illness.

Table 1 Number of heat illness claims accepted by the Quebec CNESST from May to September, 2001 to 2016, and incidence rate ratios (IRR) per 1°C increase in maximum daily temperature

Group	Number of heat illness claims, 2001-2016 (%)		IRR (95% CI)[a] T_{max} model		IRR (95% CI)[b] $WBGT_{max}$ model	
Quebec total	343	(100)	1.340	(1.240 – 1.449)	1.411	(1.346 – 1.478)
Economic region (corresponds to the administrative region)						
Gaspésie	5	(1)	1.430	(1.069 – 1.911)	1.508	(1.100 – 2.069)
Bas-Saint-Laurent	11	(3)	1.299	(1.091 – 1.546)	1.494	(1.209 – 1.845)
Capitale-Nationale	19	(6)	1.335	(1.171 – 1.521)	1.421	(1.243 – 1.625)
Chaudière-Appalaches	17	(5)	1.441	(1.232 – 1.686)	1.540	(1.323 – 1.791)
Estrie	12	(3)	1.482	(1.204 – 1.824)	1.535	1.279 – 1.842)
Centre-du-Quebec	18	(5)	1.308	(1.134 – 1.509)	1.442	(1.259 – 1.652)
Montérégie	59	(17)	1.350	(1.234 – 1.477)	1.447	(1.333 – 1.571)
Montréal	80	(23)	1.377	(1.269 – 1.494)	1.458	(1.358 – 1.566)
Laval	19	(6)	1.623	(1.354 – 1.945)	1.687	(1.444 – 1.972)
Lanaudière	25	(7)	1.583	(1.361 – 1.842)	1.543	(1.366 – 1.742)
Laurentides	15	(4)	1.369	(1.169 – 1.603)	1.400	(1.211 -1.619)
Outaouais	9	(3)	1.400	(1.148 – 1.706)	1.411	(1.164 – 1.709)
Abitibi	8	(2)	1.077	(0.935 – 1.241)	1.185	(0.995 – 1.410)
Mauricie	12	(3)	1.378	(1.159 – 1.638)	1.456	(1.230 – 1.724)
Saguenay	28	(8)	1.136	(1.046 – 1.234)	1.238	(1.122 – 1.366)
QC Nord	6	(2)	1.475	(1.133 – 1.920)	1.929	(1.333 – 2.792)
Sex						
Male	276	(80)	1.297[c]	(1.189 – 1.414)	1.380[c]	(1.263 – 1.508)
Female	67	(20)	1.444[c]	(1.309 – 1.592)	1.478[c]	(1.375 – 1.589)
Cochran's Q test	-	-	Q(df) = 3.15(1) p = 0.076		Q(df) = 2.22(1) p = 0.136	
Age						
15-24	52	(15)	1.409[d]	(1.202 – 1.653)	1.313[d]	(1.182 – 1.459)
25-44	194	(57)	1.337[d]	(1.220 – 1.464)	1.424[d]	(1.354 – 1.496)
45 and over	97	(28)	1.262[d]	(1.163 – 1.369)	1.403[d]	(1.318 – 1.492)
Cochran's Q test	-	-	Q(df) = 1.85(2) p = 0.396		Q(df) = 3.05(2) p = 0.218	
Industry (groupings of NAICS two-digit codes)						
Outdoor	80	(23)	1.437[e]	(1.341 – 1.540)	1.417[e]	(1.314 – 1.527)
Indoor	263	(77)	1.336[e]	(1.192 – 1.498)	1.444[e]	(1.378 – 1.514)
Cochran's Q test	-	-	Q(df) = 1.47(1) p = 0.225		Q(df) = 0.98(1) p = 0.322	

[a] IRR adjusted for day, month, year, holidays (including construction holidays), average daily precipitation, average daily partial pressure of water vapour, interaction between the region and temperature (regional models) and monthly regional workforce estimates.

[b] IRR adjusted for day, month, year, holidays, construction holidays, interaction between the region and temperature (regional models) and monthly regional workforce estimation.

[c] IRR generated by excluding certain regions (Gaspésie, Bas-Saint-Laurent, Capitale-Nationale, Estrie, Lanaudière, Abitibi, QC Nord) with negative binomial regression among males and Poisson regression among females. The comparison of IRR for males and females involved 194 and 63 cases, respectively, from 2001 to 2016.

[d] IRR generated by excluding certain regions (Gaspésie, Estrie, Laval, Outaouais, Abitibi, Mauricie, QC Nord) and excluding Saturdays, which involved no cases, to allow the model to converge. In these analyses, the number of injuries from 2001 to 2016 among those aged 15-24, 25-44 and 45 and over was 47, 146 and 79, respectively.

[e] IRR generated by excluding certain regions (Gaspésie, Estrie, Centre-Du-Quebec, Outaouais, QC Nord). The comparison of IRR for outdoor and indoor industries involved 73 and 200 cases, respectively, from 2001 to 2016. For the outdoor industry group, the missing values for the monthly workforce variable were estimated through linear extrapolation between two consecutive dates; otherwise, they were given a zero value. For the indoor industry group, workforce estimates were based on the total estimated workforce and that of the outdoor industry group, after imputation of the missing values.

Table 2 **Number of heat illness claims accepted by the Ontario WSIB from May to September, 2002 to 2017, and incidence rate ratios (IRR) per 1°C increase in maximum daily temperature**

Group	Number of heat illness claims, 2002-2017 (%)		IRR (95% CI)[a] T_{max} model		IRR (95% CI)[b] $WBGT_{max}$ model	
Ontario total	1,014	(100)	1.412	(1.386 – 1.438)	1.484	(1.454 – 1.514)
Economic region						
Ottawa	115	(11)	1.368	(1.289 – 1.452)	1.480	(1.390 – 1.576)
Kingston-Pembroke	22	(2)	1.488	(1.279 – 1.730)	1.591	(1.378 – 1.837)
Muskoka-Kawarthas	30	(3)	1.480	(1.314 – 1.668)	1.588	(1.418 – 1.779)
Toronto	406	(40)	1.379	(1.328 – 1.431)	1.458	(1.405 – 1.513)
Kitchener-Waterloo-Barrie	123	(12)	1.383	(1.303 – 1.468)	1.465	(1.382 – 1.554)
Hamilton-Niagara Peninsula	133	(13)	1.446	(1.357 – 1.541)	1.493	(1.410 – 1.581)
London	52	(5)	1.472	(1.333 – 1.626)	1.613	(1.463 – 1.778)
Windsor-Sarnia	68	(7)	1.620	(1.462 – 1.796)	1.694	(1.545 – 1.857)
Stratford-Bruce Peninsula	25	(2)	1.631	(1.393 – 1.910)	1.701	(1.482 – 1.952)
Northeast	28	(3)	1.380	(1.236 – 1.540)	1.470	(1.298 – 1.664)
Northwest	12	(1)	1.396	(1.174 – 1.660)	1.595	(1.301 – 1.956)
Sex						
Male	685	(68)	1.406	(1.371 – 1.441)	1.480	(1.443 – 1.517)
Female	329	(32)	1.417	(1.356 – 1.480)	1.469	(1.427 – 1.511)
Cochran's Q test	-	-	Q(df) = 0.144(1) p = 0.704		Q(df) = 0.54(1) p = 0.462	
Age						
15-24	187	(18)	1.417[c]	(1.365 – 1.470)	1.394[c]	(1.339 – 1.452)
25-44	463	(46)	1.433[c]	(1.391 – 1.477)	1.523[c]	(1.461 – 1.588)
45 and over	364	(36)	1.381[c]	(1.334 – 1.428)	1.459[c]	(1.416 – 1.505)
Cochran's Q test	-	-	Q(df) = 2.69(2) p = 0.260		Q(df) = 11.90(2) p = 0.003	

[a] IRR adjusted for day, month, year, holidays, average daily precipitation, average daily partial pressure of water vapour, interaction between the region and temperature (regional models) and monthly regional workforce estimates.

[b] IRR adjusted for day, month, year, holidays, interaction between the region and temperature (regional models) and monthly regional workforce estimates.

[c] IRR generated by excluding holidays to allow comparison of the 15–24 and over-45 age groups with the 25–44 cohort, which had no cases for the holiday variable.

Table 3 Number of heat illness claims accepted by the Workers' Compensation Board of Manitoba from May to September, 2001 to 2016, and incidence rate ratios (IRR) per 1°C increase in maximum daily temperature

Group	Number of heat illness claims, 2001-2016 (%)		IRR (95% CI)[a] T_{max} model		IRR (95% CI)[b] $WBGT_{max}$ model	
Manitoba total	130	(100)	1.361	(1.319 – 1.405)	1.406	(1.376 – 1.436)
Economic region						
Southeast	8	(6)	1.439	(1.129 – 1.834)	1.594	(1.248 – 2.037)
South Central/North Central	6	(5)	1.508	(1.144 – 1.986)	1.457	(1.130 – 1.878)
Southwest	17	(13)	1.443	(1.249 – 1.668)	1.538	(1.309 – 1.807)
Winnipeg	87	(67)	1.335	(1.245 – 1.432)	1.377	(1.283 – 1.478)
Interlake	7	(5)	1.261	(1.032 – 1.540)	1.452	(1.164 – 1.812)
Parklands and North	5	(4)	1.288	(0.997 – 1.665)	1.441	(1.094 – 1.899)
Sex						
Male	107	(82)	-	-	-	-
Female	23	(18)	-	-	-	-
Age						
15-24	26	(20)	-	-	-	-
25-44	58	(45)	-	-	-	-
45 and over	46	(35)	-	-	-	-

[a] IRR adjusted for day, month, year, average daily precipitation, average daily partial pressure of water vapour, interaction between the region and temperature (regional models) and monthly regional workforce estimates. Saturdays, holidays (1 case in Winnipeg) and the month of September (0 cases for the South Central/North Central and Parklands and North regions) were excluded.

