Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

STRIVE
Report Series No.102

Extreme Temperatures and Mortality in Ireland

STRIVE

Environmental Protection Agency Programme

2007-2013

SSTI Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

Environmental Protection Agency

The Environmental Protection Agency (EPA) is a statutory body responsible for protecting the environment in Ireland. We regulate and police activities that might otherwise cause pollution. We ensure there is solid information on environmental trends so that necessary actions are taken. Our priorities are protecting the Irish environment and ensuring that development is sustainable.

The EPA is an independent public body established in July 1993 under the Environmental Protection Agency Act, 1992. Its sponsor in Government is the Department of the Environment, Community and Local Government.

OUR RESPONSIBILITIES

LICENSING

We license the following to ensure that their emissions do not endanger human health or harm the environment:

- waste facilities (e.g., landfills, incinerators, waste transfer stations);
- large scale industrial activities (e.g., pharmaceutical manufacturing, cement manufacturing, power plants);
- intensive agriculture;
- the contained use and controlled release of Genetically Modified Organisms (GMOs);
- large petrol storage facilities;
- waste water discharges.

NATIONAL ENVIRONMENTAL ENFORCEMENT

- Conducting over 2,000 audits and inspections of EPA licensed facilities every year.
- Overseeing local authorities' environmental protection responsibilities in the areas of - air, noise, waste, waste-water and water quality.
- Working with local authorities and the Gardaí to stamp out illegal waste activity by co-ordinating a national enforcement network, targeting offenders, conducting investigations and overseeing remediation.
- Prosecuting those who flout environmental law and damage the environment as a result of their actions.

MONITORING, ANALYSING AND REPORTING ON THE ENVIRONMENT

- Monitoring air quality and the quality of rivers, lakes, tidal waters and ground waters; measuring water levels and river flows.
- Independent reporting to inform decision making by national and local government.

REGULATING IRELAND'S GREENHOUSE GAS EMISSIONS

- Quantifying Ireland's emissions of greenhouse gases in the context of our Kyoto commitments.
- Implementing the Emissions Trading Directive, involving over 100 companies who are major generators of carbon dioxide in Ireland.

ENVIRONMENTAL RESEARCH AND DEVELOPMENT

- Co-ordinating research on environmental issues (including air and water quality, climate change, biodiversity, environmental technologies).

STRATEGIC ENVIRONMENTAL ASSESSMENT

- Assessing the impact of plans and programmes on the Irish environment (such as waste management and development plans).

ENVIRONMENTAL PLANNING, EDUCATION AND GUIDANCE

- Providing guidance to the public and to industry on various environmental topics (including licence applications, waste prevention and environmental regulations).
- Generating greater environmental awareness (through environmental television programmes and primary and secondary schools' resource packs).

PROACTIVE WASTE MANAGEMENT

- Promoting waste prevention and minimisation projects through the co-ordination of the National Waste Prevention Programme, including input into the implementation of Producer Responsibility Initiatives.
- Enforcing Regulations such as Waste Electrical and Electronic Equipment (WEEE) and Restriction of Hazardous Substances (RoHS) and substances that deplete the ozone layer.
- Developing a National Hazardous Waste Management Plan to prevent and manage hazardous waste.

MANAGEMENT AND STRUCTURE OF THE EPA

The organisation is managed by a full time Board, consisting of a Director General and four Directors.

The work of the EPA is carried out across four offices:

- Office of Climate, Licensing and Resource Use
- Office of Environmental Enforcement
- Office of Environmental Assessment
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet several times a year to discuss issues of concern and offer advice to the Board.

EPA STRIVE Programme 2007–2013

Extreme Temperatures and Mortality in Ireland

(2005-DS-27)

STRIVE Report

Prepared for the Environmental Protection Agency

by

Dublin Institute of Technology

Authors:

Mathilde Pascal, Pat Goodman, Luke Clancy and Joel Schwartz

ENVIRONMENTAL PROTECTION AGENCY

An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Co. Wexford, Ireland

Telephone: +353 53 916 0600 Fax: +353 53 916 0699
Email: info@epa.ie Website: www.epa.ie

ACKNOWLEDGEMENTS

This report is published as part of the Science, Technology, Research and Innovation for the Environment (STRIVE) Programme 2007–2013. The programme is financed by the Irish Government under the National Development Plan 2007–2013. It is administered on behalf of the Department of the Environment, Community and Local Government by the Environmental Protection Agency which has the statutory function of co-ordinating and promoting environmental research.

The authors would like to thank the following for their help in this project: the Irish Environmental Protection Agency (EPA) for its grant support for the work, the Central Statistics Office for providing the mortality data, and Met Éireann for providing the climate data. In addition, they would like to thank Dr Zeka for her advice and assistance with the case cross-over analysis. The authors would also like to point out that the report is their own work and has not been influenced in any way by the Irish EPA. The views expressed in this report are those of the authors.

DISCLAIMER

The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

EPA STRIVE PROGRAMME 2007–2013

Published by the Environmental Protection Agency, Ireland

ISBN: 978-1-84095-489-0

Price: Free **Online version**

Details of Project Partners

Pat Goodman
School of Physics
Dublin Institute of Technology
Kevin St
Dublin 8
Ireland
Tel.: +353 1 4024782
Email: pat.goodman@dit.ie

Mathilde Pascal
Dublin Institute of Technology
Kevin St
Dublin 8
Ireland

Current email:
Email: m.pascal@invs.sante.fr

Luke Clancy
Research Institute for a Tobacco Free Society
Dublin
Ireland
Email: lclancy@tri.ie

Joel Schwartz
Harvard School of Public Health
665 Huntington Avenue
Landmark Center Room 415
Boston
MA 02115
USA
Email: jschwrtz@hsph.harvard.edu

Table of Contents

Executive Summary

1 Background

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) concluded that warming of the climate system is unequivocal, and that temperatures will continue to rise in the next decades. The estimates of the temperature increases vary between +1.8°C and +6.4°C by 2100, compared with the 1961–2000 average (Solomon et al., 2007[1]). Between 1961 and 2005, the climatic trends identified in Ireland were largely consistent with global trends, and projected temperature increases ranging between +1°C and +3°C by 2100, compared with the 1961–2000 average (EPA, 2009[2]).

Climate change may have several health impacts, one of them related to the increase in temperature and the increase in the frequency and severity of extreme events such as extremes of cold, drought, floods, and heatwaves. Heatwaves have been associated with significant mortality and morbidity impacts in many countries, and heat-related risks have been known for a long time. In Europe, adaptation to heat and heatwaves is now considered a priority. Although extreme temperatures have not been identified as a major cause of mortality in Ireland, climate change calls for an evaluation of the past, present and future health risks associated with heat and heatwaves. The purpose of this work is to quantify the temperature–mortality relationship during summer, in order to identify relevant adaptation strategies and to investigate if past heatwaves have been characterised by an observable excess mortality in Ireland.

1. Solomon, S.D., Quin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L., 2007. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. pp. 1–996. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
2. EPA, 2009. *A Summary of the State of Knowledge on Climate Change Impacts for Ireland.* Environmental Protection Agency, Johnstown Castle Estate, Wexford, Ireland.

2 Data

The work focused on mortality, as data were available over a long period of time. The main causes of deaths associated with heat exposure as identified in the literature were considered, i.e. total, cardiovascular and respiratory mortality. Individual mortality data were obtained from the Central Statistics Office for the period 1981–2003. Meteorological data (temperature, humidity, pressure and wind speed) from 11 meteorological stations covering the whole country were obtained from Met Éireann. The lack of postal codes in the mortality records limited the ability to perform analyses of the mortality data with a good geographical resolution. Often county level was the best available spatial resolution, and the location of death was detailed for the main population centres only. Considering that temperatures are rather homogeneous across the country, and that the literature reports major differences in heat exposure between rural and urban areas, data were aggregated to create an urban and a rural indicator. Urban areas that were easily identifiable (Dublin, Cork, Drogheda, Arklow, Dundalk, Galway, Limerick and Waterford) were used to represent the urban population, while the remaining areas were classified as rural. Temperature indicators were aggregated at a similar spatial resolution, to obtain a proxy of urban and rural heat exposure.

3 The Summer Temperature–Mortality Relationship in Ireland

A first objective to this study, the investigation of the temperature–mortality relationship, was investigated using time-series models with the same data sets. In both rural and urban areas, and for all causes of deaths, the mortality was found to increase with the mean temperature at lag 0. The relationship was roughly linear above 15°C. A 1°C increase above 15°C in the mean temperature was associated with a 1.5% (CI 95%[3] 0.9:2.1) increase in total mortality in rural areas, and a 1.6% (0.6:2.5) increase in total mortality

3. CI 95%, 95% Confidence Interval.

in urban areas. The impact was slightly lower for the total mortality over 74 years old (1.4% (0.6:2.2) and 1.5% (0.3:2.7), respectively). In rural areas, a significant impact was observed on cardiovascular mortality (1.1% (0.3:1.9)) but not on respiratory mortality (+0.0% (–1.1:1.0)). The opposite was observed in urban areas, with no impact on cardiovascular mortality (+0.2% (–0.8:1.3)) but a large impact on respiratory mortality (+2.8% (0.5:5.1)). This may indicate that respiratory mortality is driven by a confounding factor, which may be air pollution.

It was also found that the risks were significantly larger during summers preceded by low-mortality winters, than during summers preceded by high-mortality winters. For instance, for the total mortality in rural areas, the risks changed from 2.2% (1.3:3.1) to 0.9% (0.1:1.7) depending on the mortality observed during the preceding winters.

The same models were run on 4-year periods (1981–1984, 1985–1988, 1989–1992, 1993–1996, 1997–2000 and 2001–2003) to investigate possible changes in the temperature–mortality relationship over time. These periods were relatively homogenous in terms of temperatures and mortality. In rural areas, the risks associated with a 1°C increase above 15°C were around 2% for the periods 1981–1984, 1985–1988 and 1989–1992. They started to decrease between 1993 and 1996, and became negative after 1997. A similar evolution was observed for the mortality above 74 years old in rural areas and for the cardiovascular mortality. As for the respiratory mortality, low and non-significant risks were observed throughout all the periods. In urban areas, a large risk was observed during the first period (+5.1% (2.9:7.4)), while the response was lower and non-significant in the other periods. This may be partly due to changes in the population characteristics (e.g. ages), improvements in the health care system, but also an improvement in air quality.

4 The Mortality Impacts of Heatwaves in Ireland

Between 1981 and 2006, a limited number of periods were characterised by heatwaves observed in a majority of the meteorological stations: July 1983, August 1984, June 1995, August 1995, August 2003 and July 2006. A small excess mortality was observed during the 2006 heatwave (+2%), while 2003 was not associated with an excess mortality in rural areas. Earlier episodes had greater impacts, especially in July 1983, which was characterised by a classical heatwave pattern, i.e. a rapid increase in temperatures, followed by a rapid decrease. Overall, a total of 294 excess deaths attributable to heatwaves was estimated, 241 in rural areas, and 53 in urban areas. The 1983 and, to a lesser extent, the 1984 heatwaves were characterised by a significant excess mortality, especially in rural areas (+115 (CI 95% 96:137) extra deaths between 5 and 23 July 1983, +49 (29:68) deaths between 18 and 31 August 1984). The July 1983 episode was the only one presenting a characteristic heatwave mortality response, although with moderate intensity. A maximum relative risk of mortality due to the heatwave effect was observed on 14 July 1983 (1.23 (CI 95% 1.13:1.34)).

5 Opportunities for Adaptation

Although the results should be interpreted with care, due to the limits introduced by the rough geographical aggregations that were used, this work found that an increase in temperature was associated with an increase in mortality during summer in Ireland, and that past heatwaves were associated with a small but observable excess mortality. There are indications that the heat-related risks have been decreasing between the 1980s and the 1990s. However, with the perspective of climate change, and with the ageing of the population, it may be that more severe heat episodes result in a larger mortality burden, as was observed during the July 1983 heatwave.

The perspective of facing more and more intense heatwaves, together with potential increasing vulnerabilities, calls for dedicating some efforts to the minimisation of the adverse health effects from any heatwave. These efforts should, however, be proportionate to the risks expected in Ireland. Communication to promote appropriate behaviours in the population and in the health professionals may be a first and essential step to limit the adverse impacts of heatwaves. The relevance of setting a heat warning system to anticipate heatwave episodes that could result in increased mortality should be discussed. Such

a system would alert stakeholders who in turn can promote preventive actions and disseminate appropriate information. As night temperatures are usually low, most of the heat exposure is a daytime exposure, and the warning system may rely on the maximum temperature only. For instance, a threshold of 25°C may prevent an excess mortality above 2% in both urban and rural areas, and occurs on a moderate number of days, most of them corresponding to the 1983, 1995 and 2003 heatwaves. This may be integrated into a simple system where the health authorities would be informed of a potentially dangerous heatwave, and would be able to reinforce communication.

6 Ways Forward

In addition to heat prevention, a first and essential step to adapt to climate change would be to improve the surveillance of health data, and especially of the mortality data. A better geographical resolution is an asset to study any relationship between a health topic and an environmental exposure.

1 Introduction

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) concludes that warming of the climate system is unequivocal. The Earth has warmed by +0.76°C on average during the last 100 years, with 11 of the 12 years in the period (1995–2006) being the warmest on record. All climate models agree that temperatures will continue to rise. The estimates of increases vary between +1.8°C and +6.4°C (IPCC, 2007). Between 1961 and 2005, the climatic trends identified in Ireland were largely consistent with global trends. The projected temperature increases for Ireland range between +1°C and +3°C by 2100, compared with the 1961–2000 average. Adaptation and mitigation are essential elements in addressing the challenges and opportunities of climate change.

According to the IPCC, adaptation is an "*adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation*" (IPCC, 1995). The first step of adaptation is to identify possible risks and impacts. This work focuses only on the direct impacts of temperature on health.

The dominant influence on Ireland's climate is the Atlantic Ocean, creating a moderate climate. Average annual temperature is about 9°C (6.6°C for minimum temperature, 13.3°C for maximum temperature). Minimum air temperature falls below zero on about 40 days per year at the inland stations, but on less than 10 days per year in most coastal areas. Air temperatures inland normally reach 18–20°C during summer days, and about 8°C during wintertime. Ireland exhibits an extremely strong seasonal pattern in mortality, with significantly higher wintertime mortality compared with summer. In fact, the excess winter mortality is one of the biggest in the developed world (Healy, 2003). From a weather and health perspective in Ireland, addressing the excess winter mortality is of the greatest importance. However, with that said, with the possibility of warmer weather as a consequence of climate change, it is important that we have an understanding of how the Irish population responds to hot weather, so that we can assist in the planning for climate-change-related events. Heat stress and increased mortality in vulnerable groups is considered a potential climate change impact in Ireland (EPA, 2009). Climate change should result in an increase in the frequency and intensity of heatwaves (Haines et al., 2009). In Ireland, the number of heatwaves defined as days when, for at least 6 consecutive days, the maximum temperature is at least 5°C greater than the 1961–1990 climatological mean value, has increased at a number of stations (EPA, 2009). In addition to the increase in temperature, the concentration of people in urban areas and the ageing of the population should result shortly in an increase in the number of people sensitive to heat.

It is important that we have an understanding of how the Irish population responds to warm temperatures, in order to identify relevant opportunities for adaptation. This understanding implies two kinds of studies. One is to quantify the impact of temperature on mortality, in order to verify that the traditional J–V shape between temperature and mortality (Basu, 2009) is also observed in Ireland. Estimates of increased mortality associated with an increase in temperature could then be used to project the impact of future climate. A previous study found that, in Dublin, each increase in current-day temperature by 1°C was associated with a 0.4% increase in total mortality, whereas each decrease of 1°C was associated with a 2.6% increase in mortality in the following 40 days (Goodman et al., 2004).

A complementary study is to investigate past heatwaves. This would allow checking if past events had an impact on mortality, and would provide an indication for the relevance of implementing heatwave prevention and adaptation.

2 Objectives

The main objective of the project was to:

- Identify the temperature–mortality relationship for the Irish population, and, in addition, to:
  - Identify the subgroups of the population that are most at risk;
  - Identify the most relevant meteorological parameters;
  - Investigate if there is an adaptation of the population over time;
  - Investigate the urban–rural differences in respect of the temperature response;
  - Estimate the potential human consequences of the predicted temperature rises; and
  - Investigate any evidence of excess summer mortality associated with heatwave events.

Results will be used to make recommendations on what should be implemented in Ireland to address climate change and potential health effects.

It is well established that mortality rates are significantly higher in winter than in summer in Ireland, although this phenomenon is observed in most countries. It can be shown that more people die when temperatures are at either extreme, namely during cold weather and during very hot weather. From an Irish perspective, the cold weather is the more dominant feature. As part of this project, the relationship between temperature and mortality in the Irish population was investigated, and the optimum temperatures were identified.

It is known from previous work (Goodman et al., 2004) that not everyone responds in the same way to extremes of temperature. It is well accepted that people with existing medical conditions (Bouchama et al., 2007), e.g. those with cardiovascular disease, are at greater risk from extremes in temperature. This study also aimed to identify those susceptible subgroups in Ireland. For the purpose of this particular study, the emphasis was on hot weather mortality, and more specifically, mortality during heatwaves.

It is already accepted that the planet is warming, and one of the challenges is whether the population is showing any evidence of adapting to these changing temperatures. This aspect was also investigated within the study.

Although Ireland is a relatively small island, with minimal differences in temperature across the island, this study investigated whether any differences between urban and rural areas with respect to weather-related mortality could be identified.

The work also explored the potential health consequences for Ireland in relation to the various climate change scenarios that have been proposed by others.

3 Excess Mortality Associated with a Mean Temperature Increase during Summer

3.1 Background

Ireland exhibits an extremely strong seasonal pattern in mortality (Fig. 3.1), with significantly higher wintertime mortality compared with summer. In fact the excess winter mortality is one of the biggest in the developed world (Healy, 2003). From a weather and health perspective in Ireland, addressing the excess winter mortality is of the greatest importance. However, that said, with the possibility of warmer weather as a consequence of climate change, it is important that we have an understanding of how the Irish population responds to hot weather.