[b] IRR adjusted for day, month, year, interaction between the region and temperature (regional models) and monthly regional workforce estimates. Saturdays, holidays (1 case in Winnipeg) and the month of September (0 injuries for the South Central/North Central, Interlake and Parklands and North regions) were excluded.

Table 4 **Number of heat illness claims accepted by the Saskatchewan Workers' Compensation Board from May to September, 2001 to 2016, and incidence rate ratios (IRR) per 1°C increase in maximum daily temperature**

Group	Number of heat illness claims, 2001-2016 (%)		IRR (95% CI)[a] T_{max} model		IRR (95% CI)[b] $WBGT_{max}$ model	
Saskatchewan total	248	(100)	1.283	(1.245 – 1.323)	1.420	(1.376 – 1.467)
Economic region						
Regina-Moose Mountain	120	(48)	1.282	(1.207 – 1.361)	1.400	(1.318 – 1.486)
Swift Current-Moose Jaw	17	(7)	1.298	(1.120 – 1.505)	1.468	(1.246 – 1.730)
Saskatoon-Biggar	79	(32)	1.244	(1.161 – 1.333)	1.369	(1.267 – 1.479)
Yorkton-Melville	10	(4)	1.300	(1.053 – 1.603)	1.489	(1.217 – 1.822)
Prince Albert and Northern	22	(9)	1.373	(1.193 – 1.580)	1.539	(1.308 – 1.812)
Sex						
Male	197	(79)	1.284[c]	(1.249 – 1.320)	1.411	(1.363 – 1.461)
Female	50	(20)	1.280[c]	(1.162 – 1.410)	1.472	(1.351 – 1.604)
Unknown	1	(0)	-	-	-	-
Cochran's Q test	-	-	Q(df) = 0.009(1) p = 0.923		Q(df) = 0.80(1) p = 0.371	
Age						
15-24	90	(36)	1.273[d]	(1.197 – 1.354)	1.454[d]	(1.381 – 1.529)
25-44	112	(45)	1.299[d]	(1.251 – 1.348)	1.435[d]	(1.400 – 1.472)
45 and over	47	(19)	1.276[d]	(1.193 – 1.364)	1.357[d]	(1.250 – 1.474)
Cochran's Q test	-	-	Q(df) = 0.75(2) p = 0.688		Q(df) = 2.20(2) p = 0.331	

a IRR adjusted for day, month, year, average daily precipitation, average daily partial pressure of water vapour, interaction between the region and temperature (regional models) and monthly regional workforce estimates. Holidays were excluded (0 cases).

b IRR adjusted for day, month, year, interaction between the region and temperature (regional models) and monthly regional workforce estimates. Holidays were excluded (0 cases).

c Holidays (0 cases) and the Yorkton-Melville region (1 case involving a female) were excluded. The analyses involved 188 and 49 cases, respectively, among males and females.

d Holidays and the month of September were excluded (0 cases in the 15–24 age group). The analyses involved 89, 107 and 45 cases, respectively, in the 15–24, 25–44 and 45 and over age groups.

Table 5 **Number of heat illness claims accepted by the Workers' Compensation Board of Alberta from May to September, 2001 to 2016, and incidence rate ratios (IRR) per 1°C increase in maximum daily temperature**

Group	Number of heat illness, 2001-2016 (%)		IRR (95% CI)[a] T_{max} model		IRR (95% CI)[b] $WBGT_{max}$ model	
Alberta total	370	(100)	1.324	(1.287 – 1.362)	1.512	(1.458 – 1.567)
Economic region						
Lethbridge-Medicine Hat	20	(5)	1.274	(1.149 – 1.413)	1.414	(1.248 – 1.603)
Camrose-Drumheller	10	(3)	1.364	(1.174 – 1.584)	1.517	(1.257 – 1.830)
Calgary	117	(32)	1.348	(1.282 – 1.417)	1.571	(1.478 – 1.669)
Banff-Jasper-Athabasca	27	(7)	1.375	(1.242 – 1.522)	1.603	(1.408 – 1.825)
Red Deer	23	(6)	1.417	(1.268 – 1.583)	1.680	(1.461 – 1.933)
Edmonton	163	(44)	1.355	(1.299 – 1.414)	1.522	(1.447 – 1.601)
Wood Buffalo-Cold Lake	10	(3)	1.287	(1.100 – 1.505)	1.354	(1.138 – 1.610)
Sex						
Male	281	(76)	1.330[c]	(1.289 – 1.371)	1.521[c]	(1.455 – 1.589)
Female	86	(23)	1.318[c]	(1.257 – 1.382)	1.560[c]	(1.471 – 1.653)
Unknown	3	(1)	-	-	-	-
Cochran's Q test	-	-	Q(df) = 0.12(1) *p* = 0.728		Q(df) = 0.73(1) *p* = 0.393	
Age						
15-24	118	(32)	1.345	(1.296 – 1.396)	1.521	(1.459 – 1.586)
25-44	176	(48)	1.307	(1.248 – 1.370)	1.519	(1.429 – 1.615)
45 and over	76	(21)	1.316	(1.291 – 1.341)	1.487	(1.410 – 1.569)
Cochran's Q test	-	-	Q(df) = 1.36(2) *p* = 0.507		Q(df) = 0.47(2) *p* = 0.792	
Industry (groupings of NAICS two-digit codes)						
Outdoor	192	(52)	1.346[d]	(1.309 – 1.384)	1.570[d]	(1.451 – 1.699)
Indoor	177	(48)	1.308[d]	(1.244 – 1.375)	1.505[d]	(1.425 – 1.589)
Unknown	1	(0)	-	-	-	-
Cochran's Q test	-	-	Q(df) = 1.46(1) *p* = 0.227		Q(df) = 0.81(1) *p* = 0.393	

[a] IRR adjusted for day, month, year, holidays, average daily precipitation, average daily partial pressure of water vapour , interaction between the region and temperature (regional models) and monthly regional workforce estimates.

[b] IRR adjusted for day, month, year, holidays, interaction between the region and temperature (regional models) and monthly regional workforce estimates.

[c] The month of September and the Wood-Buffalo-Cold Lake region were excluded from the analyses (0 cases identified among females). The analyses involved 258 and 86 cases, respectively, among males and females.

[d] For the outdoor industry group, the missing values for the monthly workforce variable were estimated through linear extrapolation between two consecutive dates; otherwise, they were given a value of zero. For the indoor industry group, workforce estimates were based on the total estimated workforce and that of the outdoor industry group, after imputation of the missing values. The Wood Buffalo-Cold Lake region was excluded from the analyses (0 cases for the indoor industry group). The analyses involved 183 and 176 cases for the outdoor and indoor industries, respectively.

3.1.2 Traumatic injuries

Tables 6 to 10 show the number of work-related traumatic injury claims accepted by the compensation boards of each of the provinces over a 16-year period. They also show an estimate of the daily number of such claims for each 1°C increase in summer outdoor temperature (IRR and 95% CI) at the provincial and regional levels, and by sex, age, and, for Alberta and Quebec, indoor and outdoor industry.

From 2001 to 2016, Quebec's CNESST accepted 514,832 claims for compensation for work-related traumatic injuries. Table 6 shows the distribution of these injuries, which partly reflects the respective sizes of the subgroups. For the province as a whole, an increase of approximately 0.2% (95% CI: 0.1–0.3%) in the daily number of injuries was estimated for each 1°C increase in T_{max} and daily $WBGT_{max}$. This represents approximately 64 additional accepted traumatic injury claims over the five summer months of each year of the 2001-2016 period (514,832 claims between May and September from 2001 to 2016 is equivalent to 215 claims per day. Applying an increase of 0.2% translates to 0.43 additional claims per day and 64 additional claims over the five summer months of the year). The increases are broadly comparable at the economic region level but are higher for the regions of Abitibi (0.7% and 0.9% in the T_{max} and $WBGT_{max}$ models, respectively) and QC Nord (0.9% and 1.3% in the respective models). The effect of temperature increases on IRR is higher among male workers, younger workers (dose-response gradient by age) and for outdoor industries (statistically significant heterogeneity associated with the strata of age, sex and industry, Cochran Q tests, Table 6). In industries whose activities are carried out primarily outdoors, the agriculture, forestry, hunting and fishing sector stands out with a 1.1% increase in the number of injuries (95% CI: 0.6–1.6%) for each 1°C increase in T_{max} and a 1.2% increase in the number of injuries (95% CI: 0.5–1.8%) for each 1°C increase in $WBGT_{max}$. In the construction industry, a 0.5% increase is observed in the number of injuries for each additional 1°C of T_{max} (95% CI: 0.3–0.8%) and $WBGT_{max}$ (95% CI: 0.2-0.8%) (N.B.: these results are not shown in Table 6).[12]

From 2002 to 2017, Ontario's WSIB accepted 400,369 compensation claims for work-related traumatic injuries (Table 7), half of which were reported in the Toronto region. An approximate increase of 0.2% in the number of daily injuries has been estimated for each 1°C increase in T_{max} (95% CI: 0.2–0.3%) and $WBGT_{max}$ (95% CI: 0.1–0.3%). Similar increases are estimated for the economic regions. The impact of temperature increases is higher among male and younger workers.