With the development of statistical methods, many studies were able to establish a V or J shape relation between the temperature and the mortality in developed countries in recent years (Fig. 3.2). From this curve, an optimum temperature can be defined, which corresponds to the lowest mortality. This optimal

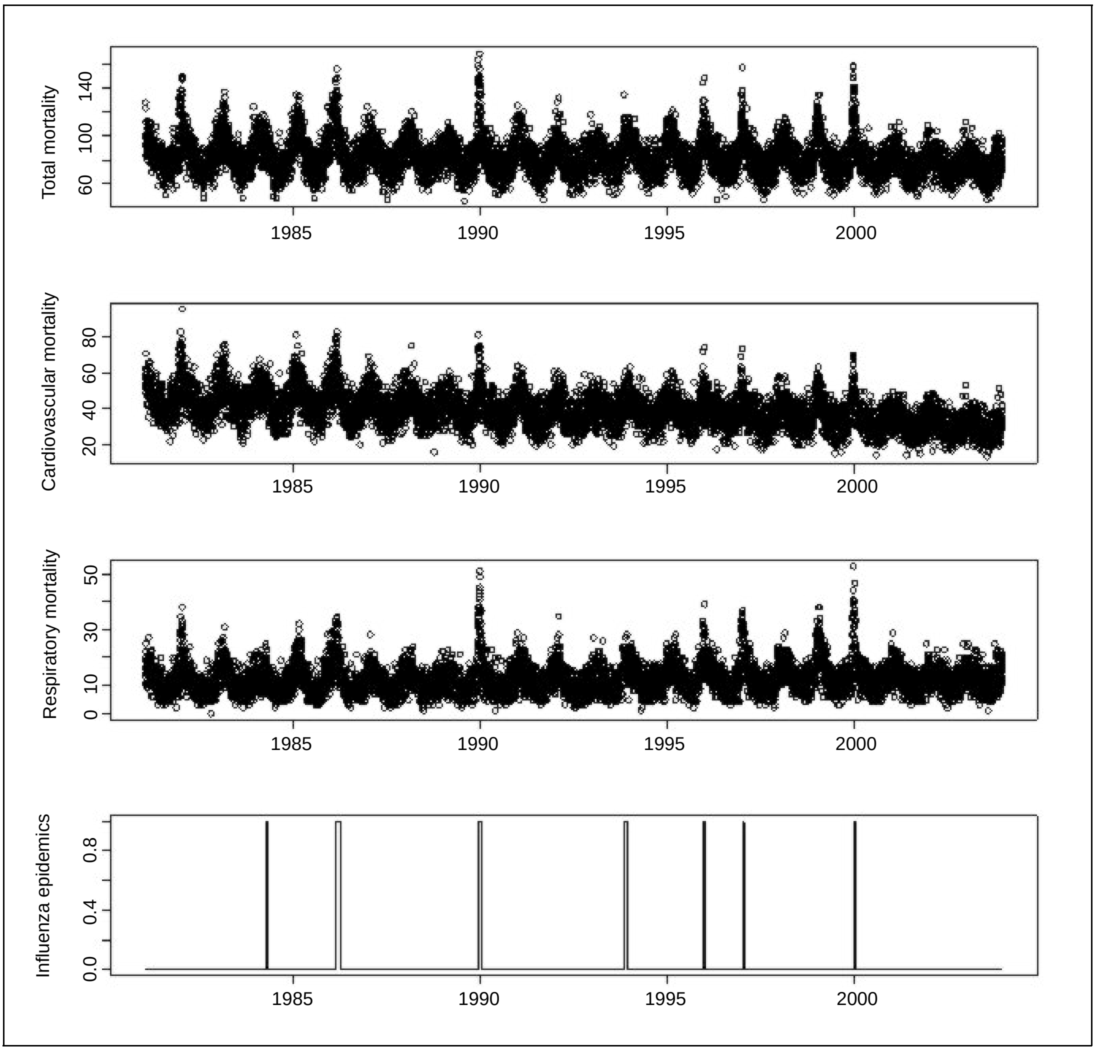


Figure 3.1. Daily total, cardiovascular, respiratory mortality and influenza epidemics in Ireland between 1981 and 2003.

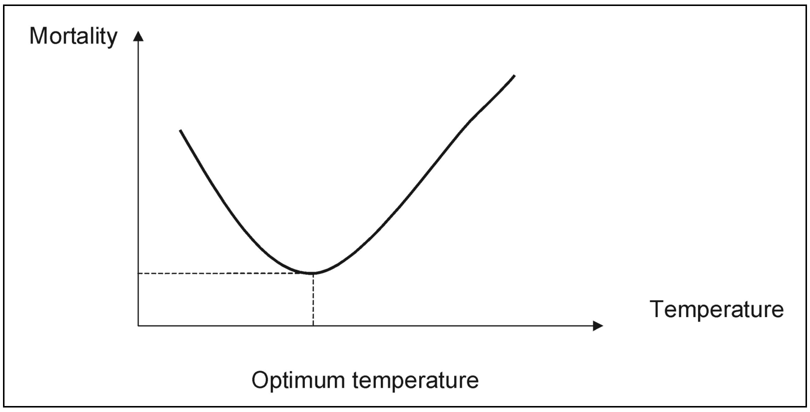


Figure 3.2. Schematisation of the temperature mortality relationship.

temperature is strongly subjected to geographical variations. All studies comparing the heat and cold-related mortality across different cities found that, as a general rule, the threshold for heat-related mortality is higher in warmer cities, while the threshold for cold-related mortality is lower in colder cities. Although it has been shown that the population acclimatised to its climate, heat-related mortality has been observed everywhere in the world. This U shape relationship has already been presented for Dublin (Goodman, 1999; Carson et al., 2006).

The first step of this work was to investigate if a similar relation could be established for Ireland, and if it has changed over time, as an approach to identify a possible adaptation.

3.2 Method

3.2.1 Mortality data

Individual mortality data were obtained from the Central Statistics Office (CSO) for the period 1981–2003 (23 years). They included date of death, sex, age, primary cause of death, location of death, marital status, occupation, and whether living or not in an institution.

Mortality data were sorted by causes of death (total, cardiovascular (ICD-9[1]: 390–459) and respiratory causes (ICD-9: 460–519) and age groups (all ages, >74 years).

1. ICD-9, International Classification of Diseases, Ninth Revision.

Although marital status, occupation and living or not in an institution have been found to be risk factors during heatwaves (Institut de Veille Sanitaire, 2004), these data were not used in this work, due to concern about the quality of the recording.

Another factor that can strongly influence mortality patterns is if there is an influenza epidemic present. Twenty episodes of influenza were identified during the period. For the purpose of defining an influenza episode, at least two consecutive weeks were required in which the percentage of deaths in Ireland from influenza and pneumonia was above the 95th percentile of expected; this approach has been successfully used before (Dockery et al., 2010).

Between 1981 and 2003, 691,394 deaths were recorded. People above 74 years old represent more than 50% of the total mortality (0–64 years: 19.5%, 64–74 years: 25%, >74 years: 54%). The distribution of age groups by location is similar, with people older than 74 years representing 51% of the urban mortality and 55% of the rural mortality.

The main cause of mortality was classified as cardiovascular (47.5%). Respiratory causes represented 15% of the total mortality.

As already outlined, mortality shows a strong seasonal pattern, with some of the most pronounced winter peaks corresponding to the influenza epidemics period (Fig. 3.1). Overall, there has been a notable decline in mortality over the study period, with the most pronounced decrease in mortality from cardiovascular disease. This can be attributed to improvements in

lifestyle and medical treatments. There have also been substantial shifts in the age distribution of the Irish population over the last 25 years. The number of children (0–14 years of age) has declined, while the number of middle-aged adults (30–59 years) has increased. The number of people older than 74 years remains a small fraction of the total population in all census years between 1981 and 2006, but there was a substantial increase (59%) in the oldest age group from 1981 to 2003 (Dockery et al., 2010).

3.2.2 Meteorological data

Daily meteorological data from 1981 to 2003 were obtained from Met Éireann, the Irish National Meteorological Service. Eleven stations were selected to cover the whole country. These were chosen as they gave good coverage with respect to the main population centres (Fig. 3.3).

Daily mean, minimum and maximum temperatures, humidity, pressure and wind speed were collected. Several meteorological indicators have been used in the literature to study the impact of temperature on mortality, including minimum, mean and maximum temperature, temperature differences between days, and mixed indicators combining temperature and humidity. The parameters tested in this study are described in Table 3.1. Minimum and maximum temperatures have been commonly used in epidemiologic studies, together with the apparent temperature (AT). The AT combines air temperature and relative humidity (Steadman, 1984). The formula for the AT is an approximation of the value provided by a mathematical model of heat balance in the human body. The wind chill is an indicator that takes into account the cooling effect of wind. A summary of the temperatures and humidity data is presented in Table 3.2. There is a good correlation between

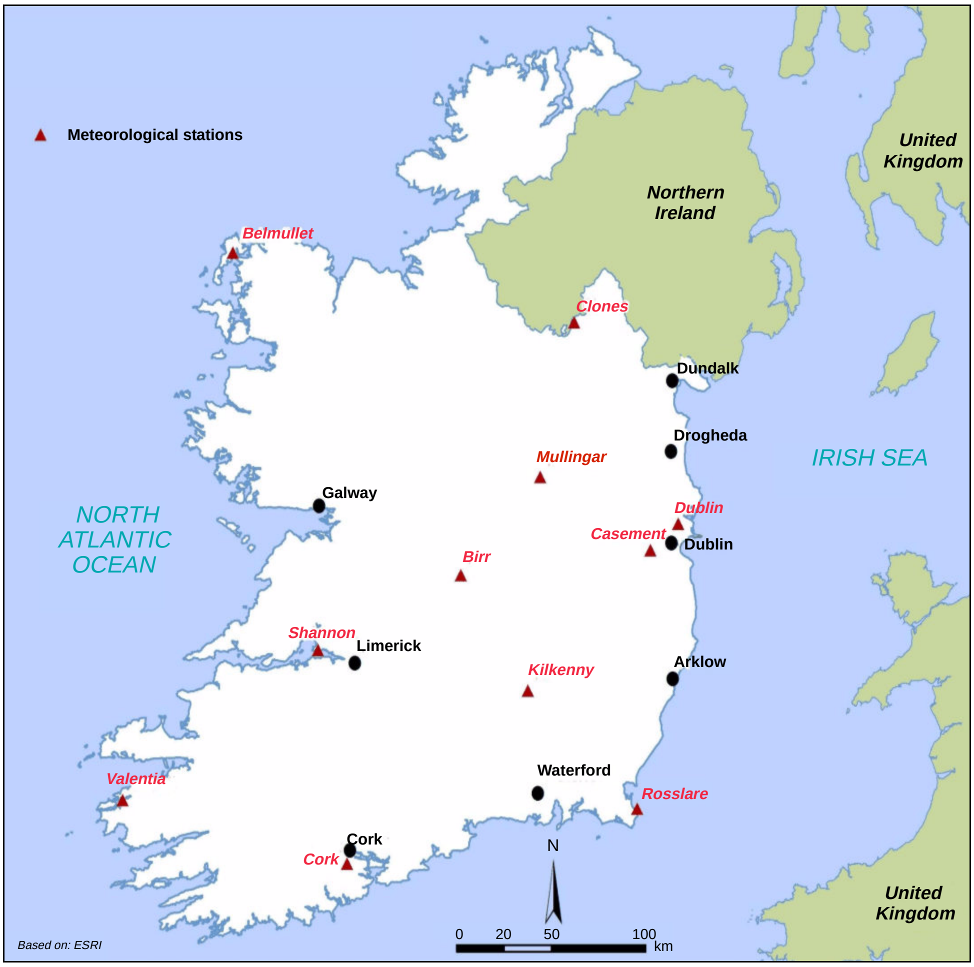


Figure 3.3. Location of the main cities and of the meteorological stations.

Table 3.1. Meteorological indicators.

Name	Description	Unit
T_{min}	Minimum temperature	°C
T_{max}	Maximum temperature	°C
T_{mean}	$0.5 \times (T_{min} + T_{max})$	°C
T_{mean24}	24-h mean temperature	°C
$T_{max}–T_{min}$	Temperature range	°C
rh	Relative humidity	%
Apparent temperature	$AT = T + 0.33 \times e - 0.70 \times ws - 4.00$, where T is the mean temperature, ws is the wind speed and e is the vapour pressure derived from the relative humidity (rh) and the temperature, as $e = rh / 100 \times 6.105 \times \exp(17.27 \times T / (237.7 + T))$	°C
Wind chill	$WC = 13.13 + 0.62 \times T - 13.95 \times ws^{0.16} + 0.486 \times T \times ws^{0.16}$, where T is the mean temperature and ws the wind speed.	°C
$T_{max\ 1–6}$	Moving average of maximum temperature lag 1–6	°C

Table 3.2. Temperature, humidity and wind speed per station – mean (min:max).

	Minimum temperature (°C)	Maximum temperature (°C)	Relative humidity (%)	Wind speed (m/s)
Belmullet	7.3 (–8.1:17.3)	13.0 (–1.1:29.9)	84.0 (54.3:99.3)	6.7 (0.0:23.0)
Birr	5.9 (–14.6:18.9)	13.5 (–3.5:30.8)	83.6 (50.0:100.0)	3.4 (0.0:13.3)
Casement	5.9 (–12.1:18.3)	13.4 (–2.9:31.0)	82.8 (47.0:100.0)	5.6 (0.1:20.6)
Clones	5.8 (–12.4:18.0)	12.9 (–6.4:30.5)	83.9 (49.6:99.9)	4.0 (0.0:15.6)
Cork	6.8 (–8.0:19.0)	12.9 (–4.3:28.7)	85.4 (50.7:100.0)	5.5 (0.8:18.1)
Dublin	6.3 (–7.9:18.4)	13.3 (–2.5:28.7)	82.2 (53.3:100.0)	5.2 (0.2:18.3)
Kilkenny	5.7 (–13.4:18.0)	13.9 (–3.6:31.4)	82.3 (47.9:100.0)	3.6 (0.0:14.5)
Mullingar	5.5 (–12.4:17.7)	12.9 (–3.4:29.7)	85.1 (53.8:99.6)	3.9 (0.0:14.4)
Rosslare	8.1 (–4.4:17.6)	13.1(–1.5:26.2)	84.0 (52.7:99.6)	5.7 (0.3:19.3)
Shannon	7.4 (–8.2:19.0)	14.0 (–1.8:30.6)	81.6 (49.7:100.0)	4.7 (0.0:17.2)
Valentia	8.0 (–6.8:18.4)	13.7 (–1.5:28.4)	83.1 (37.6:100.0)	5.2 (0.2:16.8)

stations for temperature but not for humidity (Appendix 1). Graphs of the temperatures, humidity and atmospheric pressure per stations are presented in Appendices 2–7.

3.2.3 *Geographical levels of analysis*

The mortality data are supplied with the ‘county’ of death. The lack of postal codes limits the ability to conduct a detailed small-area geographical analysis of mortality data, with quite often county level being the best available spatial resolution.

A main issue is then to find the appropriate geographical scale to match the mortality and the temperature data. Four options were considered:

1. To work at the city level only, matching the mortality observed in the city with the

meteorological parameters observed in the same city. However, the lack of statistical power would then have limited the analysis to Dublin.

2. To work at the national level, matching the mortality observed for the whole country, with temperatures averaged over all the meteorological stations. Yet, this method would introduce bias in the exposure and mix two types of populations, urban and rural, which are believed to react differently to heat.

3. To aggregate areas with a similar meteorological background, for instance inland areas versus seaside areas, but with the same limitations as for the national approach.

4. To distinguish between urban and rural areas, which has the same biases regarding exposure, but has the advantage of distinguishing the population. Therefore, this was the preferred option. Some of the larger urban areas that were easily identifiable were used to represent the urban population, and the remaining areas were classified as rural. For the purpose of this study, the mortality for Dublin, Cork, Drogheda, Arklow, Dundalk, Galway, Limerick and Waterford were used to represent the 'urban' population. In Ireland, the rural population represents more than 75% of the total mortality, while Dublin represents 15% of the urban mortality (Table 3.3).

The meteorological indicators were averaged in a consistent way, using the closest meteorological stations. Correspondences are outlined in Table 3.4.

Table 3.3. Total number of deaths between 1981 and 2003 by location.

Location	Number of deaths between 1981 and 2003	%
Arklow	443	0.06
Waterford	2,135	0.31
Drogheda	3,454	0.50
Galway	4,555	0.66
Dundalk	4,718	0.68
Limerick	6,381	0.92
Cork	25,317	3.66
Dublin	106,796	15.45
Total urban	**153,799**	**22.24**
Total rural (no location specified)	**537,595**	**77.76**

This approach has the advantage of being consistent with the literature, which indicates a larger temperature effect in cities. However, it definitely introduced a large uncertainty in the temperature estimates.

3.2.4 Statistical methods

3.2.4.1 Quantification of the increase in mortality associated with an increase in temperature

For the first objective, it was investigated whether a statistical correlation exists between daily variations of temperature and daily variations of mortality. The literature indicates a delay between exposure to temperature and death.

Table 3.4. Data used to study the relationship at the national, rural, urban and city levels.

Indicator	Mortality data	Meteorological stations
National	All	All
Rural	Location of death = 0	Kilkenny, Mullingar, Belmullet, Birr and Valentia
Urban	Location of death = Dublin, Cork, Drogheda, Arklow, Dundalk, Galway, Limerick, Waterford	Casement, Rosslare, Cork, Dublin and Shannon
Dublin	Location of death = Dublin	Dublin

In the case of heat, the impairment of the thermoregulation system results in several stresses, including heat cramp (a mild disorder caused by sodium depletion in the body), heat exhaustion (caused by inadequate fluid or sodium intake and characterised by thirst, fatigue, headache, nausea, elevated body temperature), and heat stroke (Batscha, 1997). Heat stroke is the most serious heat-related disease. The diagnosis is too often negative. An investigation of the cases that presented at a Lyon hospital in August 2003 revealed a mortality rate of 58% at 28 days, and 71% at 2 years. Serious sequels were found in all survivors (Argaud et al., 2007). Heat exhaustion can also adversely affect frail people with underlying diseases, leading to a premature mortality from multiple causes. These impacts are rapid, and a lag period of 1–3 days between the maximum temperature and the maximum mortality is usually reported (Greenberg et al., 1983; Kunst et al., 1993). This rapid effect is visible for all causes of mortality, as was illustrated during the 2003 heatwave in Paris (Le Tertre et al., 2006). Longer lag periods seem to show a compensatory effect for cardiovascular diseases (Kunst et al., 1993).

If the temperature–mortality relationship is straightforward during heatwaves, the cold-related mortality is more difficult to assess. It has been argued that exposure to cold could play a major role in the excess cardiovascular mortality during winter. The physiological effects of cold exposure – increases in arterial pressure, blood viscosity, fibrinogen and cholesterol – can induce rapid (24-h after exposure) ischaemic heart diseases (Donaldson and Keatinge, 1997). Exposure to cold also increases the risk of developing upper and lower respiratory tract infections and dying from them. Although not all studies agree, most of the available evidence from laboratory and clinical studies suggests that inhaled cold air, cooling of the body surface and cold stress induced by lowering the core body temperature cause pathophysiological responses such as vasoconstriction in the respiratory tract mucosa and suppression of immune responses, which are responsible for increased susceptibility to infections (Mourtzoukou and Falagas, 2007). Therefore, the cold impact may be expected from 5 to 15 days after the cold temperatures, with some studies finding results up to 3 weeks later. However, with such lags it becomes difficult to identify a statistical difference between the temperature variations and the seasonality of the mortality.

In addition, cold-related mortality is highly sensitive to the existence of appropriate adaptation such as low living-room temperatures, low bedroom heating, or low proportions of people with adequate clothing (hat, gloves, etc.) (The Eurowinter Group, 1997).