From 2001 to 2016, Manitoba's provincial compensation board approved a total of 180,404 claims for traumatic injuries (Table 8). The Winnipeg economic region had the highest injury frequency (64%). The IRR for each 1°C increase in the maximum outdoor temperature jumps by 0.3% for the T_{max} (95% CI: 0.2–0.4%) and 0.4% for the $WBGT_{max}$ (95% CI: 0.2–0.5%) for the province as a whole. The numbers for the regional associations are comparable to those of the province, except in the Southwest region, which stands out with increases in the number of injuries of 0.8% and 1.0% in the T_{max} and $WBGT_{max}$ models, respectively. The strength of the association between temperature and IRR is higher among males and for the 15–24 age group.

In total, 141,374 claims for traumatic injuries were accepted by the Saskatchewan compensation board from 2001 to 2016 (Table 9), distributed mainly in the regions of Saskatoon-Biggar (38%) and Regina-Moose Mountain (34%). Each 1°C increase in T_{max} is associated with an increase in the daily number of injuries of 0.4% (95% CI: 0.3–0.5%) and an increase of 0.6% (95% CI: 0.5–0.8%) in the $WBGT_{max}$ model. Comparable associations were found in the province's five economic regions. The

[12] These more detailed analyses by sector were carried out only for Quebec, with delays in access to data from the various provinces leading to the prioritization of analyses toward the achievement of the study's key objectives.

relationship is stronger among males, particularly for the $WBGT_{max}$ indicator. For both indicators, the strength of the relationship is greater within the 15–24 age group.

In Alberta, 258,129 claims were approved by the province's compensation board from 2001 to 2016 (Table 10), distributed mainly among the Edmonton (39%) and Calgary (37%) regions. For the province as a whole, an increase of approximately 0.3% (95% CI: 0.2–0.4%) in the daily number of traumatic injuries is estimated for each 1°C increase in T_{max} and approximately 0.5% (95% CI: 0.3–0.6%) for the $WBGT_{max}$. Banff-Jasper-Athabasca stands out with increases of 0.9% and 1.3% in the number of injuries in the two models, respectively. Temperature was found to have a more pronounced effect on the IRR for males, persons aged 15–24 and people working in industries whose activities are primarily performed outdoors.

Table 6 **Number of work-related traumatic injury claims accepted by the Quebec CNESST from May to September, 2001 to 2016, and incidence rate ratios (IRR) per 1°C increase in maximum daily temperature**

Group	Number of traumatic injury claims, 2001-2016 (%)		IRR (95% CI)[a] T_{max} model		IRR (95% CI)[b] $WBGT_{max}$ model	
Quebec total	514,832	(100)	1.002	(1.001 – 1.003)	1.002	(1.001 – 1.003)
Economic region (corresponds to the administrative region)						
Gaspésie	5,576	(1)	1.001	(0.995 – 1.007)	1.001	(0.994 – 1.008)
Bas-Saint-Laurent	14,409	(3)	1.004	(1.000 – 1.008)	1.005	(1.000 – 1.010)
Capitale-Nationale	51,937	(10)	1.005	(1.002 – 1.007)	1.005	(1.002 – 1.008)
Chaudière-Appalaches	29,431	(6)	1.000	(0.997 – 1.002)	0.999	(0.995 – 1.002)
Estrie	22,861	(4)	1.002	(0.999 – 1.005)	1.002	(0.999 – 1.006)
Centre-du-Quebec	18,803	(4)	0.998	(0.995 – 1.002)	0.998	(0.994 – 1.002)
Montérégie	89,410	(17)	1.001	(0.999 – 1.003)	1.001	(0.998 – 1.003)
Montréal	144,255	(28)	1.000	(0.999 – 1.002)	1.001	(0.999 – 1.003)
Laval	23,776	(5)	1.005	(1.002 – 1.008)	1.005	(1.002 – 1.009)
Lanaudière	23,937	(5)	1.000	(0.997 – 1.003)	1.000	(0.997 – 1.003)
Laurentides	24,166	(5)	1.002	(0.999 – 1.005)	1.003	(1.000 – 1.007)
Outaouais	13,478	(3)	1.003	(0.999 – 1.006)	1.003	(0.998 – 1.007)
Abitibi	11,192	(2)	1.007	(1.003 – 1.010)	1.009	(1.005 – 1.014)
Mauricie	14,782	(3)	1.006	(1.002 – 1.009)	1.007	(1.003 – 1.012)
Saguenay	17,715	(3)	1.005	(1.002 – 1.008)	1.008	(1.003 – 1.012)
QC Nord	9,104	(2)	1.009	(1.004 – 1.014)	1.013	(1.007 – 1.019)
Sex						
Male	361,204	(70)	1.003	(1.002 – 1.004)	1.003	(1.002 – 1.004)
Female	153,628	(30)	1.000	(0.999 – 1.001)	1.000	(0.998 – 1.001)
Cochran's Q test	-	-	Q(df) = 13.32(1) $p = 0.0003$		Q(df) = 11.08(1) $p = 0.0009$	
Age						
15–24	93,016	(18)	1.007	(1.006 – 1.009)	1.010	(1.007 – 1.012)
25–44	245,752	(48)	1.002	(1.001 – 1.003)	1.002	(1.001- 1.002)
45 and over	176,064	(34)	0.999	(0.998 – 1.000)	0.999	(0.997 – 1.000)
Cochran's Q test	-	-	Q(df) = 59.95(2) $p < 0.0001$		Q(df) = 70.41(1) $p < 0.0001$	
Industry (groupings of NAICS two-digit codes)						
Outdoor	90,415	(18)	1.004[c]	(1.003 – 1.006)	1.005[c]	(1.002 – 1.007)
Indoor	423,818	(82)	1.002[c]	(1.001 – 1.002)	1.002[c]	(1.001 – 1.003)
Unknown	599	(0)	-	-	-	-
Cochran's Q test	-	-	Q(df) = 8.56(1). $p = 0.0034$		Q(df) = 5.55(1) $p = 0.0184$	

[a] IRR adjusted for day, month, year, holidays, construction holidays, average daily precipitation, interaction between the region and temperature (regional models) and monthly regional workforce estimates.

[b] IRR adjusted for day, month, year, holidays, construction holidays, interaction between the region and temperature (regional models) and monthly regional workforce estimates.

[c] For the outdoor industry group, the missing values for the monthly workforce variable were estimated through linear extrapolation between two consecutive dates; otherwise, they were given a value of zero.

Table 7 **Number of work-related traumatic injury claims accepted by the Ontario WSIB from May to September, 2002 to 2017, and incidence rate ratios (IRR) per 1°C increase in maximum daily temperature**

Group	Number of traumatic injury claims, 2002-2017 (%)		IRR (95% CI)[a] T_{max} model		IRR (95% CI)[b] $WBGT_{max}$ model	
Ontario total	400,369	(100)	1.002	(1.002 – 1.003)	1.002	(1.001 – 1.003)
Economic region						
Ottawa	40,507	(10)	1.001	(0.999 – 1.004)	1.001	(0.998 – 1.004)
Kingston-Pembroke	9,872	(2)	1.007	(1.003 – 1.012)	1.007	(1.002 – 1.012)
Muskoka-Kawarthas	9,470	(2)	1.007	(1.002 – 1.011)	1.008	(1.002 – 1.013)
Toronto	201,986	(50)	1.002	(1.001 – 1.004)	1.002	(1.000 – 1.004)
Kitchener-Waterloo-Barrie	33,105	(8)	1.001	(0.998 – 1.003)	1.000	(0.997 – 1.004)
Hamilton-Niagara Peninsula	40,797	(10)	1.002	(1.000 – 1.005)	1.001	(0.999 – 1.004)
London	15,939	(4)	0.998	(0.995 – 1.002)	0.996	(0.992 – 1.000)
Windsor-Sarnia	20,997	(5)	1.003	(1.000 – 1.007)	1.004	(1.000 – 1.007)
Stratford-Bruce Peninsula	6,885	(2)	1.007	(1.002 – 1.012)	1.009	(1.003 – 1.015)
Northeast	14,508	(4)	1.001	(0.998 – 1.005)	1.002	(0.997 – 1.006)
Northwest	6,303	(2)	1.004	(0.999 – 1.009)	1.005	(0.999 – 1.011)
Sex						
Male	251,019	(63)	1.004	(1.002 – 1.005)	1.004	(1.002 – 1.005)
Female	149,242	(37)	1.000	(0.999 – 1.002)	1.000	(0.998 – 1.002)
Unknown	108	(0)	-	-	-	-
Cochran's Q test	-	-	Q(df) = 13.74(1) p = 0.0002		Q(df) = 11.50(1) p = 0.0006	
Age						
15–24	62,565	(16)	1.006	(1.004 – 1.009)	1.008	(1.005 – 1.010)
25–44	186,191	(47)	1.002	(1.001 – 1.003)	1.002	(1.000 - 1.003)
45 and over	151,613	(38)	1.001	(1.000 – 1.003)	1.001	(0.999 – 1.002)
Cochran's Q test	-	-	Q(df) = 17.26(2) p = 0.0002		Q(df) = 20.85(2) p < 0.0001	

[a] IRR adjusted for day, month, year, holidays, average daily precipitation, interaction between the region and temperature (regional models) and monthly regional workforce estimates.

[b] IRR adjusted for day, month, year, holidays, interaction between the region and temperature (regional models) and monthly regional workforce estimates.

Table 8 **Number of work-related traumatic injury claims accepted by the Workers' Compensation Board of Manitoba from May to September, 2001 to 2016, and incidence rate ratios (IRR) per 1°C increase in maximum daily temperature**

Group	Number of traumatic injury claims, 2001-2016 (%)		IRR (95% CI)[a] T_{max} model		IRR (95% CI)[b] $WBGT_{max}$ model	
Manitoba total	180,404	(100)	1.003	(1.002 – 1.004)	1.004	(1.002 – 1.005)
Economic region						
Southeast	13,693	(8)	1.005	(1.001 – 1.008)	1.006	(1.002 – 1.010)
South Central/North Central	15,607	(9)	1.003	(1.000 – 1.006)	1.004	(1.000 – 1.008)
Southwest	10,864	(6)	1.008	(1.004 – 1.011)	1.010	(1.005 – 1.014)
Winnipeg	115,071	(64)	1.001	(0.999 – 1.003)	1.001	(0.999 – 1.003)
Interlake	11,815	(7)	1.004	(1.000 – 1.007)	1.005	(1.001 – 1.009)
Parklands and North	13,354	(7)	1.006	(1.003 – 1.009)	1.009	(1.004 – 1.013)
Sex						
Male	126,439	(70)	1.004	(1.003 – 1.005)	1.005	(1.003 – 1.007)
Female	53,277	(30)	1.000	(0.998 – 1.002)	1.000	(0.997 – 1.003)
Unknown	688	(0)	-	-	-	-
Cochran's Q test	-	-	Q(df) = 11.09(1) p = 0.0009		Q(df) = 10.45(1) p = 0.0012	
Age						
15–24	35,530	(20)	1.005	(1.003 – 1.007)	1.007	(1.004 – 1.010)
25–44	82,502	(46)	1.003	(1.001 – 1.005)	1.004	(1.002 – 1.006)
45 and over	62,372	(35)	1.001	(1.000 – 1.003)	1.001	(0.999 – 1.003)
Cochran's Q test	-	-	Q(df) = 6.28(2) p = 0.0434		Q(df) = 9.19(2) p = 0.0101	

[a] IRR adjusted for day, month, year, holidays, average daily precipitation, interaction between the region and temperature (regional models) and monthly regional workforce estimates.

[b] IRR adjusted for day, month, year, holidays, interaction between the region and temperature (regional models) and monthly regional workforce estimates.

Table 9 **Number of work-related traumatic injury claims accepted by the Saskatchewan Workers' Compensation Board from May to September, 2001 to 2016, and incidence rate ratios (IRR) per 1°C increase in maximum daily temperature**

Group	Number of traumatic injury claims, 2001-2016 (%)		IRR (95% CI)[a] T_{max} model		IRR (95% CI)[b] $WBGT_{max}$ model	
Saskatchewan total	141,374	(100)	1.004	(1.003 – 1.005)	1.006	(1.005 – 1.008)
Economic region						
Regina-Moose Mountain	47,560	(34)	1.004	(1.002 – 1.006)	1.006	(1.003 – 1.009)
Swift Current-Moose Jaw	10,620	(8)	1.004	(1.000 – 1.007)	1.007	(1.002 – 1.012)
Saskatoon-Biggar	53,761	(38)	1.002	(1.000 – 1.004)	1.004	(1.002 – 1.007)
Yorkton-Melville	7,982	(6)	1.005	(1.001 – 1.009)	1.009	(1.003 – 1.014)
Prince Albert and Northern	21,451	(15)	1.006	(1.003 – 1.009)	1.010	(1.006 – 1.014)
Sex						
Male	94,617	(67)	1.004	(1.003 – 1.006)	1.007	(1.005 – 1.010)
Female	45,751	(32)	1.003	(1.001 – 1.005)	1.004	(1.001 – 1.007)
Unknown	1,006	(1)	-	-	-	-
Cochran's Q test	-	-	Q(df) = 1.85(1) p = 0.1741		Q(df) = 3.96(1) p = 0.0464	
Age						
15–24	32,289	(23)	1.006	(1.004 – 1.009)	1.011	(1.007 – 1.014)
25–44	64,459	(46)	1.003	(1.001 – 1.005)	1.006	(1.003 – 1.008)
45 and over	44,626	(32)	1.003	(1.001 – 1.005)	1.004	(1.001 – 1.007)
Cochran's Q test	-	-	Q(df) = 6.95(2) p = 0.0309		Q(df) = 9.81(2) = p = 0.0074	

[a] IRR adjusted for day, month, year, holidays, average daily precipitation, interaction between the region and temperature (regional models) and monthly regional workforce estimates.

[b] IRR adjusted for day, month, year, holidays, interaction between the region and temperature (regional models) and monthly regional workforce estimates.

Table 10 Number of work-related traumatic injury claims accepted by the Workers' Compensation Board of Alberta from May to September, 2001 to 2016, and incidence rate ratios (IRR) per 1°C increase in maximum daily temperature

Group	Number of traumatic injury claims, 2001-2016 (%)		IRR (95% CI)[a] T_{max} model		IRR (95% CI)[b] $WBGT_{max}$ model	
Total Alberta	258,129	(100)	1.003	(1.002 – 1.004)	1.005	(1.003 – 1.006)
Economic region						
Lethbridge-Medicine Hat	14,917	(6)	1.005	(1.003 – 1.008)	1.009	(1.004 – 1.013)
Camrose-Drumheller	7,998	(3)	1.007	(1.003 – 1.012)	1.013	(1.007 – 1.019)
Calgary	95,712	(37)	1.002	(1.001 – 1.004)	1.004	(1.001 – 1.006)
Banff-Jasper-Athabasca	19,663	(8)	1.009	(1.006 – 1.012)	1.013	(1.009 – 1.018)
Red Deer	14,093	(5)	1.001	(0.998 – 1.004)	1.002	(0.998 – 1.007)
Edmonton	100,804	(39)	1.002	(1.000 – 1.003)	1.004	(1.001 – 1.006)
Wood Buffalo-Cold Lake	4,942	(2)	1.003	(0.998 – 1.008)	1.003	(0.996 – 1.010)
Sex						
Male	178,373	(69)	1.003	(1.002 – 1.005)	1.006	(1.005 – 1.008)
Female	77,893	(30)	1.001	(1.000 – 1.003)	1.001	(1.000 – 1.004)
Unknown	1,863	(1)	-	-	-	-
Cochran's Q test	-	-	Q(df) = 4.80(1) p = 0.0284		Q(df) = 11.63(1) p = 0.0006	
Age						
15–24	52.058	(20)	1.005	(1.003 – 1.007)	1.009	(1.006 – 1.012)
25–44	124.157	(48)	1.002	(1.001 – 1.004)	1.004	(1.002 – 1.006)
45 and over	81.914	(32)	1.002	(1.000 – 1.003)	1.003	(1.000 – 1.005)
Cochran's Q test	-	-	Q(df) = 6.50(2) p = 0.0388		Q(df) = 12.99(2) p = 0.0015	
Industry (groupings of NAICS two-digit codes)						
Outdoor	82.609	(32)	1.005	(1.004 – 1.007)	1.010	(1.007 – 1.012)
Indoor	175.456	(68)	1.001	(1.000 – 1.003)	1.002	(1.000 – 1.004)
Unknown	64	(0)	-	-	-	-
Cochran's Q test	-	-	Q(df) = 15.55 p < 0.0001		Q(df) = 25.77(1) p < 0.0001	

[a] IRR adjusted for day, month, year, holidays, average daily precipitation, interaction between the region and temperature (regional models) and monthly regional workforce estimates.

[b] IRR adjusted for day, month, year, holidays, interaction between the region and temperature (regional models) and monthly regional workforce estimates.