This delay between exposure and death was studied, introducing a lag between the mortality and the temperature. In this study, the temperature terms were chosen a priori. Indeed, there are no rules on how to choose the temperature indicators. Considering that the temperature variations are moderate in Ireland, that minimum and maximum temperature are highly correlated but that warm days can frequently be associated with cold nights, the authors decided to use the daily mean temperature as a proxy of the mean temperature exposure. In the models, two temperature terms, mean temperature at lag 0 and mean temperature for lag 1–7 (labelled $T_{mean\ lag\ 0}$ and $T_{mean\ lag\ 1\text{–}7}$) were integrated. Temperature at lag 0 is assumed to be a good indicator of the heat short-term effect, while temperatures at lag 1–7 give an indication of the cold lagged effect (but excluding the cold effect mediated by respiratory infections, which may be lagged up to 3 weeks). This design allows for each of these effects to be considered while controlling for the other.

Computer-based statistical models that can allow examination of the relationships between all the various parameters were used. To achieve this, specialist software and large data sets were needed. Some of the key challenges in such an analysis are to control for the time trends in the data, namely how, for example, mortality rates change over time – this is quite evident in a data set spanning over 30 years of data; in addition, controlling for confounding factors is also crucial. Influenza epidemics and days of the week as confounding factors were considered.

The particular statistical approach employed was to use a generalised additive model (GAM), attempting to explain the variable *Y* using variable *X*, namely how changes in *Y* are explained by changes in *X*. The mean

of Y is related to the X variable via smooth functions and a link function (Hastie and Tibshirani, 1990; Wood, 2006). The smooth functions are chosen to best fit to data, without making assumptions on the actual shape of the relationship. Spline functions were used for that fitting, i.e. X was divided into different parts, and a different polynomial function was adjusted for each part. The spline function is the linking of those different parts.

The general model is written as:

$$Y_t \approx Poisson(\mu_t)$$
$$\ln(\mu_t) = \alpha_0 + \sum_{j=1}^{q} f_j(X_{tj}, \lambda_j) + \sum_{i=1i}^{p} \beta_i X_i \qquad \text{Eqn 3.1}$$

where Y_t is the number of deaths on day t, X_{tj} are the variables to be fitted with splines, i.e. time, temperatures and humidity, f_j are the splines, and X_i are the constant variables, i.e. influenza periods, day of the week, holidays.

Models were developed for the whole year and for summer (June–August), for the different causes of mortality and for two age groups: all ages, and those over 74 years. Only the results for summer are discussed here.

3.2.4.2 Changes over time

In order to identify possible trends in the response, an analysis was undertaken, dividing the data set into periods of 5 years for total mortality and for the >74 age groups in rural areas between 1981 and 2003: 1981–1985, 1986–1990, 1991–1995, 1996–2000, 2001–2003[2].

3.2.4.3 Influence of the previous winter mortality

Rocklov et al. (2009) found that the same people were vulnerable to heat and to cold. Therefore, low winter mortality may increase the proportion of vulnerable people during the following summer, and thus be associated with greater summer mortality. To test this hypothesis, the sensitivity of heat-related mortality in summer to the mortality of the previous winter (previous winter was defined as December–March) was explored.

In the initial model, an additional term qualifying the mortality of the previous winter was introduced, following the method described by Ha et al. (2011), and used during summer only.

$$\begin{aligned} Log(E(Y_t)) &= \beta * t_{\min lag0} + \beta 1 * (t_{\min lag0} * WL) \\ &+ \beta_0 + \alpha_i(Day-of-the-week) \\ &+ \chi(Influenza) + s(year) + s(t_{\max lag1-7}) \end{aligned} \qquad \text{Eqn 3.2}$$

To classify winters, yearly average winter mortality was regressed against calendar year to predict a winter mortality accounting for secular trends. Winters with observed mortality below the model-predicted values were classified as low winter mortality.

Figure 3.4 illustrates the difference between the mean winter mortality and the predicted values. In rural areas, winters preceding summers 1981, 1983, 1984, 1985, 1988, 1989, 1998, 2001, 2002 and 2003 were characterised by lower than usual mortality. In urban areas, winters preceding summers 1984, 1986, 1987, 1988, 1992, 1993, 2001, 2002 and 2003 were characterised by lower than usual mortality.

The low winter mortality may be explained by several factors, including influenza epidemics, cold spells, or pollution episodes. These factors were not investigated here.

3.2.4.4 Exploration of the lag structures

In many situations, there can be quite a time difference between the exposure to a hazard and the manifestation of any adverse health effects, e.g. smoking is associated with lung cancer, but it can take many years for lung cancer to develop after a person commences smoking. In the case of exposure to temperature, it may take a period of time between exposure and any adverse health outcome, especially for cold. On the other hand, there is evidence that high temperatures seem to have a fairly immediate health effect, with people dying within 48 h of the high temperatures. An important aspect of this study was to explore the lag structure of the temperature–mortality relationship. To do this, an additional distributed lag model was tested using lags of exposure up to 16 days prior to the day of death. These lags were incorporated within the GAM design (Schwartz, 2000). These

---
2. Only 3 years of data were available for the 2001–2003 period.

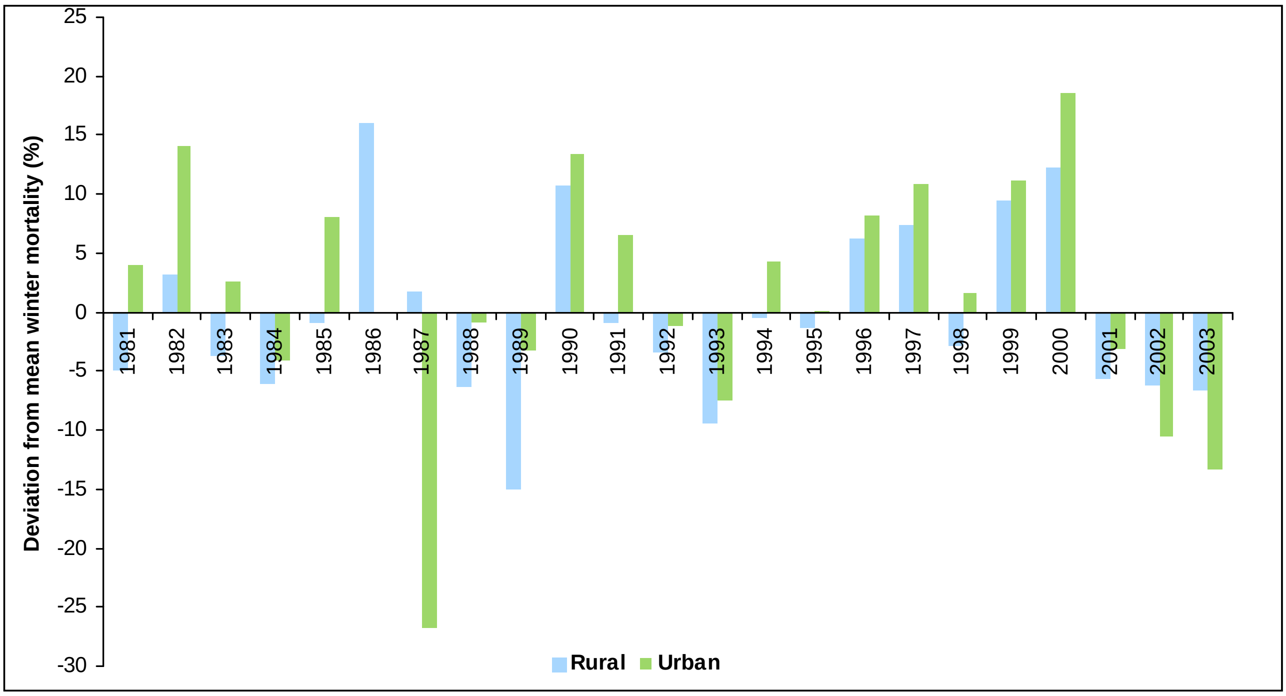


Figure 3.4. Differences between the mean winter mortality, and the mean winter mortality predicted based on year.

models are also useful to investigate a possible harvesting effect, or mortality-displacement effect (Zanobetti et al., 2000).

$$Y_t \approx Poisson(\mu_t)$$

$$\ln(\mu_t) = \alpha_0 + \sum_{s=0}^{16} \beta_s Z_{t-s} + \sum_{j=1}^{q} f_j(X_{tj}, \lambda_j) + \sum_{i=1i}^{p} \beta_i X_i \qquad \text{Eqn 3.3}$$

where Y_t is the number of deaths on day t, Z_{t-s} is the temperature at lag s, X_{tj} are the variables we want to fit with splines, e.g. time, f_j are the splines, X_i are the constant variables, i.e. influenza periods, day of the week, holidays and β_S is the response of the temperature at lag s. To allow a stable estimation of the coefficients, the estimation was constrained using a polynomial of degree 3, using the method described by Almon (1965).

$$\beta_s = \beta(s) = \sum_{k=0}^{d} \eta_k s^k \qquad \text{Eqn 3.4}$$

Computations were done using the mgcv[3] package and the survival packages of the R software (R Development Core Team, 2004; Wood, 2006).

3. mgcv, Mixed GAM Computation Vehicle.

3.2.4.5 *Sensitivity analysis*

Sometimes when modelling data, there is a risk that the result might be biased based on the specific model used, so it is important that the results are not totally dependent on the specific model and that it can be altered somewhat without changing the overall results. This can involve changing some of the input variables within the model – this approach is called a sensitivity analysis.

As a sensitivity analysis, all the above models were alternatively developed using the minimum temperature at lag 0 and the maximum temperature at lag 1–7.

An alternative modelling strategy was also tested, namely a time-stratified, case-crossover (CXO) model. In a CXO model, the information on the individual exposure to a certain activity or agent during the hazard period (i.e. just before the disease) and control period are compared (Maclure, 1991). This design is appropriate to study mortality and extreme heat exposure, as heat can be considered as a brief exposure that causes a transient change in risk of an acute event. Confounding factors are included either during the design phase (characteristics of each

individual, day of the week, seasons, etc.) or as co-variables in the model (e.g. influenza, air pollution). The effect period, i.e. the period after exposure where there is a change in risk due to exposure, is of a few days, the peaks of mortality classically occurring within 48 h after the temperature peak. The choice of the control period is the main difficulty of a CXO design. It has to be close enough to the hazard period, not to lose information, but not too close to avoid autocorrelation and biases. For this study, a time-stratified approach was chosen. Control days were defined as the same days of the week of the same months as the cases. This approach allows controlling for short- and long-term variations (Janes et al., 2005). Data are then analysed using a conditional logistic regression. Temperatures were also modelled using splines, as described above.

3.3 Results

3.3.1 Shape of the relationship

The graphs in Fig. 3.5 show the splines obtained for the mean temperatures at lag 0 and at lag 1–7. They show that the mortality increases when the mean temperature increases, and that it increases when the mean temperature decreases. A similar pattern was found for the whole year. This is consistent with the authors' assumption that temperature at lag 1 captures a short-term warm effect, while the temperature at lag 1–7 captures a cold effect (Fig. 3.5). The shape of the relation was similar for total mortality and total mortality over 74 years in urban and rural areas. A similar shape was observed for cardiovascular mortality in rural, but not in urban areas where the mean temperature does not influence the cardiovascular mortality. On the other hand, temperature did not influence the respiratory mortality in rural areas, but a linear relationship was observed for urban areas. Similar shapes were observed for Dublin.

Considering the shapes of the temperature–mortality relationship observed in rural and urban areas for the different causes of mortality, a linear relationship was assumed above 15°C. The slope of this term is used to compute the excess relative risk for a 1°C increase above 15°C.

3.3.2 Risk estimates

A 1°C increase above 15°C in the mean temperature was associated with a 1.5% (CI 95% 0.9:2.1) increase in the total mortality in rural areas, and a 1.6% (0.6:2.5) increase in total mortality in urban areas. The estimate was lower in Dublin, +0.6% (–0.1:1.3). The impact was slightly lower for the total mortality over 74 years (1.4%

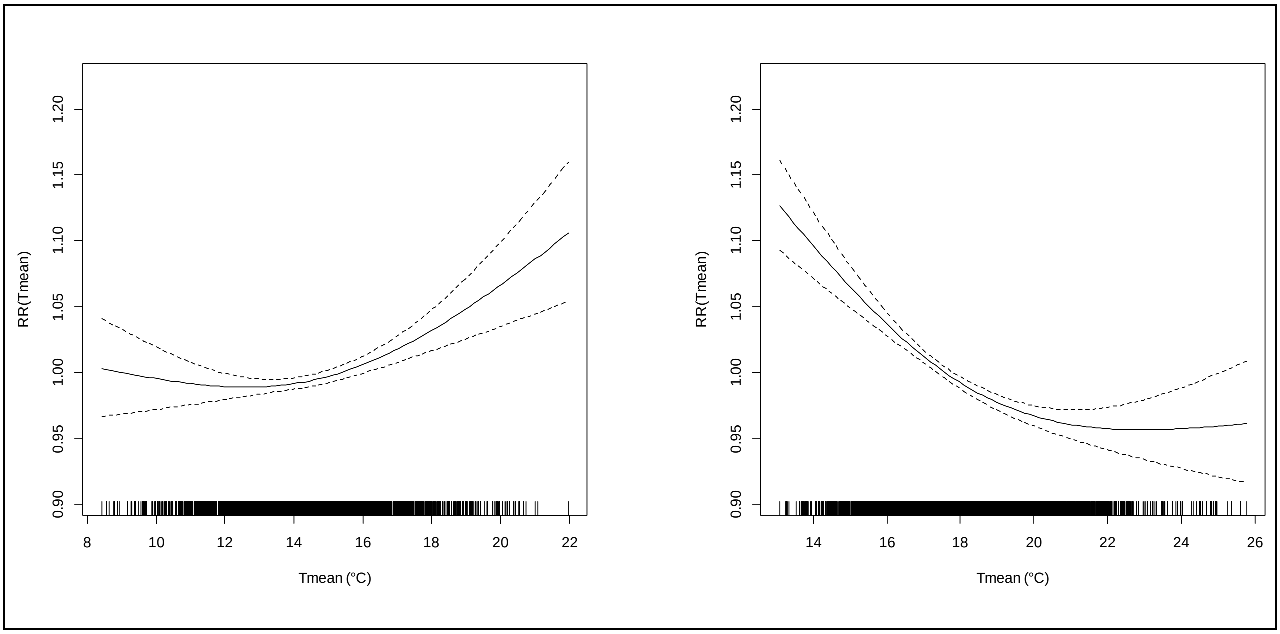


Figure 3.5. Relative risk (RR) of total mortality associated with mean temperature lag 0 (left) and lag 1–7 (right).

(0.6:2.2) and 1.5% (0.3:2.7), respectively). A significant result was obtained in Dublin (+1.4% (0.1:2.7)).

In rural areas, a significant impact was observed on cardiovascular mortality (1.1% (0.3:1.9)) but not on respiratory mortality (+0.0% (–1.1:1.0)). The opposite pattern was observed in urban areas, with no impact on cardiovascular mortality (+0.2% (–0.8:1.3), and in Dublin only –0.1% (–1.2:0.9)) but with a large impact on respiratory mortality (+2.8% (0.5:5.1)) (Fig. 3.6).

3.3.3 Changes over time

The periods were relatively homogenous in terms of temperatures (Table 3.5) and mortality (Table 3.6).

In rural areas, the risk associated with a 1°C increase above 15°C was around 2% for the periods 1981–1984, 1985–1988 and 1989–1992. It started to decrease between 1993 and 1996, and temperature was even associated with a reduced mortality during the period 1997–2000 (+1°C increase above 15°C was associated with a 1.1% (–2.0:0.6) decrease in the total mortality (Fig. 3.7). A similar evolution was observed for the mortality above 74 years in rural areas (Fig. 3.8) and for the cardiovascular mortality (Fig. 3.9). As for respiratory mortality, low and non-significant risks were observed throughout all the periods (Fig. 3.10).

In urban areas, a large risk was observed during the first period (+5.1% (2.9:7.4)), while the response was lower and non-significant in the other periods (Fig. 3.11). For the total mortality above 74 years, the risks were non-significant across all the periods, except between 1993 and 1996. However, large positive risks were observed between 1981 and 1996, while the risks had been decreasing since 1997, and were negative between 2001 and 2003 (Fig. 3.12). The risks were non-significant for cardiovascular mortality (Fig. 3.13). As for respiratory mortality, large risks were observed before 1998 (+13.7% (7.2:20.7) between 1981 and 1984), and dropped rapidly to become non-significant since that period (Fig. 3.14).

3.3.4 Influence of the previous winter mortality

In rural areas, the relative risks were consistently higher in summers preceded by winters with a low mortality for the total mortality, the total mortality in people greater than 74 years and cardiovascular mortality. A similar difference was observed in urban areas for the total mortality, but not for the mortality above 74 years. The largest difference was associated

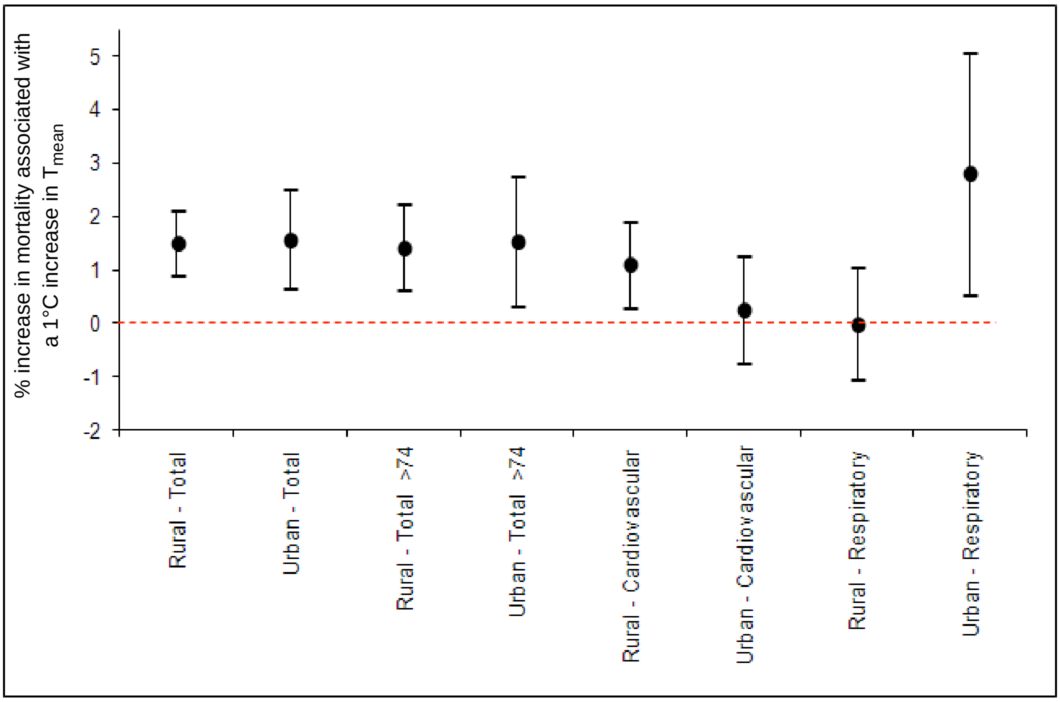


Figure 3.6. Percentage increase in mortality associated with a 1°C increase above 15°C in mean temperature at lag 0 – summer.

Table 3.5. Temperature characteristics of the summers over the different time periods.

	Urban areas			Rural areas		
	Mean	Min	Max	Mean	Min	Max
1981–1984	15.3	9.9	23.0	14.8	8.8	22.0
1985–1988	14.0	8.3	19.9	13.6	8.6	18.9
1989–1992	15.0	8.1	20.7	14.7	8.4	20.4
1993–1996	14.8	9.7	21.0	14.6	9.7	21.1
1997–2000	14.8	9.8	19.9	14.7	10.0	19.5
2001–2003	14.8	9.1	20.8	14.5	9.2	20.7

Table 3.6. Mortality characteristics of the summers over the different time periods.

	Urban				Rural			
	Total	Total >74	Cardiovascular	Respiratory	Total	Total >74	Cardiovascular	Respiratory
1981–1984	16.5	7.3	7.8	1.9	57.5	27.9	30.4	6.8
1985–1988	16.7	7.9	7.9	1.7	59.6	30.4	30.5	7.2
1989–1992	16.5	8.4	7.4	1.8	56.4	31.1	27.3	6.8
1993–1996	16.8	8.7	7.5	2.0	57.3	32.8	26.9	7.6
1997–2000	17.0	9.4	7.3	2.0	55.5	33.1	24.2	8.1
2001–2003	15.9	9.1	5.9	2.4	53.4	32.8	22.0	7.4

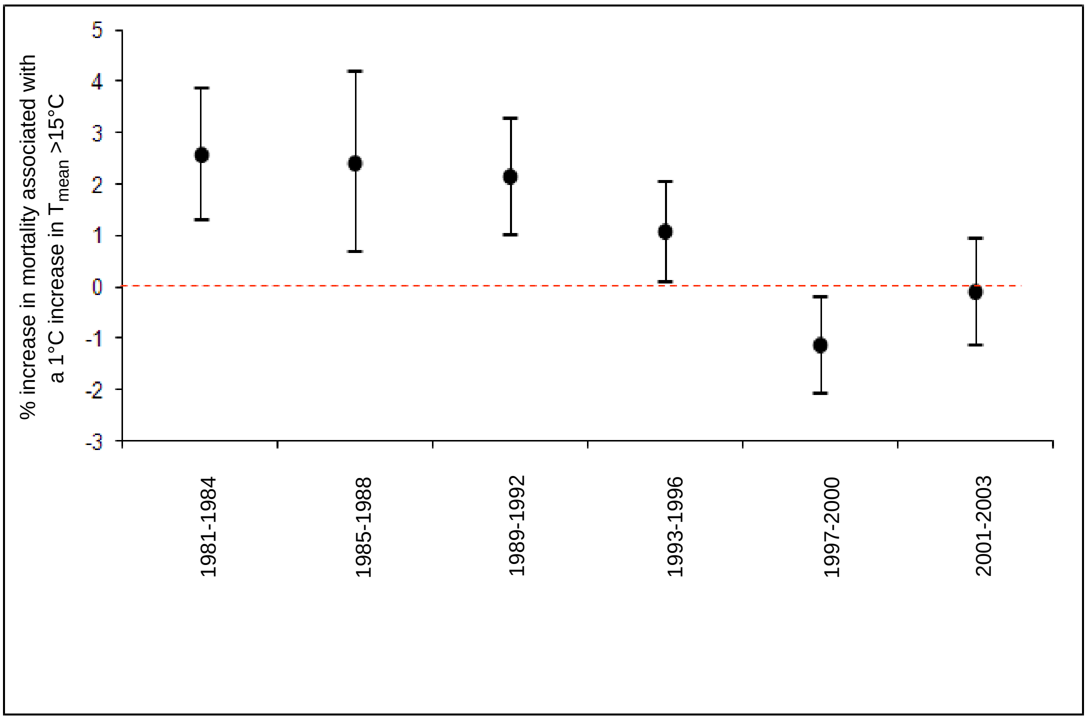


Figure 3.7. Evolution over the time of the percentage increase in total mortality associated with a 1°C increase above 15°C in mean temperature at lag 0 in rural areas.

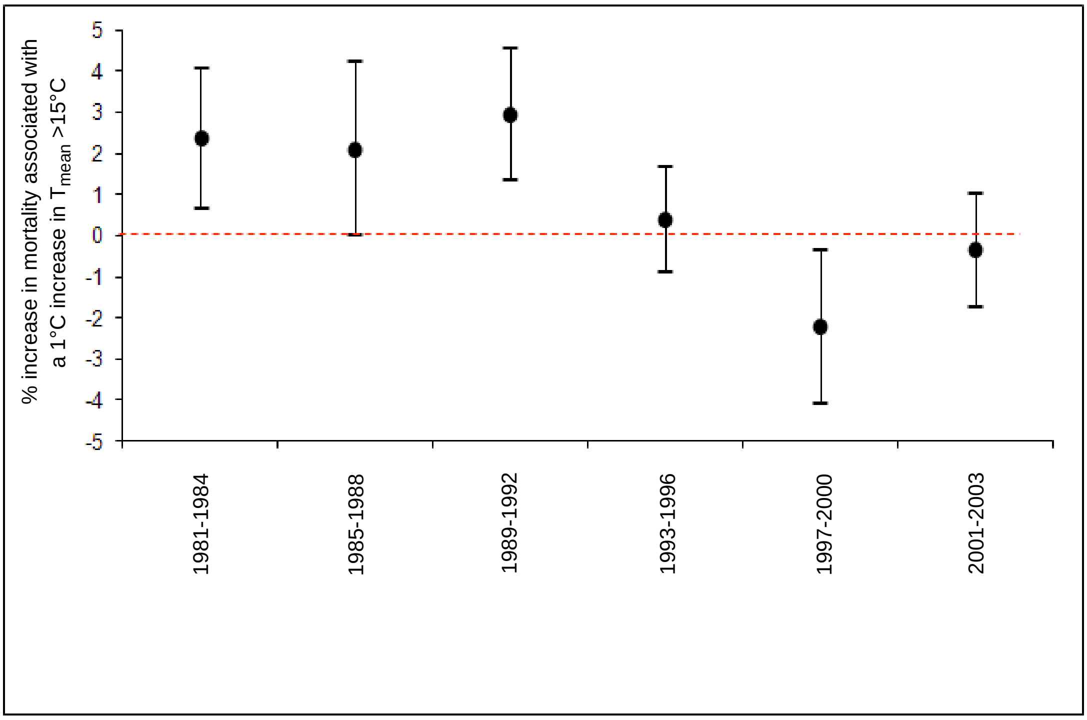


Figure 3.8. Evolution over the time of the percentage increase in total mortality above 74 years associated with a 1°C increase above 15°C in mean temperature at lag 0 in rural areas.

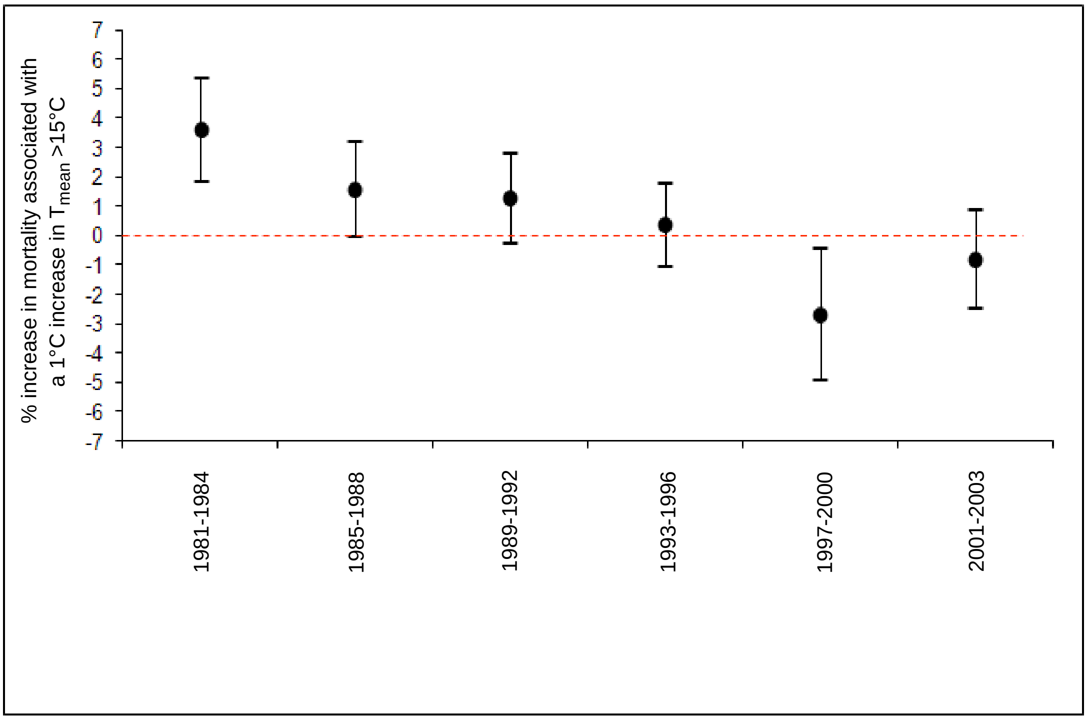


Figure 3.9. Evolution over the time of the percentage increase in cardiovascular mortality associated with a 1°C increase above 15°C in mean temperature at lag 0 in rural areas.

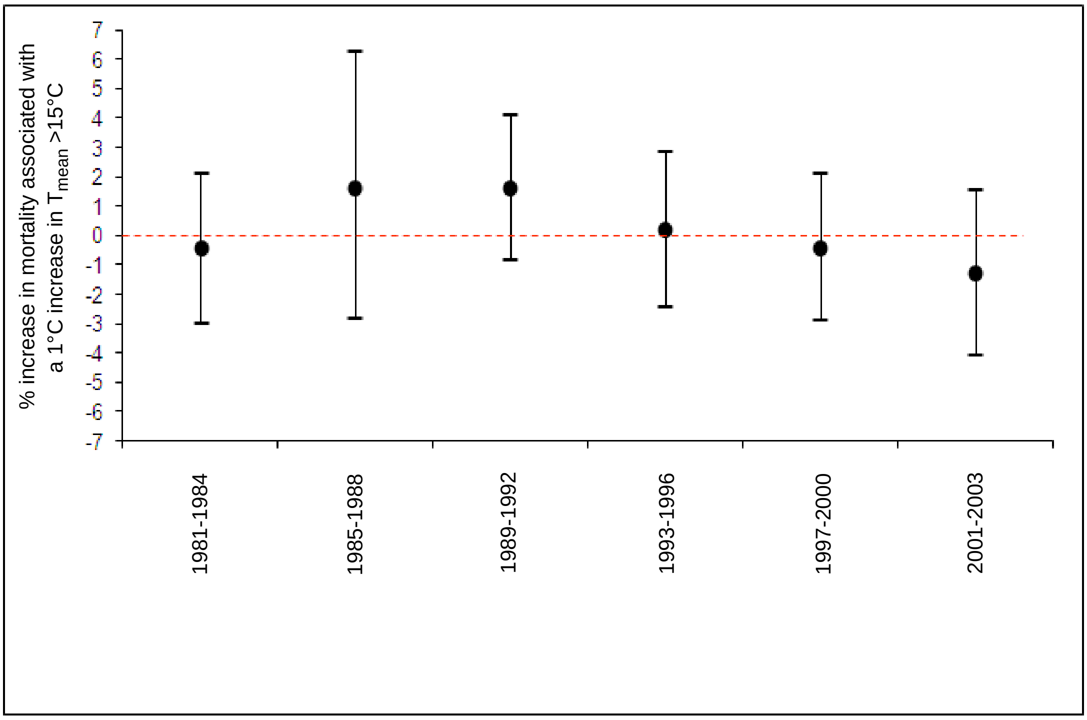


Figure 3.10. Evolution over the time of the percentage increase in respiratory mortality associated with a 1°C increase above 15°C in mean temperature at lag 0 in rural areas.

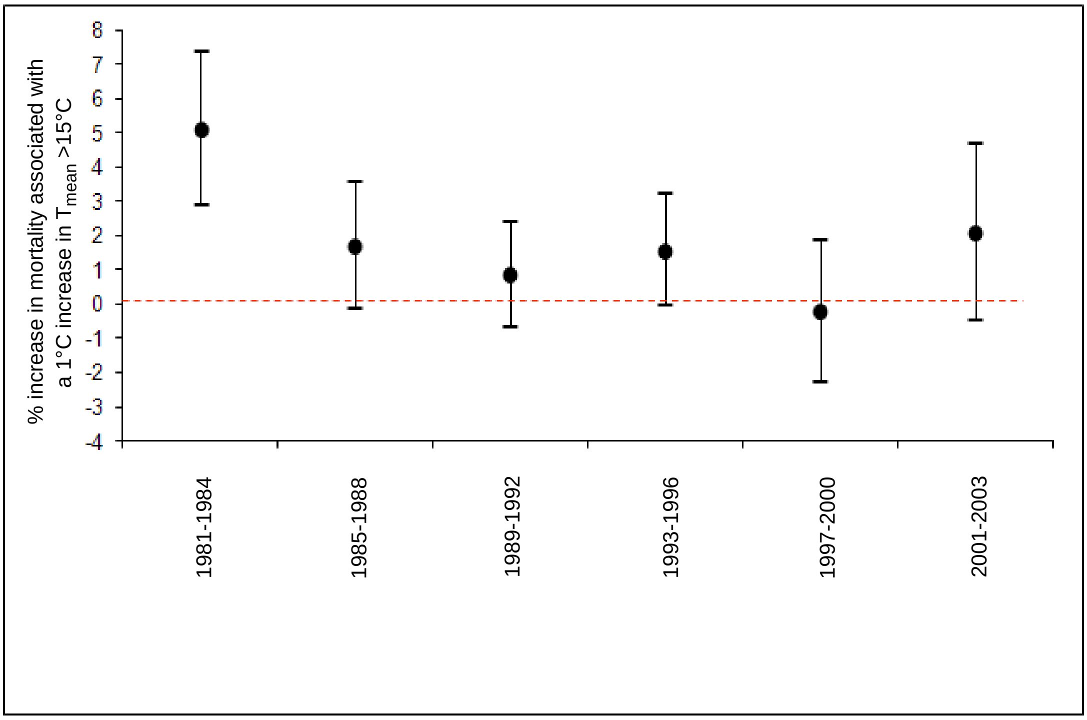


Figure 3.11. Evolution over the time of the percentage increase in total mortality associated with a 1°C increase above 15°C in mean temperature at lag 0 in urban areas.

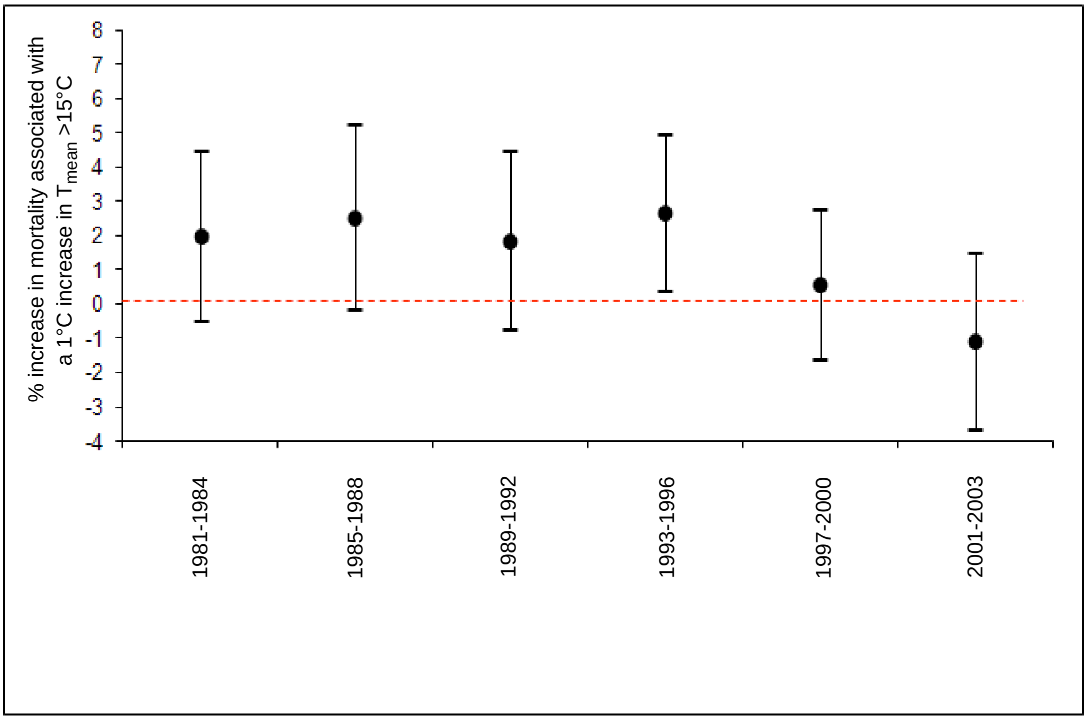


Figure 3.12. Evolution over the time of the percentage increase in total mortality above 74 years associated with a 1°C increase above 15°C in mean temperature at lag 0 in urban areas.

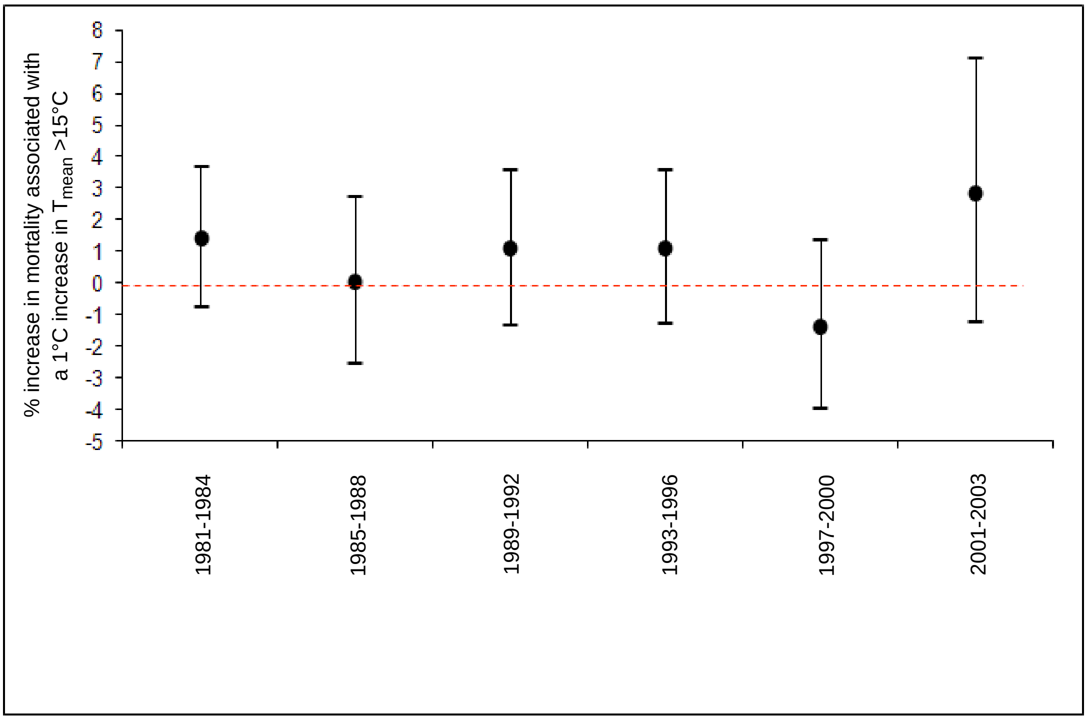


Figure 3.13. Evolution over the time of the percentage increase in cardiovascular mortality associated with a 1°C increase above 15°C in mean temperature at lag 0 in urban areas.