3.2 Heat illness by 2050

Table 11 shows the projected temperature increases by 2050 (for the period 2041–2060) according to optimistic (RCP4.5) and pessimistic (RCP8.5) scenarios, as well as the anticipated daily number of heat illness claims that could be accepted by workers' compensation boards by economic region and province, given the number of such claims during the reference period (1997–2016).

In Quebec, climate scenarios project regional T_{max} increases of 1.8 to 2.0°C under the optimistic scenario and 2.2 to 2.6°C under the pessimistic scenario by 2050. The corresponding projected increases in the $WBGT_{max}$ indicator are 1.5 to 1.7°C and 1.9 to 2.2°C. Given the projected T_{max} increases, the number of daily cases ofheat illness for a summer day will climb from 0.139 to 0.256—

an increase of 84% under the optimistic scenario. The number of heat illness cases per day will increase to 0.309 by 2050 under the pessimistic scenario—an increase of 122%. Similar increases in the $WBGT_{max}$ indicator are anticipated: 85% under the optimistic scenario (0.139 to 0.257 cases of heat illness per day) and 129% under the pessimistic scenario (0.139 to 0.318 cases of heat illness per day).

For Ontario, regional T_{max} increases of 1.7 to 1.9°C are projected for the 2041-2060 period under the optimistic scenario and of 2.3 to 2.6°C under the pessimistic scenario. With respect to the $WBGT_{max}$, the projected increases are 1.6 to 1.7°C (optimistic scenario) and 2.1 to 2.4 C (pessimistic scenario). As a result, for these T_{max} increases, daily heat illness counts for one day will jump by 90% between the reference period and the future period, under the optimistic scenario (0.417 to 0.791 cases of heat illness per day). They will increase by 139% between the reference period and the future period under the pessimistic scenario (0.417 to 0.998 heat illness cases per day). The increases for the $WBGT_{max}$ indicator are 99% (0.831 cases per day by 2050) under the optimistic scenario and 157% (1.070 cases per day by 2050) under a pessimistic outlook.

Projected regional warming in Manitoba is 2.0 to 2.1°C for the T_{max} indicator under the optimistic scenario. Warming of 2.7 to 3.0°C is anticipated under the pessimistic outlook. The projected $WBGT_{max}$ increases are 1.6 to 1.7°C (RCP4.5 scenario) and 2.2 to 2.3°C (RCP8.5 scenario). We anticipate that the modelled T_{max} warming will be accompanied by an 89% increase in the number of daily cases of heat illness between the reference period and the future period under the optimistic scenario (0.053 to 0.100 cases per day) and an increase of 136% under the pessimistic scenario (0.125 cases per day in 2050). The modelled warming for $WBGT_{max}$ would yield an 81% increase in the number of cases of heat illness under the RCP4.5 scenario (0.096 cases per day by 2050) and 121% under scenario RCP8.5 (0.117 cases of heat illness per day by 2050).

In Saskatchewan, regional T_{max} temperatures will climb by 2.2 to 2.3°C under the optimistic scenario and by 2.8 to 3.1°C under the pessimistic outlook. $WBGT_{max}$ temperatures will increase by 1.7 to 1.8°C and 2.2 to 2.4°C, respectively, under the same scenarios. These increases in summer T_{max} temperatures will be accompanied by a 73% increase in the daily number of cases of heat illness (0.101 to 0.175 cases per day) under the optimistic scenario. The pessimistic outlook would involve a 110% increase in the number of cases of heat illness per day (0.212 cases per day by 2050). For the $WBGT_{max}$, there would be a jump of 83% (0.185 cases per day by 2050) under the optimistic scenario and 121% (0.223 cases per day) under the pessimistic outlook.

In Alberta, the climate scenarios show regional T_{max} increases of 2.0 to 2.4°C under the optimistic scenario and 2.4 to 3.3°C under the pessimistic scenario. The anticipated $WBGT_{max}$ increases are 1.6 to 1.9°C and 2.0 to 2.5°C under the optimistic and pessimistic outlooks, respectively. These summer T_{max} temperature increases would be accompanied by a 95% increase in the daily number of cases of heat illness (0.151 to 0.295 cases per day) under the optimistic scenario and a 137% increase between the reference period and the future period under the pessimistic scenario (0.358 cases per day by 2050). For $WBGT_{max}$ increases, the number of cases of heat illness per summer day is expected to rise by 113% under the optimistic scenario (0.321 cases per day) and by 165% under the pessimistic scenario (0.400 cases per day) by 2050.

Table 11 Estimated average daily number of heat illness claims by 2050 for five Canadian provinces, taking into account projected temperature increases (Delta)[13] under two forcing scenarios

	Average daily number of claims, 1997-2016	Delta T_{max} (°C) RCP4.5	Average daily number of claims 2041-2060 RCP4.5	Delta T_{max} (°C) RCP8.5	Average daily number of claims, 2041-2060 RCP8.5	Delta $WBGT_{max}$ (°C) RCP4.5	Average daily number of claims, 2041-2060 RCP4.5	Delta $WBGT_{max}$ (°C) RCP8.5	Average daily number of claims, 2041-2060 RCP8.5
Quebec total	**0.139**		**0.256**		**0.309**		**0.257**		**0.318**
Gaspésie	0.002	2.0	0.004	2.5	0.005	1.7	0.004	2.1	0.005
Bas-Saint-Laurent	0.004	1.8	0.007	2.3	0.008	1.5	0.008	2.0	0.010
Capitale-Nationale	0.008	1.9	0.013	2.5	0.016	1.6	0.013	2.1	0.016
Chaudière-Appalaches	0.007	1.9	0.014	2.5	0.017	1.6	0.014	2.1	0.018
Estrie	0.005	2.0	0.011	2.6	0.014	1.6	0.010	2.2	0.013
Centre-du-Quebec	0.007	1.9	0.012	2.5	0.014	1.6	0.013	2.2	0.016
Montérégie	0.024	1.9	0.043	2.5	0.051	1.6	0.045	2.2	0.055
Montréal	0.032	1.9	0.059	2.4	0.071	1.6	0.060	2.2	0.074
Laval	0.008	1.9	0.019	2.4	0.025	1.6	0.018	2.2	0.024
Lanaudière	0.010	1.9	0.024	2.5	0.031	1.6	0.020	2.2	0.025
Laurentides	0.006	1.9	0.011	2.5	0.013	1.6	0.011	2.2	0.013
Outaouais	0.004	1.9	0.007	2.5	0.009	1.7	0.006	2.2	0.008
Abitibi	0.003	2.0	0.004	2.5	0.004	1.6	0.004	2.1	0.005
Mauricie	0.005	1.9	0.009	2.4	0.011	1.6	0.009	2.1	0.011
Saguenay	0.011	1.9	0.014	2.4	0.015	1.5	0.016	2.0	0.017
QC Nord	0.002	1.8	0.005	2.2	0.006	1.5	0.006	1.9	0.008
Ontario total	**0.417**		**0.791**		**0.998**		**0.831**		**1.070**
Ottawa	0.047	1.9	0.085	2.5	0.104	1.7	0.091	2.2	0.113
Kingston-Pembroke	0.009	1.8	0.019	2.5	0.024	1.6	0.019	2.2	0.025
Muskoka-Kawarthas	0.012	1.9	0.025	2.5	0.033	1.7	0.026	2.3	0.035
Toronto	0.168	1.8	0.302	2.5	0.372	1.7	0.319	2.3	0.403
Kitchener-Waterloo-Barrie	0.050	1.9	0.094	2.6	0.117	1.7	0.098	2.4	0.125
Hamilton-Niagara Peninsula	0.055	1.8	0.104	2.4	0.134	1.6	0.106	2.3	0.137
London	0.021	1.8	0.043	2.5	0.056	1.7	0.049	2.3	0.066
Windsor-Sarnia	0.028	1.7	0.063	2.3	0.086	1.6	0.066	2.2	0.091
Stratford-Bruce Peninsula	0.010	1.9	0.025	2.6	0.035	1.7	0.025	2.3	0.035
Northeast	0.011	1.9	0.021	2.5	0.026	1.6	0.021	2.2	0.027
Northwest	0.005	1.9	0.009	2.5	0.011	1.6	0.010	2.1	0.013

[13] Overall, the climate change signal exceeded inter-model dispersion, i.e., natural climate variability.