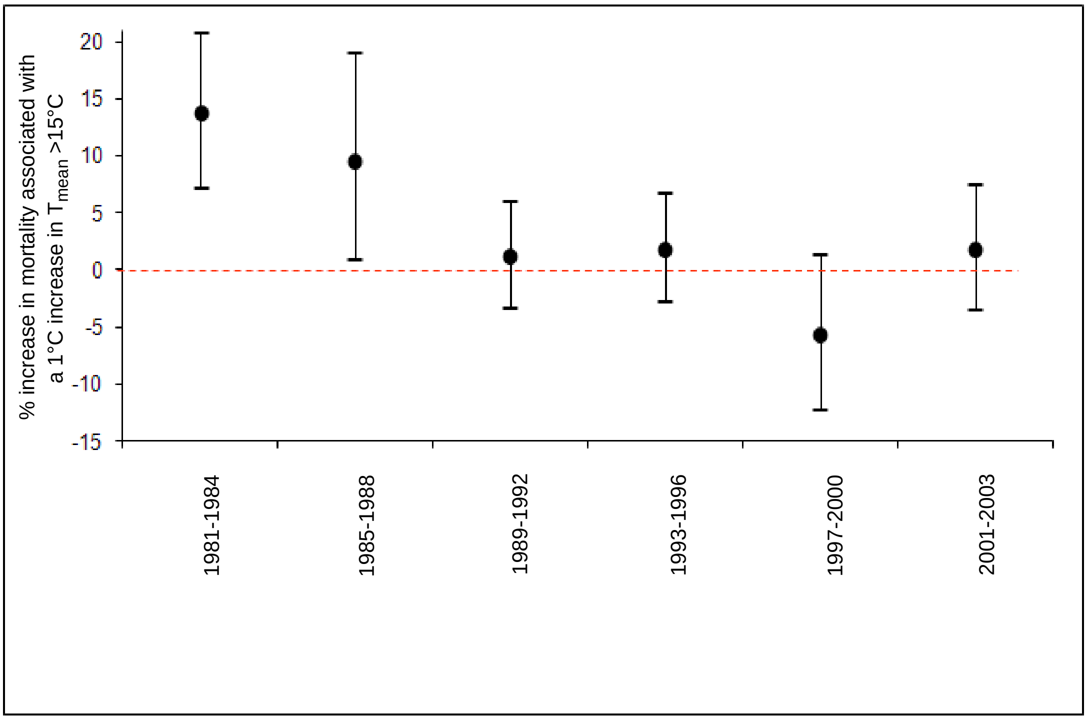


Figure 3.14. Evolution over the time of the percentage increase in respiratory mortality associated with a 1°C increase above 15°C in mean temperature at lag 0 in urban areas.

with the respiratory mortality in urban areas (Table 3.7).

The analysis was not performed on the Dublin data due to a lack of statistical power when differentiating the winters.

3.3.5 Investigation of the lagged structure

The results of the distributed lagged model are presented graphically in Figs 3.15–3.18. In rural areas, it can be seen that the largest significant effects were observed on the first 2 days after heat exposure (Fig. 3.15); this is consistent with the rapid effect described in the literature. From Day 3 to Day 5, the effects are non-significant, meaning that there are no observed impacts on mortality 3–5 days after heat exposure. However, a protective effect is observed from Day 6 to Day 10, i.e. the mortality is significantly lower 6–10 days after exposure. This is known as a harvesting effect, based on the hypothesis that heat-related deaths affect highly vulnerable persons whose deaths are anticipated by a few days. After 10 days, no significant effect on mortality is observed. A similar pattern was found for the total mortality in those over 74 years, although the results were non-significant at lags 1 and 2 (Fig. 3.16), possibly due to a lack of statistical power. The harvesting effect is more pronounced at lags 6 to 12, consolidating the idea that heat deaths are anticipated by a few days. A similar

Table 3.7. Percentage increase in mortality for a 1°C increase in temperature above 15°C, depending on the preceding winter mortality.

	Rural areas		Urban areas	
	Low-mortality winters	High-mortality winters	Low-mortality winters	High-mortality winters
Total mortality	2.2 (1.3:3.1)	0.9 (0.1:1.7)	2.2 (0.5:3.9)	1.2 (0.3:2.0)
Total mortality >74	2.7 (1.4:4.0)	0.3 (–0.5:1.1)	1.3 (–0.3:2.9)	1.6 (0.1:3.1)
Cardiovascular mortality	2.4 (1.2:3.7)	0.2 (–0.5:0.9)	0.4 (–1.4:2.1)	0.3 (–0.9:1.6)
Respiratory mortality	0.1 (–1.6:1.7)	0.1 (–1.3:1.5)	9.8 (4.6:15.2)	2.3 (–0.2:4.8)

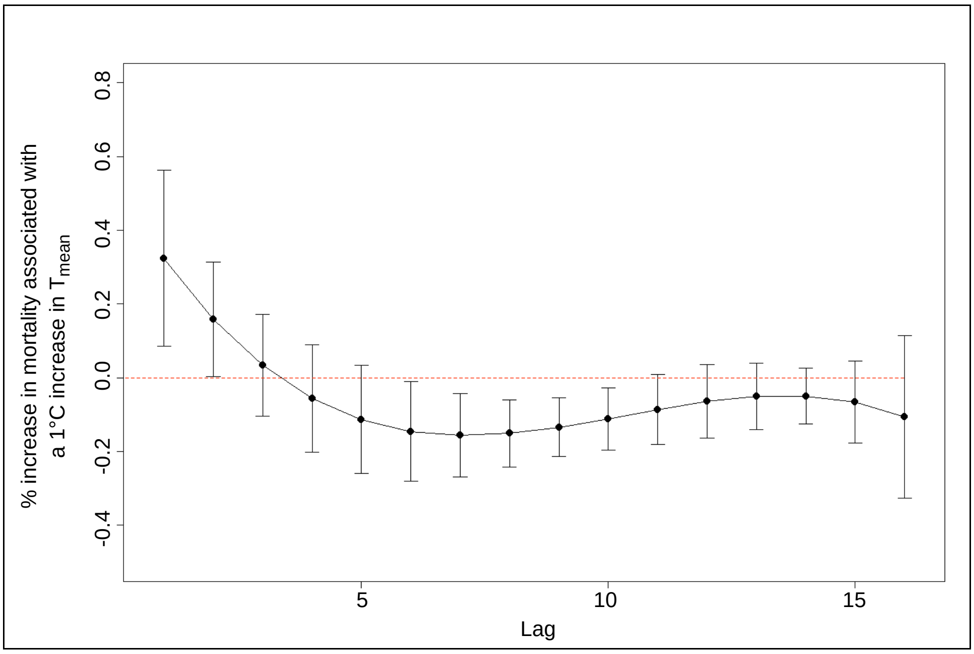


Figure 3.15. Percentage increase in total mortality associated with a 1°C increase in mean temperature at lag 1–16 during summers in rural areas.

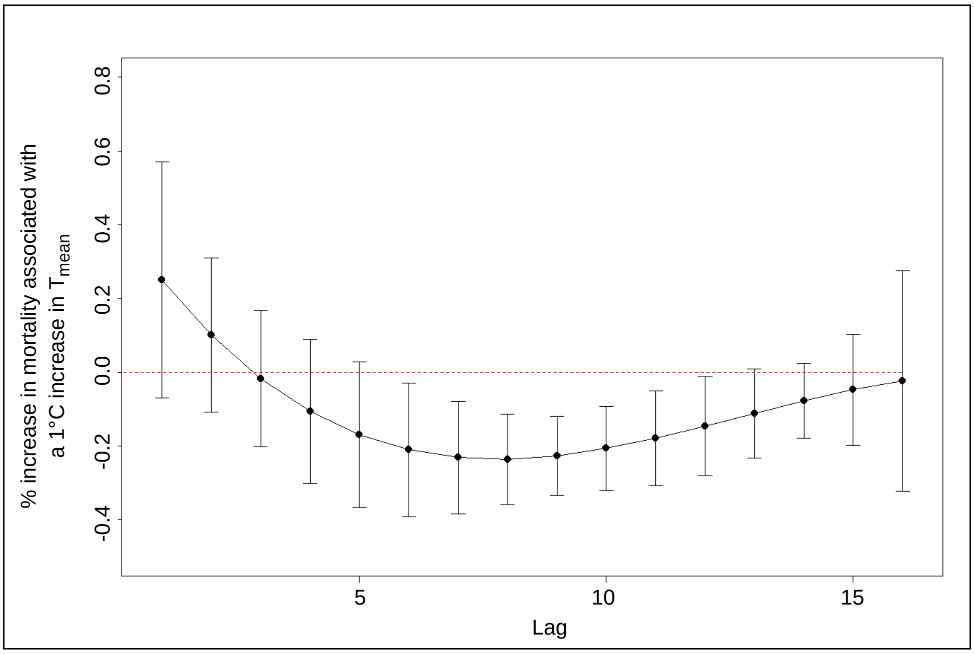


Figure 3.16. Percentage increase in total mortality above 74 years associated with a 1°C increase in mean temperature at lag 1–16 during summers in rural areas.

trend was observed for cardiovascular mortality (Fig. 3.17). In urban areas, the risk decreased with the lags, but all the estimates were non-significant, as illustrated in Fig. 3.18. A similar shape was observed for the mortality in the elderly, and by causes. This is likely to be due to a lack of statistical power.

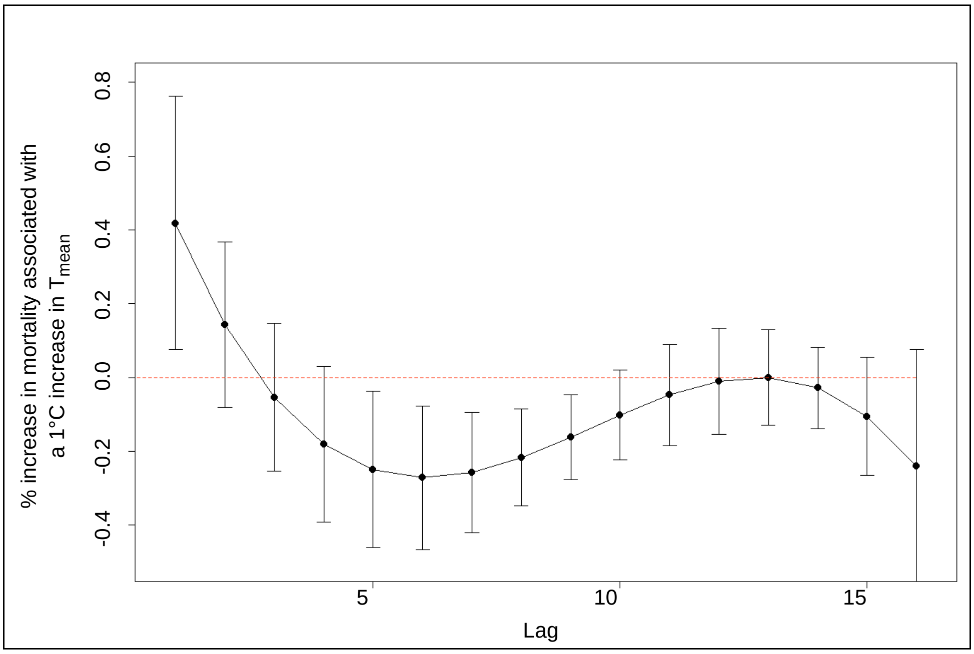


Figure 3.17. Percentage increase in cardiovascular mortality associated with a 1°C increase in mean temperature at lag 1–16 during summers in rural areas.

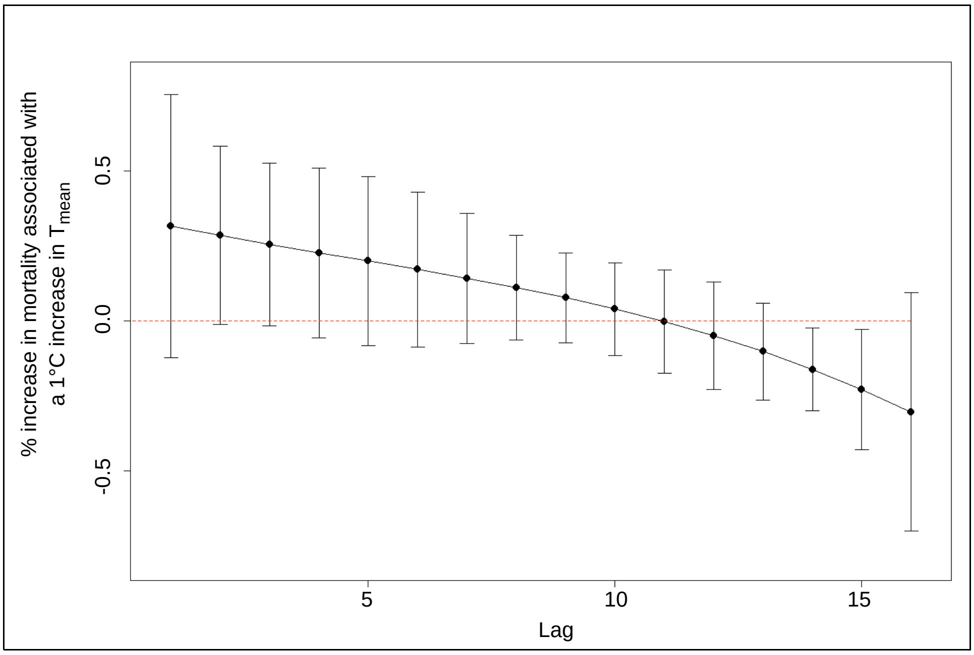


Figure 3.18. Percentage increase in total mortality associated with a 1°C increase in mean temperature at lag 1–16 during summers in urban areas.

3.4 Discussion

3.4.1 Limits

The main limit is the availability of the mortality data at a low geographical scale. Therefore, the health outcomes and heat exposure cannot be perfectly matched. The error in the exposure assessment may lead to an over or an underestimation of the risks, introducing a bias that could not be estimated with the available data.

The analysis is also limited by the quality of the data. Changes in reporting practices may explain some of the differences observed over time, or between rural and urban areas, especially when considering the cardiovascular and the respiratory mortality.

Finally, the lack of air pollution data limits the analysis of a potential confounding by air pollution, especially in urban areas. However, as the results are consistent with the literature and the current knowledge on heat-related mortality, and as they are robust when doing the sensitivity analysis, they may be considered as reasonable.

3.4.2 Comparison with the literature

In the literature, published estimates of the impact of mean temperature on mortality ranged from no evident heat effect in Dublin (Ireland), Dallas and Charlotte (USA), and Busan (South Korea) to a 12.3% (CI 95% 5.7:19.4) increase in mortality per 1°C increase in high temperature in Beirut (Lebanon) and 18.8% (13.0:25.0) in Monterrey (Mexico), with both cities having correspondingly high heat thresholds (Hajat and Kosatky, 2010).

An increase in mortality at the highest temperatures is observed in countries with moderate climate and relatively cold summers. In Sweden, an increase in 1°C in the summer temperature above the 90th percentile of temperature distribution was associated with a 5.1% increase in mortality (0.3:10.1) (Rocklov and Forsberg, 2010). In England and Wales, during summer, a 1°C increase in maximum temperature above a heat threshold set as the 93rd percentile of the temperature distribution was associated with a 2.1% increase in all causes of mortality (CI 95% 1.6:2.6). A larger increase was found for respiratory mortality (+4.1% (3.5:4.8)), while cardiovascular mortality was associated with a smaller risk (+1.8% (1.2:2.5)) (Armstrong et al., 2011; Gasparrini et al., 2012). The estimates observed in this work are consistent with such results, with a 1°C increase above 15°C in the mean temperature associated with a 1.5% (CI 95% 0.9:2.1) increase in the total mortality in rural areas, and a 1.6% (0.6:2.5) increase in total mortality in urban areas. The study also found a significant increase in mortality associated with an increase in temperatures above 15°C in Dublin for the total mortality above 74 years (1.4% (0.6:2.2)). In urban areas, no risk was observed for cardiovascular mortality, but a large impact was observed on the respiratory mortality, similarly to what has been observed in the US. Results on respiratory mortality might be explained by an interaction with air pollution.

3.4.3 Changes over time

Although there is no general clear trend, the analysis over the different periods of time tends to show a decrease in the risks, with the larger risks observed before 1987. Similar decreases in the risks have been observed in the UK and the US. A comparison of the weekly mortality in the UK between 1990 and 1996 showed that the temperature mortality gradient for cold deaths and heat deaths diminished over time. Overall, there was a progressive reduction in temperature-related deaths (Carson et al., 2006). Similar results were observed in the US, where daily cardiovascular mortality counts from 107 cities in the US National Morbidity and Mortality Air Pollution Study were regressed against daily temperature using the CXO method between 1987 and 2000 (Barnett, 2007). In summer 1987, the average increase in cardiovascular deaths due to a 10°F increase in temperature was 4.7%. By summer 2000, the risk due to higher temperature had disappeared (–0.4%). In contrast, an increase in temperature in autumn, winter and spring was associated with a decrease in deaths, and this decrease remained constant over time (Barnett, 2007).

However, it may be that the risks observed before 1987 are driven by the 1983 and 1984 heatwaves. Changes in the reporting of the mortality, and in the demographics between urban and rural areas, may also partly explain the observed differences.

3.4.4 Effect of previous winters

The study found that the risks associated with an increase in temperature were significantly larger when the summer had been preceded by a low-mortality winter, especially in rural areas. Similar results were obtained in South Korea (Ha et al., 2011). For instance, in Seoul, a 1°C increase in the summer temperature above 27.9°C was associated with an increase in total mortality of 7.97% (5.5–10.5). The risk estimate was of 10.57% (7.30:13.963) for summers preceded by a low-mortality winter, and of 4.85% (1.54:8.26) for summers

preceded by high-mortality winters. In Italy, the relative risk of mortality comparing days with a temperature of 30°C to days with a temperature of 20°C was 1.73 (1.50:2.01) during summers preceded by a low-mortality winter, and 1.34 (1.17:1.55) during summers preceded by a high-mortality winter (Stafoggia et al., 2009).

3.4.5 Sensitivity analysis – influence of the modelling strategy

In rural areas, the GAM and the CXO models give the same estimates for all causes of mortality considering the whole year. A similar pattern is found when focusing on summer, although CXO results are less significant, probably due to a problem with statistical power. Striking differences are observed, however, for the respiratory mortality, where the GAM found no results and the CXO a significant estimate. Similar results are found in urban areas, with consistent estimates, except in the case of respiratory mortality. However, during summer, the CXO design tends to give higher estimates than the GAM design in urban areas.

4 Projections of Mortality Increase Associated with Temperature Rises Due to Climate Change

4.1 Method for Estimating Future Impacts

Projections of future mortality impacts in the context of climate change were obtained by applying the relative risk to the temperature increase predicted by the climate models.

$$\Delta y = y_0(e^{\beta \Delta T} - 1) \qquad \text{Eqn 4.1}$$

where Δy is the excess mortality associated with the change in temperature ΔT, y_0 is the mortality baseline and β is the exposure response function.

Since the risk was estimated for the temperature increase above 15°C, ΔT is estimated as additional days above 15°C compared with the current climate.

$$\Delta T = \frac{\sum_{i=1}^{N_2} T_i + \delta - 15}{N_2} - \frac{\sum_{i=1}^{N_1} T_i - 15}{N_1} \qquad \text{Eqn 4.2}$$

where δ is the mean daily increase of temperature according to the climate scenarios; δ values of 1, 2 and 3°C were tested. N_2 is the number of days when $T + \delta$ exceeds 15°C and N_1 is the number of days when T exceeds 15°C.

4.2 Projections of Mortality Increase Associated with Temperature Rises Due to Climate Change

Results are presented in Table 4.1. Considering the worst-case scenario, +3°C, the excess mortality associated with such an increase would be 26 extra deaths per summer in rural areas and 32 deaths per summer in urban areas.

4.3 Discussion

These projections rely on strong hypotheses, including no demographic changes and no ageing of the population, no modification of the characteristics of the urban and rural areas, no adaptation of the population, and no evolution of the pool of vulnerable people, which can be influenced by winter mortality. This is conditioned by the choice of a constant baseline and a constant relative risk. These estimates also do not take into account potential heatwave impacts.

A major source of uncertainty is also the crude estimate of the temperature changes.

Table 4.1. Projections of mortality increase associated with temperature rises due to climate change.

Scenarios	Mean number of additional days above 15°C per summer	Average cumulated degrees above 15°C per summer	Number of associated excess deaths per summer
Rural areas			
+1°C	18	47	17 (10:24)
+2°C	37	111	20 (12:28)
+3°C	49	191	26 (15:37)
Urban areas			
+1°C	19	51	19 (8:30)
+2°C	35	119	24 (10:38)
+3°C	45	207	32 (13:51)

5 Impacts of Heatwaves on Mortality

5.1 Definition of Heatwaves

A heatwave can be defined as a period of sustained heat during several consecutive days, with intensity and duration arbitrarily fixed. The definition used in this work was to have at least 2 consecutive days with minimum and maximum temperatures greater than the 90th percentile of the monthly distribution of temperatures. Periods fitting that definition were identified in each station, but due to the low geographical resolution of the mortality data, only episodes occurring simultaneously in several stations were considered. Since the heatwave periods overlap across stations, extended heatwave periods were defined in order to include the first and the last heatwaves observed in the stations.

5.2 Estimation of the Mortality Impact

5.2.1 Estimation of the excess mortality attributable to heat

To estimate the mortality attributable to heat, the daily count of deaths was regressed on temperatures, controlling for long-term trends, seasonality, and day of the week, using a GAM. Minimum and maximum temperatures on several lags up to 7 days were introduced in the models, using penalised spline functions. Final lags and number of degrees of freedom for the different temperature terms were selected by using Akaïke information criteria.

The daily excess mortality was estimated by comparing the predicted with the expected mortality if the temperatures were equal to the average temperatures observed for the summertime between 1980 and 2003.

5.2.2 Estimation of an additional heatwave effect

The method described by Le Tertre et al. (2006) was used to search for a possible additional heatwave effect during the main heatwaves. It consisted of adding into the models a flexible term of time covering a period centred on the heatwave. The daily relative risk of the specific effect of the heatwave was computed as the number of expected deaths estimated by this term divided by the number of expected deaths estimated in the absence of a heatwave. The number of deaths in the absence of the heatwave was predicted using references values for temperature.

All computations were done using the mgcv package of the R software (R Development Core Team, 2004; Wood, 2006).

5.3 Results

Seven heatwaves were included in the analysis – in July 1983, August 1984, June and August 1995, August 2003 and July 2006. Minimum and maximum temperatures during these heatwaves are presented in Table 5.1, and graphs of the mean temperatures per station are presented in Appendix 8.

July 1983 was characterised by a progressive increase of temperatures, with the highest temperatures observed between 10 and 15 July. The 1984 heatwave in rural areas was characterised by a steep increase in temperatures between 18 and 19 August, but with a moderate intensity. In urban areas, a moderate increase in temperature was observed during the same period, mainly driven by the temperatures observed in Shannon. Summer 1995 presented an interesting pattern, comparable in rural and urban areas. A first period of heat was observed between 22 and 30 June, with a rapid increase followed by a rapid decrease of temperatures. Temperatures were consistently above the usual values during July and August, with daily peaks. The highest values were observed between 1 and 4 August. August 2003 was characterised by two short peaks between 5 and 7 August and between 24 and 26 August. In some cases, the increase and the drop in temperature were steep. Temperatures were above threshold values in July 2006, but a clear heatwave pattern was not visible in rural areas, and was of moderate intensity in urban areas.

Table 5.1. Excess mortality estimated during the selected heatwaves.

Heatwave	Areas	Temperatures mean (min:max) (°C)		Excess mortality (CI 95%)			
		T_{min}	T_{max}	Total mortality	Total mortality >74 years	Cardiovascular mortality	Respiratory mortality
5–18 July 1983 14 days	Rural	13.6 (10.4:16.1)	23.5 (18.0:28.1)	115 (96:137)	65 (51:79)	64 (50:79)	19 (12:26)
	Urban	14.5 (10.7:17.5)	23.8 (18.5:28.5)	21 (9:33)	16 (7:24)	0 (0:17)	7 (3:11)
18–31 August 1984 14 days	Rural	13.9 (10.7:16.2)	22.2 (19.6:25.7)	49 (29:68)	37 (24:51)	22 (7:36)	20 (14:26)
	Urban	14.3 (10.9:16.2)	22.1 (20.2:24.3)	9 (–2:21)	17 (9:25)	0 (–6:10)	3 (–1:6)
22–30 June 1995 9 days	Rural	11.4 (7.3:14.0)	24.8 (22.4:27.1)	54 (40:68)	36 (26:47)	22 (13:31)	13 (8:18)
	Urban	12.0 (8.6:14.4)	23.8 (21.3:26.4)	–13 (–21:–5)	–10 (–16:–4)	–5 (–15:–1)	2 (–1:5)
1–22 August 1995 22 days	Rural	13.2 (9.7:16.3)	24.0 (19.4:27.1)	9 (–25:43)	–18 (–43:8)	9 (–14:32)	6 (–5:17)
	Urban	13.5 (9.8:16.8)	24.0 (20.3:26.6)	–10 (–29:9)	–8 (–21:6)	1 (–20:5)	9 (2:15)
4–12 August 2003 9 days	Rural	13.0(9.7:14.8)	23.3 (20.5:27.2)	–45 (–56:–33)	–31 (–40:–21)	–27 (–34:–20)	–10 (–15:–6)
	Urban	13.7 (10.9:15.4)	23.6 (22.2:26.4)	13 (6:19)	3 (–2:8)	2 (0:10)	–1 (–3:2)
22–27 August 2003 6 days	Rural	14.5 (11.6:16.2)	22.0 (19.2:25.2)	–7 (–15:1)	–5 (–18:14)	14 (9:19)	–22 (–25:–19)
	Urban	14.7 (11.4:17.1)	21.1 (18.4:24.4)	10 (5:14)	–2 (–5:2)	0 (–4:2)	5 (3:7)
17–30 July 2006 14 days	Rural	13.5 (11.1:15.2)	23.1 (19.9:28.6)	14 (–7:35)	15 (–2:32)	6 (–6:19)	–9 (–18:–1)
	Urban	14.0 (12.1:16.2)	23.6 (21.0:26.8)	–36 (–48:–24)	–25 (–33:–16)	–17 (–24:11)	–1 (–5:3)

The mortality impacts during these heatwaves are presented in Table 5.1. Overall, a total of 294 excess deaths attributable to heatwaves was estimated, 241 in rural areas and 53 in urban areas. The 1983 and, to a lesser extent, the 1984 heatwaves were characterised by a significant excess mortality, especially in rural areas. The July 1983 episode is the only one presenting a characteristic heatwave pattern, although with moderate intensity.

5.3.1 The July 1983 heatwave

In rural areas, an excess mortality of +115 (CI 95% 96:137) deaths was estimated between 5 and 18 July 1983. Most of the deaths occurred in people older than 74 years: +65 deaths. In urban areas, the estimated excess mortality was 21 (9:33) deaths, the majority occurring in elderly people. In urban areas, no increase was estimated for cardiovascular mortality, and an increase was estimated for respiratory mortality.

In addition to the usual effect of temperature on mortality, a heatwave effect was observed with significant relative risks between 2 and 23 of July (Fig. 5.1). The effect was slightly more pronounced for elderly people. A maximum relative risk of 1.23 (CI 95% 1.13:1.34) was observed on 14 July 1983 for the total mortality. The impact was similar for elderly people. In total 42 excess deaths can be attributed to

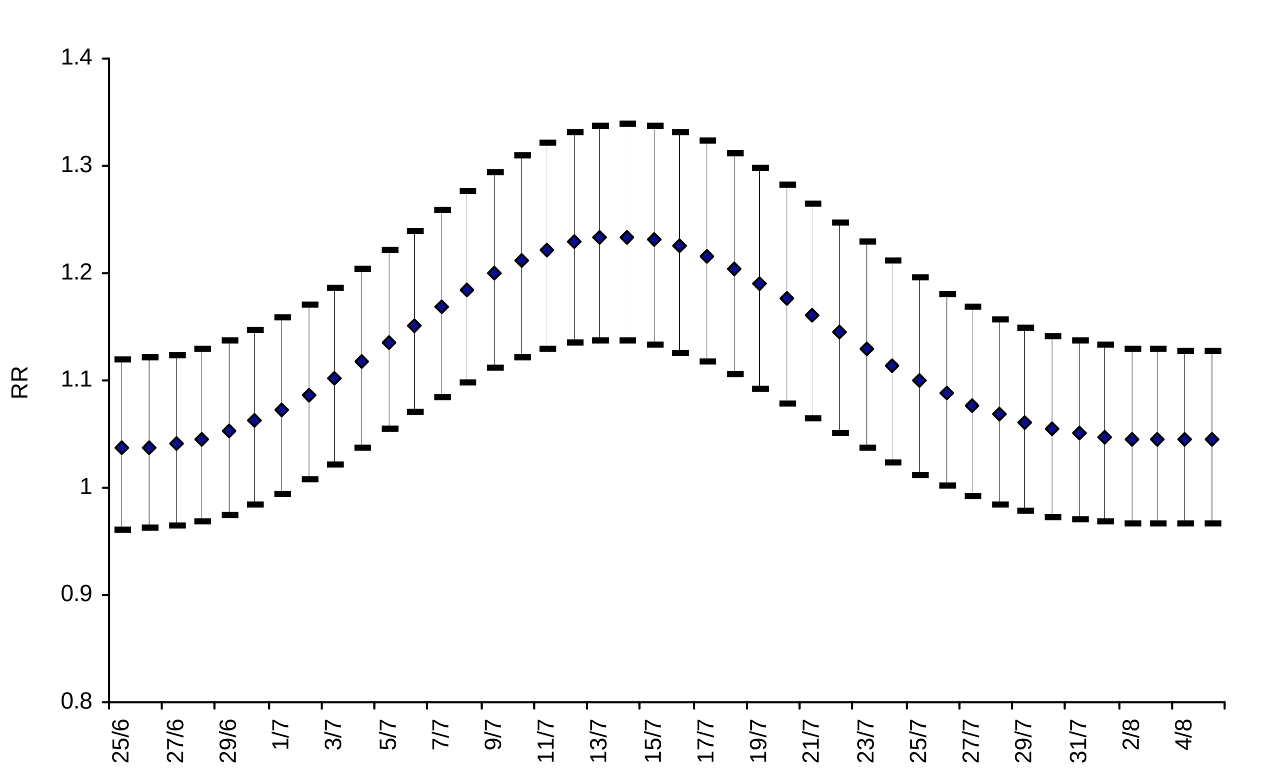


Figure 5.1. Daily relative risk (RR) for total mortality associated with a heatwave effect during the 1983 heatwave in rural areas.

this specific heatwave effect between 12 and 18 July 1983.

5.3.2 The August 1984 heatwave

An excess mortality of 49 (29:68) deaths between 18 and 31 August 1984 was observed for rural areas. The majority concerned people older than 74 (37 extra deaths). In urban areas, an excess mortality was observed in elderly people only (+7 deaths). In urban areas, no increase was observed for cardiovascular or respiratory mortality. The overall excess mortality was of +15% in rural areas. In urban areas, there was small increased mortality between 18 and 25 August 1984, followed by a deficit in mortality associated with a decline in minimum temperatures. The overall excess mortality was +9% in rural areas.

5.3.3 The 1995 heatwaves

An excess mortality of 54 (40:68) deaths was observed between 22 and 30 June 1995 in rural areas, corresponding to a 11% increase. The majority concerned people older than 74 (36 extra deaths). In urban areas, a deficit in mortality was observed for both total mortality, and for mortality in the elderly age groups (–10 deaths). No excess mortality was observed in rural or urban areas between 1 and 22 August 1995, a slight increase being observed for respiratory mortality in urban areas only.

5.3.4 The 2003 heatwaves

In 2003, deficit mortality was observed during the first heatwave in rural areas for all age groups and all causes (Fig. 5.2). In urban areas, a small increase was observed in the total mortality (+10%), mainly driven by an increase in respiratory mortality (+42%). During the second episode, a similar increase was observed for total mortality, but not for respiratory mortality (Fig. 5.3).

5.3.5 The 2006 heatwave

In contrast, during the 2006 episode, deficit mortality was observed in urban areas for all causes of mortality, and the increase in rural areas was small (+14 excess deaths, corresponding to +2%).

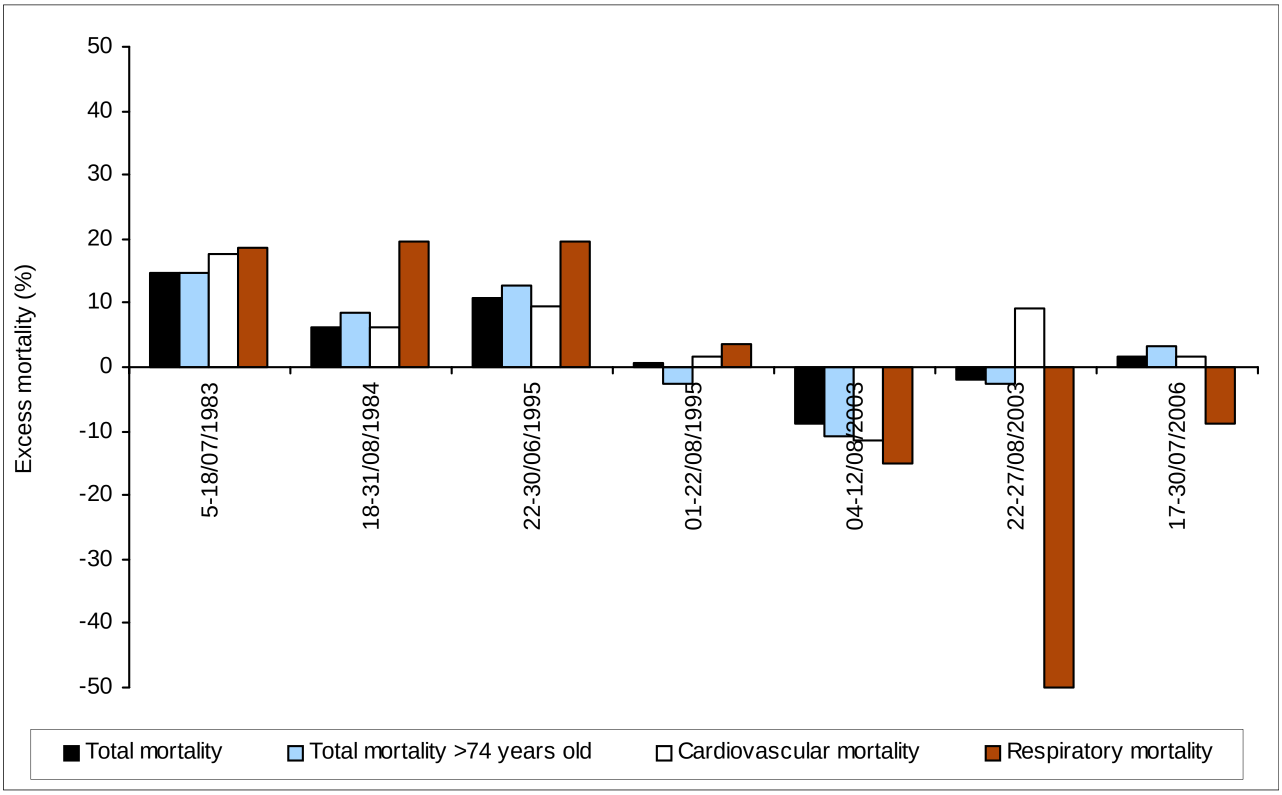


Figure 5.2. Excess mortality (%) associated with heatwaves in rural areas.