Table 11 Estimated average daily number of heat illness claims by 2050 for five Canadian provinces, taking into account projected temperature increases (Delta)[14] under two forcing scenarios (cont'd)

	Average daily number of claims, 1997-2016	Delta T_{max} (°C) RCP4.5	Average daily number of claims, 2041-2060 RCP4.5	Delta T_{max} (°C) RCP8.5	Average daily number of claims, 2041-2060 RCP8.5	Delta $WBGT_{max}$ (°C) RCP4.5	Average daily number of claims, 2041-2060 RCP4.5	Delta $WBGT_{max}$ (°C) RCP8.5	Average daily number of claims, 2041-2060 RCP8.5
Manitoba total	**0.053**		**0.100**		**0.125**		**0.096**		**0.117**
Southeast	0.003	2.0	0.007	2.8	0.009	1.7	0.007	2.2	0.009
South Central/ North Central	0.002	2.0	0.006	2.8	0.008	1.6	0.005	2.2	0.006
Southwest	0.007	2.1	0.015	3.0	0.021	1.7	0.014	2.3	0.019
Winnipeg	0.036	2.1	0.064	2.8	0.079	1.7	0.061	2.2	0.073
Interlake	0.003	2.1	0.005	2.8	0.006	1.7	0.005	2.3	0.007
Parklands and North	0.002	2.1	0.003	2.7	0.004	1.7	0.004	2.2	0.004
Saskatchewan total	**0.101**		**0.175**		**0.212**		**0.185**		**0.223**
Regina-Moose Mountain	0.049	2.2	0.084	3.1	0.105	1.7	0.088	2.3	0.108
Swift Current-Moose Jaw	0.007	2.3	0.013	3.1	0.016	1.8	0.014	2.4	0.017
Saskatoon-Biggar	0.032	2.2	0.053	2.9	0.061	1.8	0.056	2.2	0.065
Yorkton-Melville	0.004	2.3	0.007	2.9	0.009	1.8	0.008	2.3	0.010
Prince Albert and Northern	0.009	2.2	0.018	2.8	0.022	1.7	0.019	2.2	0.023
Alberta total	**0.151**		**0.295**		**0.358**		**0.321**		**0.400**
Lethbridge-Medicine Hat	0.008	2.4	0.014	3.3	0.018	1.9	0.016	2.5	0.019
Camrose-Drumheller	0.004	2.3	0.008	2.8	0.010	1.8	0.009	2.2	0.010
Calgary	0.048	2.2	0.094	3.1	0.122	1.7	0.105	2.4	0.140
Banff-Jasper-Athabasca	0.011	2.2	0.022	2.6	0.025	1.7	0.025	2.1	0.030
Red Deer	0.009	2.2	0.020	2.8	0.025	1.7	0.023	2.2	0.030
Edmonton	0.066	2.2	0.129	2.7	0.150	1.7	0.137	2.1	0.164
Wood Buffalo-Cold Lake	0.004	2.0	0.007	2.4	0.008	1.6	0.007	2.0	0.007

14 Overall, the climate change signal exceeded inter-model dispersion, i.e., natural climate variability.

4 Discussion

4.1 Main findings

This study sheds new light on the relationship between summer temperatures and occupational morbidity in Canada. Based on workers' compensation data and meteorological data for five provinces in Central and Western Canada over a 16-year period, the study demonstrated thateach 1°C increase in daily maximum summer temperature (T_{max}) was associated withan increase of 28% to 41%, varying by province, in the daily number of heat illness claims accepted by workers' compensation boards in those provinces. With the $WBGT_{max}$ indicator, the increase was in the range of 41% to 51%. Applied to the province of Quebec, a 34% increase (T_{max} model) represents seven additional heat illness claims accepted by the CNESST over the five summer months of each year of the 2001-2016 period. No sex- or age-based disparities were observed in these associations. In Quebec and Alberta, no disparities were found between indoor and outdoor industries. In addition, each 1°C increase in T_{max} was associated with a 0.2% to 0.4% increase, depending on the province, in the daily number of accepted claims for work-related traumatic injuries, whereas with $WBGT_{max}$ an increase between 0.2% to 0.6% was observed. This increase, though it may appear small, is important because of the large number of workers concerned. Applied to the province of Quebec, a 0.2% increase represents approximately 64 additional accepted claims over the five summer months of each year of the 2001-2016 period. The effect of the increase in temperature on the risk of traumatic injuries was more pronounced for males, younger workers (ages 15–24), and, in the case of Quebec and Alberta (where information on industries was analyzed), workers employed in industries that operate mainly outdoors.

In light of the projected global warming by 2050, this study predicts a troubling increase in the number of claims that could be accepted by workers' compensation boards for heat illness due to exposure to high temperatures. Under the optimistic scenario (RCP4.5), the projected increase in the summer T_{max} temperature between the reference period and the future period would be associated with an increase of 73% to 95%, depending on the province, in heat illness claims. For $WBGT_{max}$, the corresponding increase would range from 81% to 113%. Under the pessimistic scenario (RCP8.5), depending on the province, by 2050 the daily number of heat illness claims would increase by 110% to 139% for T_{max} and by 121% to 165% for $WBGT_{max}$. Applied to the province of Quebec, the number of accepted heat illness claims per year during the summer period would increase from 21 in the reference period to 39 by 2050 under an optimistic scenario and to 47 under a pessimistic scenario (models based on T_{max}).

4.2 Comparisons with the literature

Few studies have quantified the relationship between outdoor summer temperatures and worker morbidity. The increases in occupational morbidity in Quebec estimated for the 2001–2016 period in this study are similar to those estimated in the authors' two earlier studies covering shorter periods (Adam-Poupart et al., 2014; 2015a, b). Using a similar methodology, the authors estimated a 42% increase in the number of accepted claims for heat illness for each 1°C increase in the maximum summer temperature during the 1998–2010 period (Adam-Poupart et al., 2014). They estimated a 0.2% increase in the number of work-related traumatic injury claims for every additional 1°C during the 2003–2010 summer period (Adam-Poupart et al., 2015a). No sex- or age-based disparities were observed in the relationship between temperature and heat illness (this finding could be explained by the small number of cases in the 15–24 age group) (Adam-Poupart et al., 2014). This was not the case for traumatic injuries: men had higher risk ratios (IRR) than women, and younger workers (15–

24) had higher risk ratios than older workers (Adam-Poupart et al., 2015a). The present study replicated these results for Quebec over a longer period and highlighted similar findings for the other four provinces evaluated.

In the metropolitan area of Adelaide, South Australia, Xiang et al. (2015) estimated that in 2001–2010, the daily number of heat illness claims accepted by the workers' compensation board (WorkCover SA) rose by 12.7% (95% CI: 6.7%–19%) for each 1°C increase in T_{max} above the threshold temperature of 35.5°C. The incidence rate ratios were not broken down by sex or age. Certain industries had higher incidence rates, including mining (18.9 cases per 100,000 employees), electricity, gas and water (9.2 cases per 100,000 employees), public administration (8.8 cases per 100,000 employees), and construction (6.8 cases per 100,000 employees).

In Ontario, Fortune et al. (2013) found that for the January 2004 to December 2010 period, men and young workers (15–24) had the highest incidence rate of occupational heat illness events giving rise to WSIB compensation claims and the highest rate of associated emergency department visits. For example, from the claim records the authors calculated a rate of 1.9 cases per million male full-time equivalent (FTE) worker months (95% CI: 1.7–2.1) and 1.4 cases per million female FTE worker months (95% CI: 1.2–1.6). Corresponding rates for emergency department visits were 2.2 for men (95% CI: 2.0–2.4) and 0.8 for women (95% CI: 0.7–0.9). The authors also found that compared to all lost time claims, claims for heat illness events were more frequent in the public administration, agriculture and construction sectors by a factor of 1.4 to 2.3 (proportional morbidity ratio).

The results of this study did not allow for a definitive conclusion to be reached regarding disparities in the risk of heat illness between different subgroups. Comparisons were hindered in part by the small number of cases (e.g. 47 cases in the 15–24 age group in Quebec, Table 1). In Quebec, women appeared to have higher risk ratios than men, but these estimates featured overlapping CIs, whether they were based on T_{max} or $WBGT_{max}$. For Manitoba, the small number of cases in sex and age strata made it impossible to carry out stratified analyses. A systematic review focusing on members of the armed forces indicated that men had a slightly higher incidence of sunstroke (0.22 to 0.48 cases per 1,000 person-years) than women (0.10 to 0.26 cases per 1,000 person-years). For other heat-related health problems, the opposite seemed to be true, but the variability associated with the point estimates precludes a definitive conclusion (men: 0.98 to 1.98 cases per 1,000 person-years; women: 1.30 to 2.89 cases) (Alele et al., 2020). Any disparities could be attributed to the difference in exposure between men and women, given that women in the U.S. were excluded from combat positions until 2013, as noted by the authors (most of the studies examined focused on the United States Armed Forces). Laboratory studies on physiological responses to heat stress have shown that when factors such as muscle mass, body surface area, cardiovascular function and acclimatization are taken into account, sex- and age-based differences tend to disappear (Kenney and Munce, 2003; Notley et al., 2017). Sex and age could therefore act as proxies for other factors influencing the physiological response to heat stress or its components (e.g. certain vasomotor and sudomotor skin responses that may manifest differently depending on experimental conditions) (Gagnon and Kenney, 2012; Meade et al., 2020). To better understand the risk of heat illness in relation to sex, age and other occupational subgroups, more studies are needed that incorporate detailed analyses of heat exposure for different working conditions and specific tasks and that account for personal characteristics (chronic illness, medication use, history of heatstroke, body mass index, etc.).