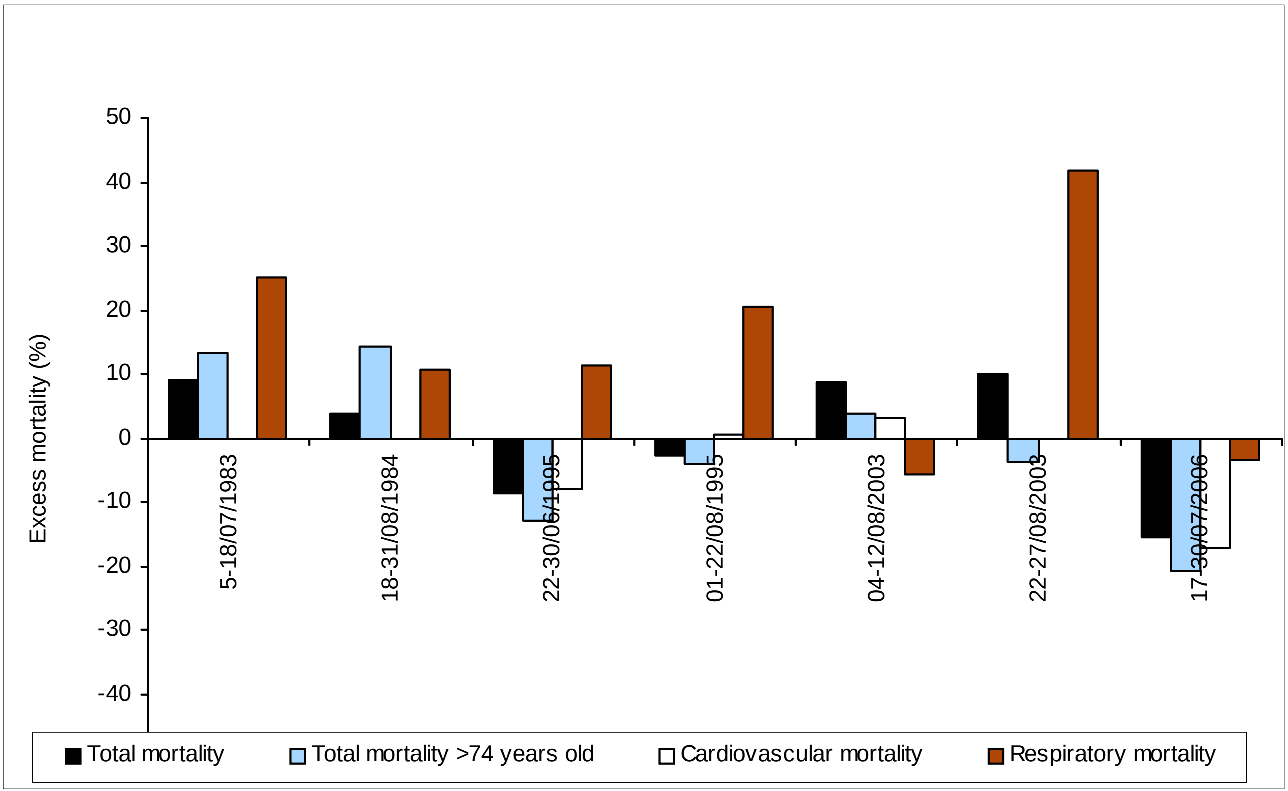


Figure 5.3. Excess mortality (%) associated with heatwaves in urban areas.

5.4 Discussion

This study experienced the same limits discussed earlier, the first one being the large geographical scale used to perform the analysis.

The study quantified the mortality impacts of heatwaves, without investigating a possible morbidity impact. However, the literature suggests that mortality is the main indicator in most heatwaves, especially when the heat-related risks are unknown, so that people cannot identify the symptoms that should alert them to seek medical assistance.

Overall, this study provides an indication that past heatwaves have resulted in a moderate excess mortality, especially in 1983 and 1984. The differences observed between rural and urban areas, though more pronounced in the most recent years, may be due to biases and limits of the design, or may be explained by real differences in the vulnerability to heat. Urban areas are affected by the urban heat island, which increases the heat stress within the city centres. They may also concentrate the most vulnerable people at risk during a heatwave, e.g. the elderly, people with chronic illnesses, or physically impaired, and infants. A low socio-economic status is also a risk factor (homeless people, people with low income, or people socially isolated). Rural areas are not affected by the urban heat island, but small towns may also concentrate elderly people living alone. Occupational exposure is also a concern during heatwaves – either environmental (people working outdoors) or workplace exposure (indoors, for instance near ovens). Heat increases physical strain and can lead to inattentiveness, potentially leading to an increase in work accidents. Farming and outdoor work may partly explain the increased mortality observed in rural areas.

6 Opportunities for Adaptation

This study found that although the impacts of heat are limited in Ireland, future more severe heatwaves may result in a significant excess mortality. From the perspective of climate change, associated with the ageing of the population, it may be that more severe heat episodes will result in a larger mortality burden. The Irish Environmental Protection Agency (EPA) has a high confidence that the heatwave frequency heat wave will increase in future years (EPA, 2009). Moreover, the number of people in the over-74 age group is expected to increase to between 273,289 and 284,413 in 2021, compared with 190,398 recorded in the 2002 census. It is also expected that more than 20% of people older than 65 years will be living in Dublin City and County (National Council on Ageing and Older People, 2009). The ageing of the population and the changing climate may increase Ireland's vulnerability to extreme heat.

Based on the existing literature, two main axes of adaptation can be identified:

1. One is a long-term adaptation, focusing on housing and the reduction of the urban heat island, which are the main risk factors of mortality and morbidity during heatwaves. These are not discussed here.

2. The second is a short-term adaptation, based on heat prevention plans that are being developed in an increasing number of countries and cities, to anticipate the effects of adverse heatwaves. Indeed, during a heatwave, most of the preventative measures are simple: to rest, to protect oneself from the sun and the heat, and to drink and eat regularly. However, in the absence of a responsible organisation, these measures were found not to be easily implemented, especially for the most vulnerable people.

6.1 Opportunities for Developing a Heat Prevention Plan

Although few heatwaves have been identified in Ireland in the historical analysis with moderate impacts on mortality compared with what has been observed elsewhere, one cannot exclude the possibility of more severe impacts arising from a sustained and intense heatwave. The perspective of facing more and more intense heatwaves, together with potential increasing vulnerabilities (urban densities, ageing, and poverty), calls for dedicating some efforts to preventing the adverse effects of heatwaves.

Measures involved in heat prevention should be proportionate to the risks expected in Ireland. Communication to promote appropriate behaviours in the population and among health professionals may be a first and essential step to limit the adverse impacts of heatwaves. Good communication practices during extreme heat have been reviewed by Health Canada (2011) to guide the development of targeted heat-health communication campaigns. They included special consideration for the residents of rural and small town communities, which would form a good ground for communication in Ireland. Additional actions, including identification of the most vulnerable populations, at-home visits, etc., may be implemented in co-operation with non-governmental organisations (NGOs). Such actions could be targeted at the most vulnerable populations (O'Neill et al., 2009), similar to the initiatives taken in California (California Department of Public Health, 2011) or in Canada (Vescovi et al., 2005). There, a geographical information system (GIS) is used to map the number of people older than 65, the number of those below the poverty threshold, the number of people living alone, and the number of people with poor education.

6.2 Basics of Heatwave Warning Systems

The heat prevention and action plans usually rely on warning systems, commonly labelled heat-health warning systems (HHWSs). These systems have been designed to anticipate heatwaves that present a risk to the population and to provide timely information to ensure an efficient and co-ordinated response. Timely warning is needed to ensure rapid responses from the population and the authorities. The warning system

must therefore be simple, easy to understand and communicate, and avoid false warnings as far as possible.

Hajat et al. (2010) proposed the classification of the main types of warning systems into four categories:

1. A synoptic system, which takes into account that health may be affected by a number of weather factors acting in combination. Adverse meteorological conditions are assessed using air-mass categories. Epidemiological analysis of historical mortality data is used to model the mortality relationship within each category (e.g. in the US and Shanghai (Tan et al., 2004)).

2. Temperature systems, which are based on models of the direct relationship between temperature and mortality. Thresholds are then chosen based on temperature values that have an acceptable combination of sensitivity and specificity in terms of identifying high mortality days (e.g. in France (Pascal et al., 2006)).

3. An indices system that encompasses the spectrum of indices that are composite measures of temperature and humidity, including AT or humidex (humidity index) (e.g. Canada).

4. A system based on physiological principles of heat budget models of the human body, for instance the Environmental Stress Index (ESI), which is based on commonly used and easily measured weather variables, and which was developed and tested under hot-humid and hot-dry climates. It has been found to be highly correlated with the Wet Bulb and Globe Temperature (WGBT), which is a physiologically based heat metric widely used in occupational health settings.

In Ireland, the purpose of a heat warning system would be to identify heatwave episodes that could result in increased mortality and morbidity. It would alert relevant stakeholders, who in turn could promote preventative actions and disseminate appropriate information. A key to the success of a warning system is a limited number of false warnings – it is important to use indicators that can be forecasted with the highest possible confidence. Therefore, a system based on temperature seems preferable to one based on indices involving humidity, since meteorological services have a higher confidence in temperature forecast up to several days in advance.

The basic premise of a temperature-based system is to find a meteorological indicator associated with a meteorological threshold, i.e. to be able to separate the days when mortality is above an acceptable level from those when it is below that level. The cut-offs have to be in accordance with the objectives of the organisations in charge of the plan. Different temperatures can be used, minimum, mean, maximum, or a combination of these. For instance, in Melbourne (Nicholls et al., 2008), the system relies on the mean daily temperature for a single day, while in France the system relies on the minimum and maximum temperatures averaged over 3 days (Pascal et al., 2006).

In Ireland, as heat exposure is mostly daytime exposure (temperatures being moderate at night, even during past heatwaves), the maximum temperature seems to be a good indicator. It is routinely forecasted by the meteorological services, and is easily understood by the general population.

One way to determine the thresholds is to regress the daily count of deaths, on the temperature indicator, controlling for long-term trends, seasonality, and day of the week, using a GAM. This model is then used to compute the excess mortality predicted for each value of the temperature indicator. Figure 6.1 presents the excess mortality associated with maximum temperature urban and rural mortality, obtained from the following equation using data between 1980 and 2003:

Total mortality =

$$\text{s (time) + day of the week + s } (T_{max} \text{ lag 0}) \quad \text{Eqn 6.1}$$

Excess mortality is predicted for temperatures corresponding to the 50–100 percentiles of the mean temperature distribution. The indicator T_{max} averaged over 3 days was also tested, but did not provide any added value compared with the indicator T_{max} alone.

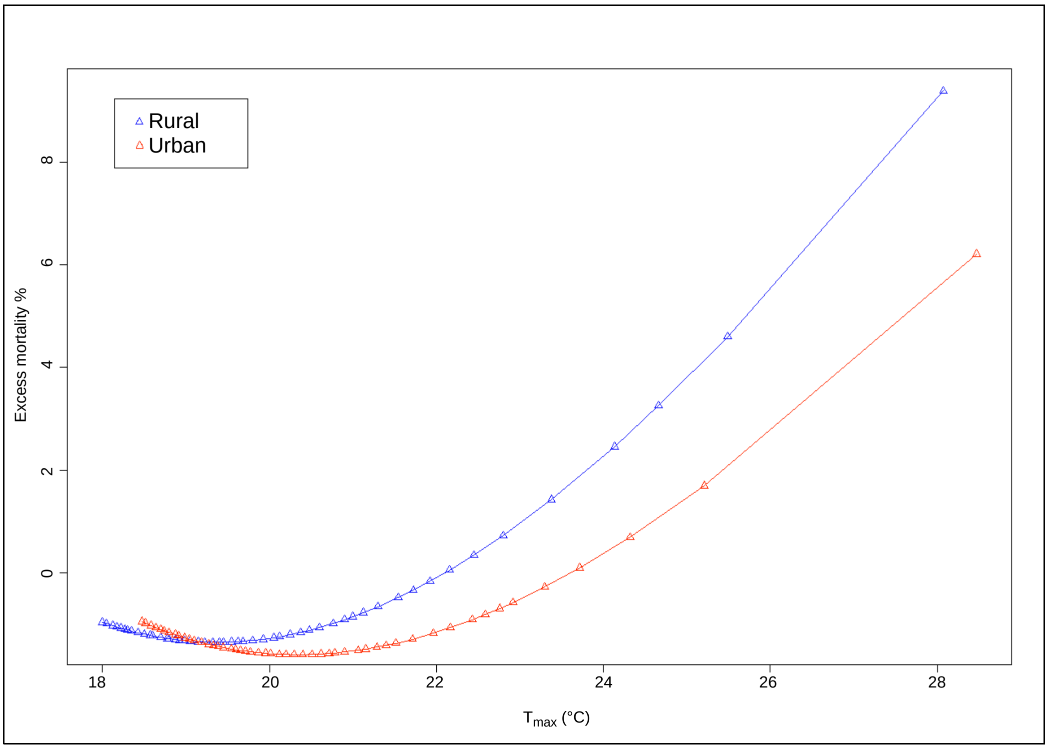


Figure 6.1. Excess mortality associated with the maximum temperature.

For instance, a 25°C maximum temperature threshold may prevent an excess mortality above 2% in both urban and rural areas, and occurs on a moderate number of warning days. Applied to the study period, it would have resulted in 45 warnings in rural areas and 30 in urban areas. The thresholds would have anticipated the July 1983 episode (first warning on 8 July 1983), summer 1995 episodes (first warning on 1 August 1995), the August 2003 episodes (first warning on 5 August 2003) and the July 2006 episode (first warning on 17 July 2006).

7 Conclusions

This work has demonstrated that mortality in Ireland shows a classical relationship with temperature, with increased mortality at both high and low temperatures, consistent with the classic U shape relationship described in the literature. The optimum temperature is approximately 14°C. This work shows that both hot and cold temperatures have an impact on mortality in Ireland. Winter mortality remains higher than summer mortality, and cold-related mortality will still be of greater concern than heat-related mortality in the short term, the next 10–15 years.

The work has also shown that when the mean temperature rises above 15°C more people start to die.

The authors found that hot temperatures have a greater effect on rural communities. However, the role of a warm temperature might be exacerbated in urban areas because of the creation of an urban heat island. Conclusions are subject to caution because of data quality concerns, the most important one being the inability to localise deaths in rural areas.

The authors found that there were seven heatwaves during the study period, and that these were associated with approximately 290 excess deaths.

8 Recommendations

Past heatwaves had a significant impact on mortality. Developing and putting in place the capacity to relay timely warning messages would be useful in the case of future heatwaves. An analysis of the impact of the 2006 heatwave would provide valuable information. Investigating the intensity and shape of the urban heat island in Dublin would be useful in understanding the vulnerability to heatwaves.

However, the excess winter-related mortality remains a significant problem in Ireland and this is not likely to decrease because of climate change. The authors recommend that efforts continue to warn people of expected cold winter weather, and to offer appropriate advice on what measures to take to stay warm. This should also be done in conjunction with a policy of improving the energy efficiency of the housing stock.

Finally, this work has been limited by the spatial resolution of the mortality data. With a significant proportion of the population living in rural areas, it would be helpful to have access to better coding of the location of deaths, in order to refine the characterisation of exposure.

References

Almon, S., 1965. The Distributed lag between capital appropriations and net expenditures. *Econometrica* **33:** 178–196.

Argaud, L., Ferry, T., Le, Q.H., Marfisi, A., Ciorba, D., Achache, P., Ducluzeau, R. and Robert, D., 2007. Short- and long-term outcomes of heatstroke following the 2003 heat wave in Lyon, France. *Archives of Internal Medicine* **167(20):** 2177–2183.

Armstrong, B.G., Chalabi, Z., Fenn, B., Hajat, S., Kovats, S., Milojevic, A. and Wilkinson, P., 2011. Association of mortality with high temperatures in a temperate climate: England and Wales. *Journal of Epidemiology and Community Health* **65(4):** 340–345.

Barnett, A.G., 2007. Temperature and cardiovascular deaths in the US elderly: changes over time. *Epidemiology* **18(3):** 369–372.

Basu, R., 2009. High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008 *Journal of Environmental Health* **8:** 40.

Batscha, C.L., 1997. Heat stroke. Keeping your clients cool in the summer. *Journal of Psychosocial Nursing and Mental Health Services* **35(7):** 12–17.

Bouchama, A., Dehbi, M., Mohamed, G., Matthies, F., Shoukri, M. and Menne, B., 2007. Prognostic factors in heat wave related deaths: a meta-analysis. *Archives of Internal Medicine* **167(20):** 2170–2176.

California Department of Public Health, 2011. *Public Health Impacts of Climate Change in California: Community Vulnerability Assessments and Adaptation Strategies*. California Department of Public Health, Sacramento, CA, USA. pp. 1–49.

Carson, C., Hajat, S., Armstrong, B. and Wilkinson, P., 2006. Declining vulnerability to temperature-related mortality in London over the 20th century. *American Journal of Epidemiology* **164(1):** 77–78.

Dockery, D., Rich, D., Goodman, P., Clancy, G., Ohman-Strickland, P., George, P. and Kotlov, T., 2010. *Effect of Air Pollution Control on Mortality and Hospital Admissions in Ireland*. Health Effects Institute, Health Effects Institute Annual Conference, Alexandria, VA, USA.

Donaldson, G.C. and Keatinge, W.R., 1997. Early increases in ischaemic heart disease mortality dissociated from and later changes associated with respiratory mortality after cold weather in south east England. *Journal of Epidemiology and Community Health* **51(6):** 643–648.

EPA, 2009. *A Summary of the State of Knowledge on Climate Change Impacts for Ireland.* Environmental Protection Agency, Johnstown Castle Estate, Wexford, Ireland.

Gasparrini, A., Armstrong, B., Kovats, S. and Wilkinson, P., 2012. The effect of high temperatures on cause-specific mortality in England and Wales. *Occupational and Environmental Medicine* **69(1):** 56–61.

Goodman, P.G., 1999. *Particulate Air Pollution and Mortality in Dublin 1980–1996*. PhD Thesis. University of Dublin, Dublin, Ireland.

Goodman, P.G., Dockery, D.W. and Clancy, L., 2004. Cause-specific mortality and the extended effects of particulate pollution and temperature exposure. *Environmental Health Perspectives* **112(2):** 179–185.

Greenberg, J.H., Bromberg, J., Reed, C.M., Gustafson, T.L. and Beauchamp, R.A., 1983. The epidemiology of heat-related deaths, Texas – 1950, 1970–79, and 1980. *American Journal of Public Health* **73(7):** 805–807.

Ha, J., Kim, H. and Hajat, S., 2011. Effect of previous-winter mortality on the association between summer temperature and mortality in South Korea. *Environmental Health Perspectives* **119(4):** 542–546.

Haines, A., McMichael, A.J., Smith, K.R., Roberts, I., Woodcock, J., Markandya, A., Armstrong, B.G., Campbell-Lendrum, D., Dangour, A.D., Davies, M., Bruce, N., Tonne, C., Barrett, M. and Wilkinson, P., 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. *Lancet* **374:** 2104–2114.

Hajat, S. and Kosatky, T., 2010. Heat-related mortality: a review and exploration of heterogeneity. *Journal of Epidemiology and Community Health* **64(9):** 753–760.

Hajat, S., Sheridan, S.C., Allen, M.J., Pascal, M., Laaidi, K., Yagouti, A., Bickis, U., Tobias, A., Bourque, D., Armstrong, B.G. and Kosatsky, T., 2010. Which days of hot weather are identified as dangerous by Heat-Health Warning Systems? A comparison of the predictive capacity of different approaches. *American Journal of Public Health* **100(6):** 1137–1144.

Hastie, T.J. and Tibshirani, R.J., 1990. *Generalized Additive Models*. Routledge, Chapman & Hall, New York, USA.

Healy, J.D., 2003. Excess winter mortality in Europe: a cross country analysis identifying key risk factors. *Journal of Epidemiology and Community Health* **57(10):** 784–789.

Health Canada, 2011. *Communicating the Health Risks*

of Extreme Heat Events: Toolkit for Public Health Officials and Emergency Management Officials. Health Canada, Ottawa, Ontario, Canada. pp. 1–60.

Institut de Veille Sanitaire, 2004. *Étude des facteurs de risque de décès des personnes âgées résidant à domicile durant la vague de chaleur d'août 2003*. Institut de Veille Sanitaire, Saint-Maurice, France.

IPCC (Intergovernmental Panel on Climate Change), 1995. *Climate Change: a Glossary by the Intergovernmental Panel on Climate Change*. IPCC, Geneva, Switzerland.