Regarding traumatic injuries, the reported effect sizes and subgroup differences reported in this study are in line with results found in the literature. Xiang et al. (2014a) estimated a 0.2% increase in the daily number of injury claims accepted by WorkCover SA for every 1°C increase in T_{max} between 14.2°C and 37.7°C during the warm season in 2001–2010. The authors concluded that there was a stronger association between temperature and number of compensated claims for men, younger workers (under age 25) and workers in industries that operate mainly outdoors, which is consistent with the findings of the present study. In that study, industries were also categorized as “outdoor” or “indoor” in a similar manner to this study (outdoor industries included agriculture, forestry, fishing and construction, as well as electricity, gas and water; mining industry claims were excluded from analysis).

Results consistent with the above were found in a meta-analysis by Binazzi et al. (2019) of six time series and case-crossover studies published between 2000 and 2018, focusing on workers in Canada (Quebec), the United States, Australia, Spain, Italy and China. The pooled estimate of the increase in relative risk of sustaining an occupational injury was 1.005 (95% CI: 1.001 to 1.009) for every 1°C increase in the daily maximum temperature during the warm months (the indicators used to measure heat exposure varied among the studies and included T_{max}, $WBGT_{max}$ and $humidex_{max}$). In subgroup analyses, the authors reported a higher relative risk for men, individuals younger than 25 and agricultural workers, but these results were not statistically significant.

In a later study which examined warm period traumatic injury claims among construction workers in Washington State from 2000 to 2012, Calkins et al. (2019) reported a0.5% (95% CI: 0.3%–0.7%) increase in the likelihood of traumatic injury, in terms of odds ratio (OR), for every 1°C increase in $humidex_{max}$. For agricultural workers, the narrative review by Spector et al. (2019) found an increase in the likelihood of injury (OR) of around 14% (two studies), with possible values ranging from 1% to 27% for T_{max} > 95th percentile (vs. T_{max} < 75th percentile) or for various categories of $humidex_{max}$ above 25°C (vs. $humidex_{max}$ < 25°C).

Disparities in the risk of traumatic injury among industries could be the result of differences in exposure to health hazards and in the preventive measures and health and safety culture that characterize different workplaces (Spector et al., 2019). Sex- and age-based disparities have already been documented: the traumatic injury incidence rate of workers aged 15-24 years was found to be twice that of workers aged 25 and older (respectively 5.0 injuries treated in the emergency department per 100 FTEs compared to 2.4) (CDC, 2010). For both age groups, men had higher injury incidence rates than women (CDC, 2010). This could be explained by the fact that men dominate the labour force in industries with a higher risk of injury, for example forestry, construction and mining. In Quebec, men make up 67% to 70% of sector groups 1, 2 and 3 (these refer to primary sectors except agriculture and certain manufacturing sectors; this grouping is specific to Quebec). In these sector groups, the proportion of men having suffered fractures, cuts or other work-related traumatic injuries was higher than in sectors 4, 5 and 6 (service sectors, including trade, health, education), according to an analysis of population survey data from the 2014–2015 Enquête québécoise sur la santé de la population (EQSP) (Stock, Nicolakakis et al., 2020). Regarding age-based disparities, our results could indicate that younger people are overrepresented in certain industries with a higher risk of injury. Findings could also reflect industry gaps in health and safety training of theyounger, less experienced workforce, or suggest that younger workers perceive there to be less risk and adhere to health and safety rules in a suboptimal manner (Spector et al., 2019).

No other study to date has sought to predict the number of occupational injuries for a future period (2041–2060) taking into account projected global warming. Martin et al. (2012) modelled future heat- and cold-related mortality in 15 Canadian cities, but this analysis focused on the general population and did not consider work activities. Some studies have predicted future productivity losses (reviewed in Kjellstrom et al., 2016). For example, Dunne et al. (2013) modelled the future reduction in individuals’ capacity to work during periods of heat stress in various regions of the world (using the

WBGT). A worldwide reduction of about 10% in work capacity is predicted by 2050 under optimistic (RCP4.5) and pessimistic (RCP8.5) scenarios.

4.3 Methodological considerations

The results of this study should be interpreted with the following methodological considerations kept in mind. First, the use of workers' compensation data can lead to an underestimation of the incidence and magnitude of occupational injuries, in light of workers' tendency to under-report these injuries to compensation boards, a phenomenon that has been documented in various jurisdictions (Stock et al., 2014; Groenewold and Baron, 2013; Cloutier et al., 2011; Dong et al., 2011; Luckhaupt and Calvert, 2010; Safe Work Australia, 2009; Alamgir et al., 2006). According to the 2007–2008 Enquête québécoise sur des conditions de travail, d'emploi, de santé et de sécurité du travail (EQCOTESST), 67% of Quebec salaried employees submitted claims for work-related traumatic injuries (Cloutier et al., 2011). In Australia, it was estimated that no claim was submitted for 62% of all occupational injuries and illnesses (Safe Work Australia, 2009).

Heat illness in particular may be misdiagnosed, or workers may fail to associate it with their work. This lack of recognition could contribute to under-reporting and, therefore underestimation, of injuries. Other reasons for under-reporting include the belief that injuries are not severe enough or are not covered by the occupational health and safety regime, complicated claims processes and concern about affecting current and future employment status (Stock et al., 2014; Safe Work Australia, 2009; Azaroff et al., 2002). Some employers may contest claims in order to limit their contributions to the health and safety regime, possibly dissuading employees aware of this practice from reporting injuries (Confédération des syndicats nationaux [CSN], 2020; Lippel, 2012; 2009). This may more often be the case among non-unionized workers, who may not be aware of their right to compensation (Morse et al., 2003). Therefore, raising employee awareness about their rights and about compensation procedures and raising awareness among attending physicians regarding the above issues (the physician's report establishes the work-related origin of the injury and often triggers the compensation process in Quebec and the rest of Canada) could prevent unnecessary suffering and the transfer of compensable injuries to the health care system and workers themselves (Stock et al., 2014). In addition, improved surveillance of heat-related occupational injuries, by their inclusion in population health surveys mandated by government authorities, would allow us to better appreciate the magnitude of these health problems among the working population and better define the scope of prevention needs.

The choice of analyzing only injuries recognized as work accidents may have contributed to a slight underestimation of the incidence of heat illness events, some of which may have been recognized as occupational illnesses by the compensation boards. There is reason to believe that in Quebec, this would concern only a very small proportion of cases of heat illness. In fact, almost all other types of injuries, such as non-traumatic work-related musculoskeletal disorders, are classified as work accidents in Quebec. This could also be the case for heat illness events, which manifest very quickly during heat stress. For the provinces of Saskatchewan, which does not make this distinction for the purposes of compensation, and Ontario, which recognizes the majority of injuries as occupational illnesses, exposure misclassification may have occurred if the injury date entered in the file was the date of diagnosis rather than the date of occurrence. If, for example, the date of diagnosis was colder than the date of occurrence of the heat illness, the association between temperature and health may have been somewhat underestimated for these provinces. However, it appears unlikely that this was a systematic issue.

It is also possible that certain individuals suffered an occupational injury off-site, something that is particularly likely for employees who perform their work far from their employer's premises (e.g. transportation industry). Occupational injury files provide the postal codes of the establishment employees were working for at the time of injury, with the exception of Saskatchewan's files, some of which contained the postal code of the occurrence site. We expect that possible exposure classification errors, involving certain industries, had a minimal impact on the results because the main analyses focused on all industries and, in Alberta and Quebec, the analyses stratified by industry were based on broad groupings of "outdoor" and "indoor" industries.

Heat exposure was estimated on a regional scale; the prevailing conditions when an injury occurred or a health problem manifested were not known. For example, we simply had no information on the presence of air conditioning in the workplace, the location of the individual (outside or inside the establishment), the use of personal protective equipment or the level of exertion when the injury occurred or the health problem manifested. In addition, information on personal characteristics that could have influenced the manifestation of heat illness (chronic illnesses, medication use, history of heatstroke, body mass index, alcohol consumption, etc.) was not available in administrative databases and was therefore not considered in the analyses.

In general, the study findings were similar regardless of the heat exposure indicator used, whether we used T_{max}, adjusting models for relative humidity, or $WBGT_{max}$, which accounts for humidity and serves as an indicator of heat stress. For certain provinces (Ontario, Saskatchewan, Alberta), the association between temperature and heat illness was more pronounced with $WBGT_{max}$, but this was not observed for these provinces' economic regions. The same applied to the temperature–traumatic injury association in Saskatchewan. Studies comparing the different temperature–health relationships obtained using various heat exposure indicators would allow for a better understanding of the behaviour of these indicators and their impact on the results obtained.

Finally, the heat illness projections assume that the populations under study will not change between the reference and future periods, which is obviously a simplification of reality. In addition, as was the case for the 2001–2016 analyses, a number of conjectural, contextual and personal factors that could influence the occurrence of these health problems between the present period and 2050 were not considered in the projections. Legislative changes such as the modernization of the occupational health and safety regime that is underway in Quebec (Ministère du Travail, de l'Emploi et de la Solidarité sociale, 2020), changes in workers' compensation boards' practices for recognizing occupational injuries, and the changing labour market could all have a significant impact on the projections.

5 Conclusion

This study on the relationship between summer temperatures and worker health in five Canadian provinces has led to new knowledge that can guide decision makers and stakeholders in the prevention of occupational morbidity. The results show that every 1°C increase in the daily maximum summer temperature was associated with an increase of 28% to 51% (depending on the province and the heat exposure indicator used) in the daily number of heat illness claims and a 0.2% to 0.6% increase (depending on the province and the heat exposure indicator) in the daily number of traumatic injury claims accepted by workers' compensation boards. It also demonstrated that the risk of traumatic injury for each 1°C daily increase was higher for men and younger workers (15–24 years of age). In Quebec and Alberta, provinces for which industry-specific information was analyzed, the risk of traumatic injury was also found to be higher for workers in industries that operate mainly outdoors. It should be noted that interprovincial comparisons were not possible owing to legislative and administrative differences between the provinces' respective occupational health and safety regimes. Nonetheless, the main findings of the study are similar across all provinces studied.

These results underscore the vulnerability of Canadian workers to heat and the need to implement and build on preventive efforts. For example, adequate occupational health and safety training must be provided to workers, including younger workers. In addition, workplaces should receive support and guidance to develop and execute action plans to assess and limit employee heat stress on hot days, including appropriate enforcement of work-rest schedules and adequate hydration (CNESST 2020; Institut de recherche Robert-Sauvé en santé et en sécurité du travail, 2019). Studies conducted in real work settings are also needed to identify effective interventions against heat strain in the workplace, given that current knowledge stems primarily from laboratory studies on athletic performance and from studies focusing on a limited number of occupations (e.g. firefighting) (Morris et al., 2020).

In addition, this study is the first to provide projections among workers of the daily number of heat illness claims expected by the 2050 horizon, taking into account projected global warming. Unsettling increases of 73% to 113% are estimated (depending on province and heat exposure indicator) under an optimistic scenario (RCP4.5) and of 110% to 165% under a pessimistic scenario (RCP8.5). According to the Intergovernmental Panel on Climate Change, if global warming continues at the current rate, global temperatures will rise 1.5°C (above pre-industrial [1850–1900] levels) by 2040 (Allen et al., 2018). This would negatively affect ecosystems, natural resources and human health. Beyond effects on heat-related mortality and morbidity (Hoegh-Guldberg et al., 2018), various repercussions on worker health and safety could be expected (Adam-Poupart et al., 2013). For example, we could expect an increase in the risk of certain zoonotic diseases and other illnesses whose vectors may spread to higher latitudes (Adam-Poupart et al., 2021; Hoegh-Guldberg et al., 2018), or impacts on the mental health of agricultural producers and other workers who have to cope with heat stress and drought (Austin et al., 2018), and possible psychological impacts on first responders and other intervention specialists involved in the management of increasingly frequent disasters (e.g. forest fires, floods) (Adam-Poupart et al., 2020; Biggs et al., 2014; West et al., 2008).

Our projections are very important in terms of prevention, as they would enable more targeted awareness raising and engagement efforts aimed at legislators, the research community and key actors. Clearly, climate change is a major public health issue that calls for concerted action in order to reduce, if not eliminate, many potential risks. Since the heat illness projections in this study are based on current preventive programs and strategies and since these health problems are often preventable, much is to be gained from taking action.

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Appendix 1

Average and Range of Maximum Daily Temperatures (T_{max} and $WBGT_{max}$) by Province, 2001–2016

Table 12 Average and range of maximum daily temperatures (T_{max} and $WBGT_{max}$), Quebec, 2001–2016

Economic region	T_{max} Average[a] (range)			$WBGT_{max}$ Average[a] (range)		
Gaspésie	18.1	(3.4;	29.5)	19.1	(7.9;	29.5)
Bas-Saint-Laurent	18.9	(5.2;	31.4)	19.2	(9.5;	28.8)
Capitale-Nationale	22.0	(5.2;	34.9)	21.7	(9.4;	33.8)
Chaudière-Appalaches	22.3	(4.8;	34.7)	21.8	(9.1;	34.1)
Estrie	22.7	(5.0;	33.2)	22.2	(9.3;	33.9)
Centre-du-Québec	22.8	(5.4;	33.8)	22.5	(9.5;	34.7)
Montérégie	23.7	(5.4;	35.1)	23.4	(9.8;	35.5)
Montréal	23.6	(5.7;	35.2)	23.4	(9.9;	35.8)
Laval	23.6	(5.9;	35.0)	23.5	(10.1;	35.8)
Lanaudière	23.7	(6.3;	35.0)	23.2	(10.3;	35.5)
Laurentides	23.5	(5.6;	34.9)	23.0	(9.9;	34.7)
Outaouais	23.8	(5.0;	36.1)	23.0	(9.4;	34.7)
Abitibi	20.9	(0.5;	36.0)	20.2	(6.2;	32.2)
Mauricie	22.6	(5.4;	34.4)	22.3	(9.5;	34.6)
Saguenay	21.1	(4.4;	36.0)	20.7	(8.5;	34.1)
QC Nord	17.2	(3.3;	29.6)	18.0	(8.4;	27.5)

[a] Average weighted by the population size of each postal code in the economic region (three digits used).

Table 13 Average and range of maximum daily temperatures (T_{max} and $WBGT_{max}$), Ontario, 2002–2017

Economic region	T_{max} Average[a] (range)			$WBGT_{max}$ Average[a] (range)		
Ottawa	23.6	(5.2;	35.4)	23.0	(9.2;	34.7)
Kingston–Pembroke	23.4	(6.7;	33.9)	22.9	(10.3;	34.4)
Muskoka–Kawarthas	22.9	(6.6;	34.6)	22.3	(10.2;	35.6)
Toronto	23.7	(7.5;	36.6)	23.3	(10.6;	36.8)
Kitchener–Waterloo–Barrie	23.1	(6.3;	34.5)	22.4	(9.8;	35.7)
Hamilton–Niagara Peninsula	23.8	(7.9;	35.6)	23.5	(11.1;	36.0)
London	23.9	(6.2;	36.0)	23.3	(10.4;	36.1)
Windsor–Sarnia	24.7	(7.8;	36.0)	24.5	(11.2;	36.9)
Stratford–Bruce Peninsula	22.7	(4.9;	33.8)	22.4	(9.3;	35.3)
Northeast	21.5	(3.4;	34.3)	20.9	(8.0;	31.5)
Northwest	20.4	(1.0;	33.6)	20.0	(6.3;	29.7)

[a] Average weighted by the population size of each postal code in the economic region (three digits used).

Table 14 Average and range of maximum daily temperatures (T_{max} and $WBGT_{max}$), Manitoba, 2001–2016

Economic region	T_{max} Average[a] (range)			$WBGT_{max}$ Average[a] (range)		
Southeast	22.8	(1.7;	35.4)	21.8	(6.4;	34.6)
South Central / North Central	22.5	(1.0;	35.3)	21.6	(6.4;	33.2)
Southwest	22.6	(1.1;	39.0)	21.1	(6.2;	34.1)
Winnipeg	22.6	(0.5;	36.1)	21.7	(5.7;	35.0)
Interlake	22.4	(0.0;	36.4)	21.7	(5.7;	34.6)
Parklands and Northern	20.6	(0.2;	34.8)	19.7	(4.6;	31.8)

[a] Average weighted by the population size of each postal code in the economic region (three digits used).

Table 15 Average and range of maximum daily temperatures (T_{max} and $WBGT_{max}$), Saskatchewan, 2001–2016

Economic region	T_{max} Average[a] (range)			$WBGT_{max}$ Average[a] (range)		
Regina-Moose Mountain	22.8	(3.0;	37.5)	20.6	(7.1;	33.8)
Swift Current-Moose Jaw	22.5	(3.3;	38.4)	20.8	(7.9;	32.3)
Saskatoon–Biggar	22.6	(3.9;	38.9)	20.2	(7.1;	31.9)
Yorkton–Melville	22.6	(0.6;	35.7)	20.4	(5.2;	32.9)
Prince Albert and Northern	22.4	(3.7;	36.9)	19.8	(7.0;	30.3)

[a] Average weighted by the population size of each postal code in the economic region (three digits used).

Table 16 Average and range of maximum daily temperatures (T_{max} and $WBGT_{max}$), Alberta, 2001–2016

Economic region	T_{max} Average[a] (range))			$WBGT_{max}$ Average[a] (range)		
Lethbridge--Medicine Hat	23.3	(0.9;	38.4)	20.7	(6.6;	31.6)
Camrose–Drumheller	21.3	(2.1;	36.8)	19.5	(6.4;	30.1)
Calgary	20.9	(-1.7;	35.0)	19.3	(4.4;	29.8)
Banff–Jasper–Athabasca	20.5	(0.2;	35.1)	18.9	(5.3;	29.0)
Red Deer	20.5	(0.4;	34.4)	19.1	(5.6;	29.4)
Edmonton	21.1	(1.5;	35.0)	19.5	(6.8;	30.3)
Wood Buffalo–Cold Lake	21.2	(-0.2;	37.3)	19.5	(4.4;	29.8)

[a] Average weighted by the population size of each postal code in the economic region (three digits used).

No de publication : 2791 – English version

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