IPCC (Intergovernmental Panel on Climate Change), 2007. *Rapport du Groupe de travail I du Groupe d'experts intergouvernemental sur l'évolution du climat*. IPCC, Geneva, Switzerland. pp. 2–18.

Janes, H., Sheppard, L. and Lumley, T., 2005. Case-crossover analyses of air pollution exposure data: referent selection strategies and their implications for bias. *Epidemiology* **16(6):** 717–726.

Kunst, A.E., Looman, C.W. and Mackenbach, J.P., 1993. Outdoor air temperature and mortality in The Netherlands: a time-series analysis. *American Journal of Epidemiology* **137(3):** 331–341.

Le Tertre, A., Lefranc, A., Eilstein, D., Declercq, C., Medina, S., Blanchard, M., Chardon, B., Fabres, P., Filleul, L., Jusot, J.F., Pascal, L., Prouvost, H., Cassadou, S. and Ledrans, M., 2006. Impact of the 2003 heatwave on all-cause mortality in 9 French cities. *Epidemiology* **17(1):** 75–79.

Maclure, M., 1991. The case-crossover design: a method for studying transient effects on the risk of acute events. *American Journal of Epidemiology* **133(2):** 144–153.

Mourtzoukou, E.G. and Falagas, M.E., 2007. Exposure to cold and respiratory tract infections. *International Journal of Tuberculosis and Lung Disease* **11(9):** 938–943.

National Council on Ageing and Older People, 2009. *Population Ageing in Ireland – Projections 2002–2021*. National Council on Ageing and Older People, Dublin, Ireland.

Naughton, M.P., Henderson, A., Mirabelli, M.C., Kaiser, R., Wilhelm, J.L., Kieszak, S.M., Rubin, C.H. and McGeehin, M.A., 2002. Heat-related mortality during a 1999 heat wave in Chicago. *American Journal of Preventive Medicine* **22(4):** 221–227.

Nicholls, N., Skinner, C., Loughnan, M. and Tapper, N., 2008. A simple heat alert system for Melbourne, Australia. *International Journal of Biometeorology* **52(5):** 375–384.

O'Neill, M.S., Carter, R., Kish, J.K., Gronlund, C.J., White-Newsome, J.L., Manarolla, X., Zanobetti, A. and Schwartz, J.D., 2009. Preventing heat-related morbidity and mortality: new approaches in a changing climate. *Maturitas* **64(2):** 98–103.

Pascal, M., Laaidi, K., Ledrans, M., Baffert, E., Caserio-Schonemann, C., Le Tertre, A., Manach, J., Medina, S., Rudant, J. and Empereur-Bissonnet, P., 2006. France's heat health watch warning system. *International Journal of Biometeorology* **50(3):** 144–153.

R Development Core Team, 2004. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Rocklov, J. and Forsberg, B., 2010. The effect of high ambient temperature on the elderly population in three regions of Sweden. *International Journal of Environmental Research and Public Health* **7(6):** 2607–2619.

Rocklov, J., Forsberg, B. and Meister, K., 2009. Winter mortality modifies the heat-mortality association the following summer. *European Respiratory Journal* **33(2):** 245–251.

Schwartz, J., 2000. The distributed lag between air pollution and daily deaths. *Epidemiology* **11(3):** 320–326.

Solomon, S.D., Quin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L., 2007. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. pp. 1–996.

Stafoggia, M., Forastiere, F., Michelozzi, P. and Perucci, C.A., 2009. Summer temperature-related mortality: effect modification by previous winter mortality. *Epidemiology* **20(4):** 575–583.

Steadman, R., 1984. A universal scale of apparent temperature. *Journal of Applied Meteorology* **23(12):** 1674–1687.

Tan, J., Kalkstein, L.S., Huang, J., Lin, S., Yin, H. and Shao, D., 2004. An operational heat/health warning system in Shanghai. *International Journal of Biometeorology* **48(3):** 157–162.

The Eurowinter Group, 1997. Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe. *Lancet* **349(9062):** 1341–1346.

Vescovi, L., Rebetez, M. and Rong, F., 2005. Assessing public health risk due to extremely high temperature events: climate and social parameters. *Climate Research* **30(1):** 71–78.

Wood, S.N., 2006. *Generalized Additive Models: An Introduction with R*. Chapman & Hall/CRC.

Zanobetti, A., Wand, M.P., Schwartz, J. and Ryan, L.M., 2000. Generalized additive distributed lag models: quantifying mortality displacement. *Biostatistics* **1(3):** 279–292.

Acronyms

AR4	Fourth Assessment Report
AT	Apparent temperature
CI	Confidence Interval.
CSO	Central Statistics Office
CXO	Case-crossover
EPA	Environmental Protection Agency
ESI	Environmental Stress Index
GAM	Generalised additive model
GIS	Geographical information system
HHWS	Heat-health warning system
ICD-9	International Classification of Diseases, Ninth Revision
IPCC	Intergovernmental Panel on Climate Change
mgcv	Mixed GAM Computation Vehicle
NGO	Non-governmental organisation
RR	Relative risk
WGBT	Wet Bulb and Globe Temperature

Appendix 1 Correlations Observed between Stations during Summer

Table A1.1. Correlation T_{mean} during summer (R^2).

Rural stations	Belmullet	Birr	Clones	Kilkenny	Mullingar	Valentia
Belmullet	1					
Birr	0.8088	1				
Clones	0.8206	0.9157	1			
Kilkenny	0.7378	0.9249	0.853	1		
Mullingar	0.806	0.9602	0.9469	0.9107	1	
Valentia	0.8279	0.827	0.7804	0.7901	0.8022	1

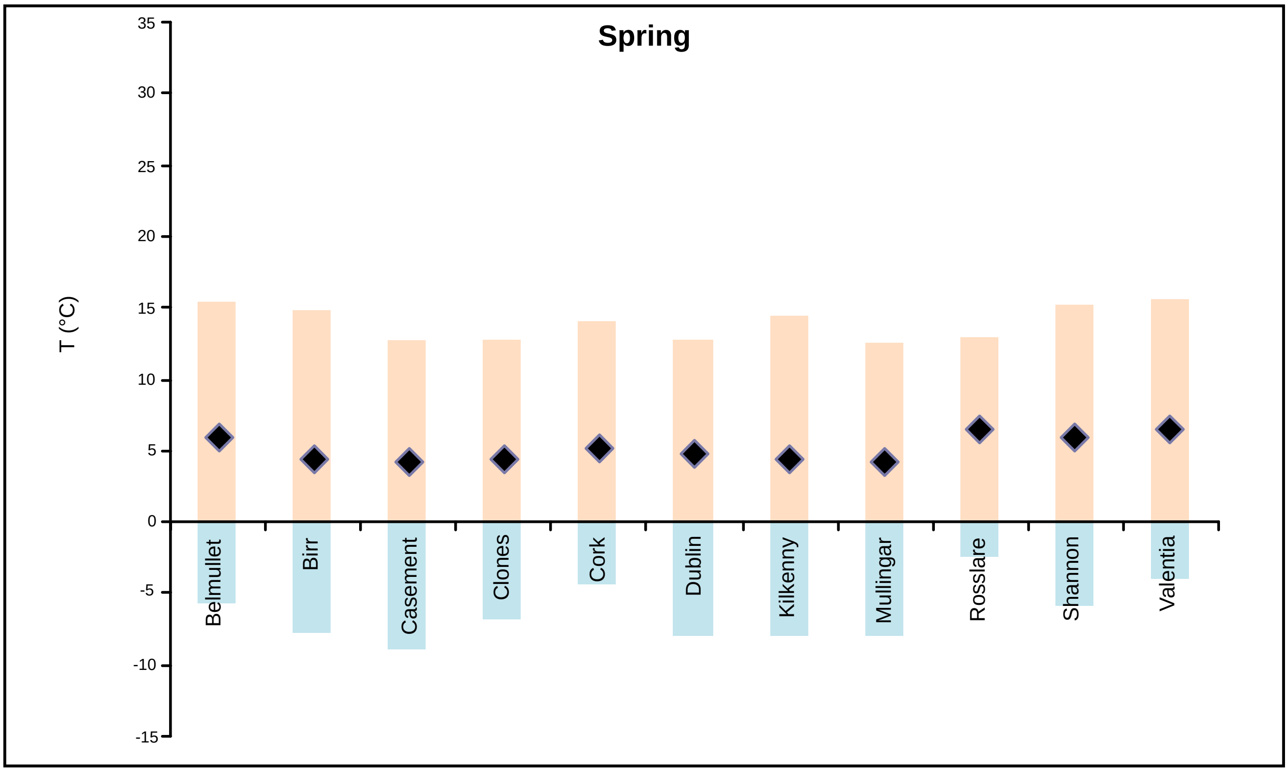
Urban stations	Casement	Cork	Dublin	Rosslare	Shannon
Casement	1				
Cork	0.8058	1			
Dublin	0.9554	0.7928	1		
Rosslare	0.833	0.8523	0.8279	1	
Shannon	0.8469	0.8795	0.8169	0.7769	1

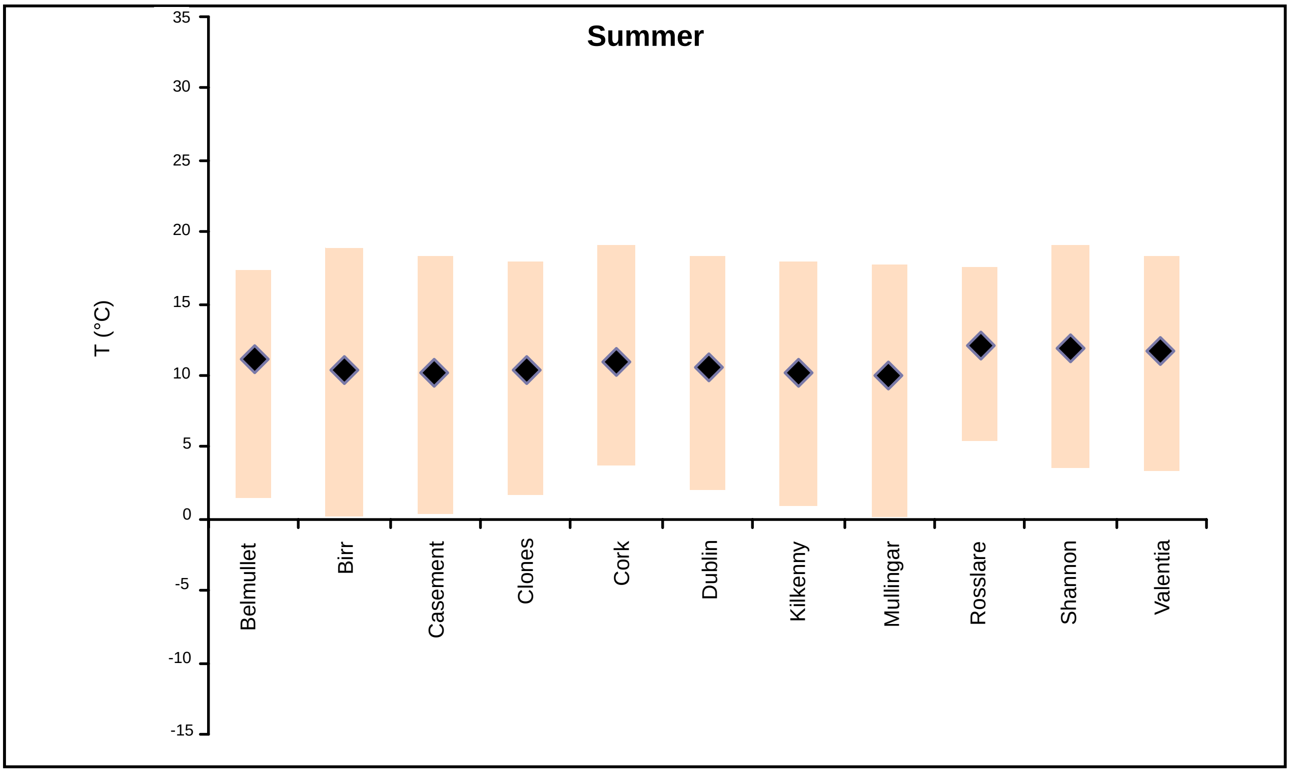
Table A1.2. Correlation relative humidity during summer (R^2).

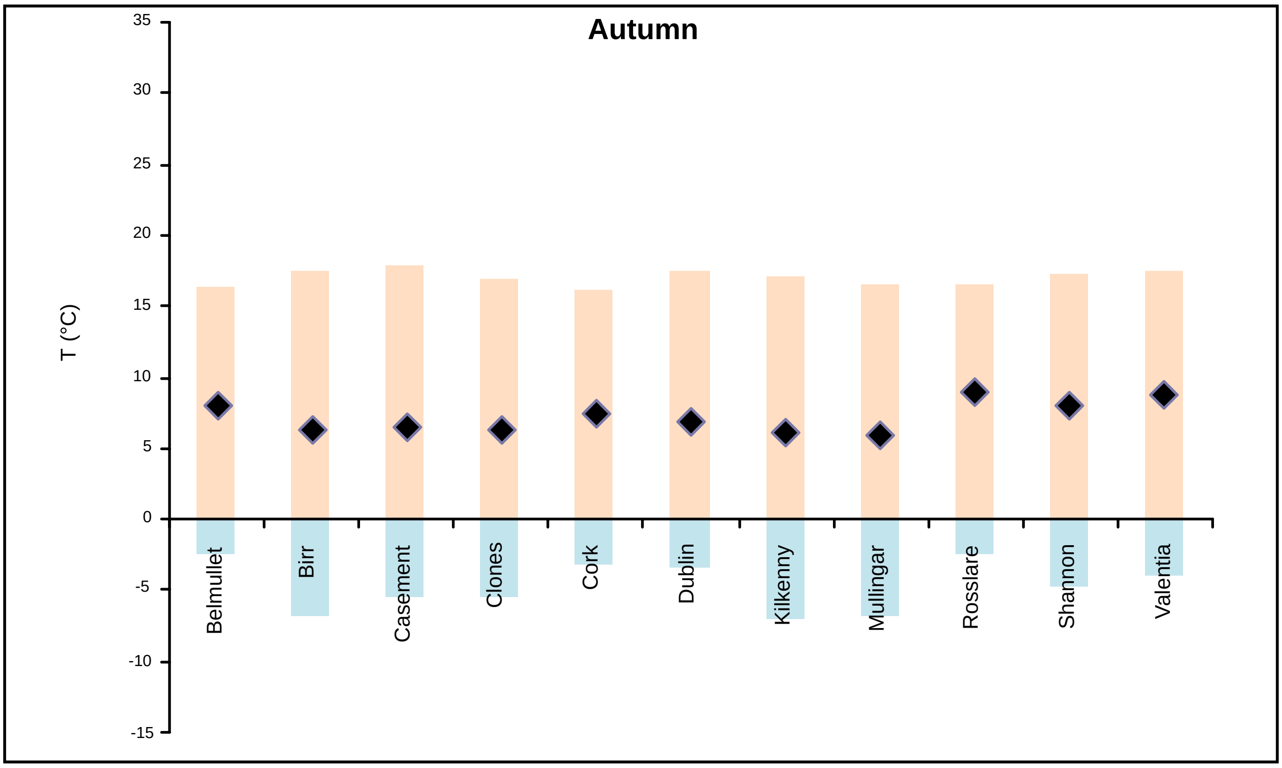
Rural stations	Belmullet	Birr	Clones	Kilkenny	Mullingar	Valentia
Belmullet	1					
Birr	0.549	1				
Clones	0.624	0.7697	1			
Kilkenny	0.4851	0.8487	0.6631	1		
Mullingar	0.5855	0.8958	0.8676	0.7896	1	
Valentia	0.7	0.6173	0.5382	0.6133	0.5915	1

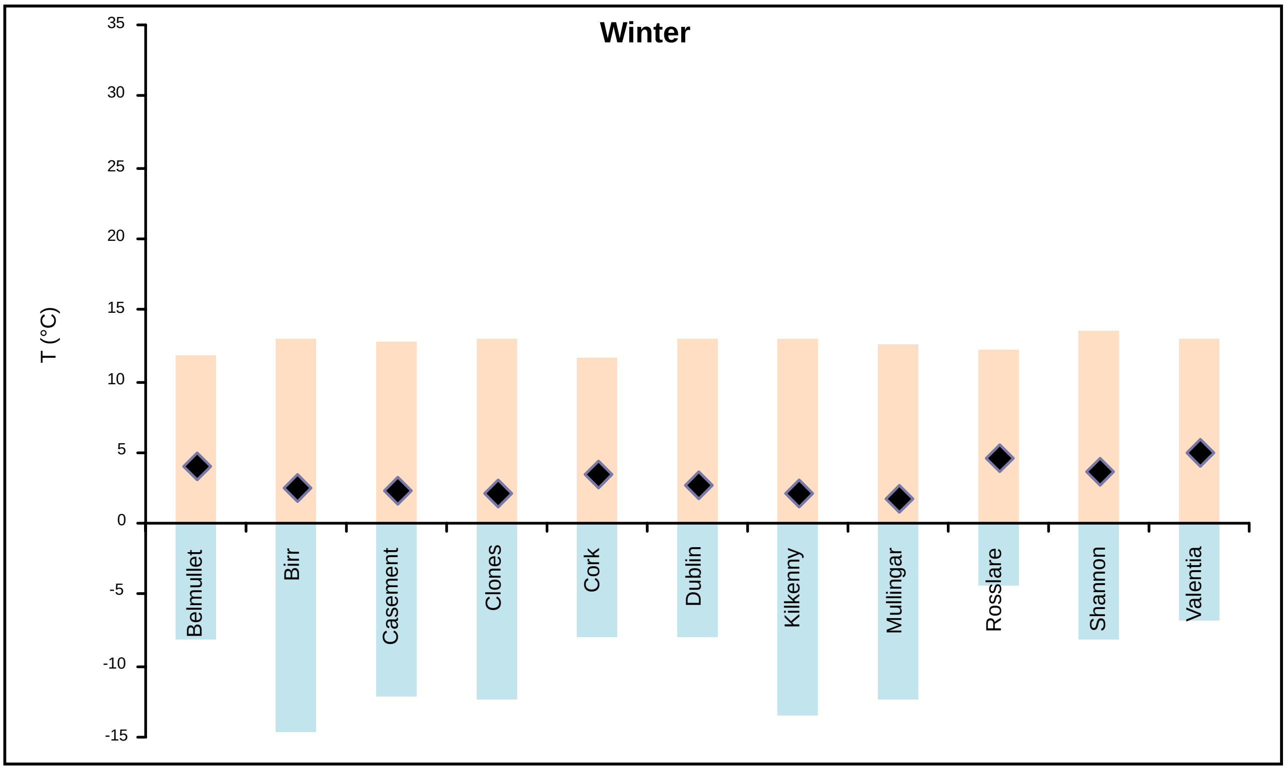
Urban stations	Casement	Cork	Dublin	Rosslare	Shannon
Casement	1				
Cork	0.4297	1			
Dublin	0.7964	0.4933	1		
Rosslare	0.4631	0.744	0.5722	1	
Shannon	0.6201	0.7245	0.5735	0.5807	1

Appendix 2 Ranges of Minimum Temperature per Station and Season

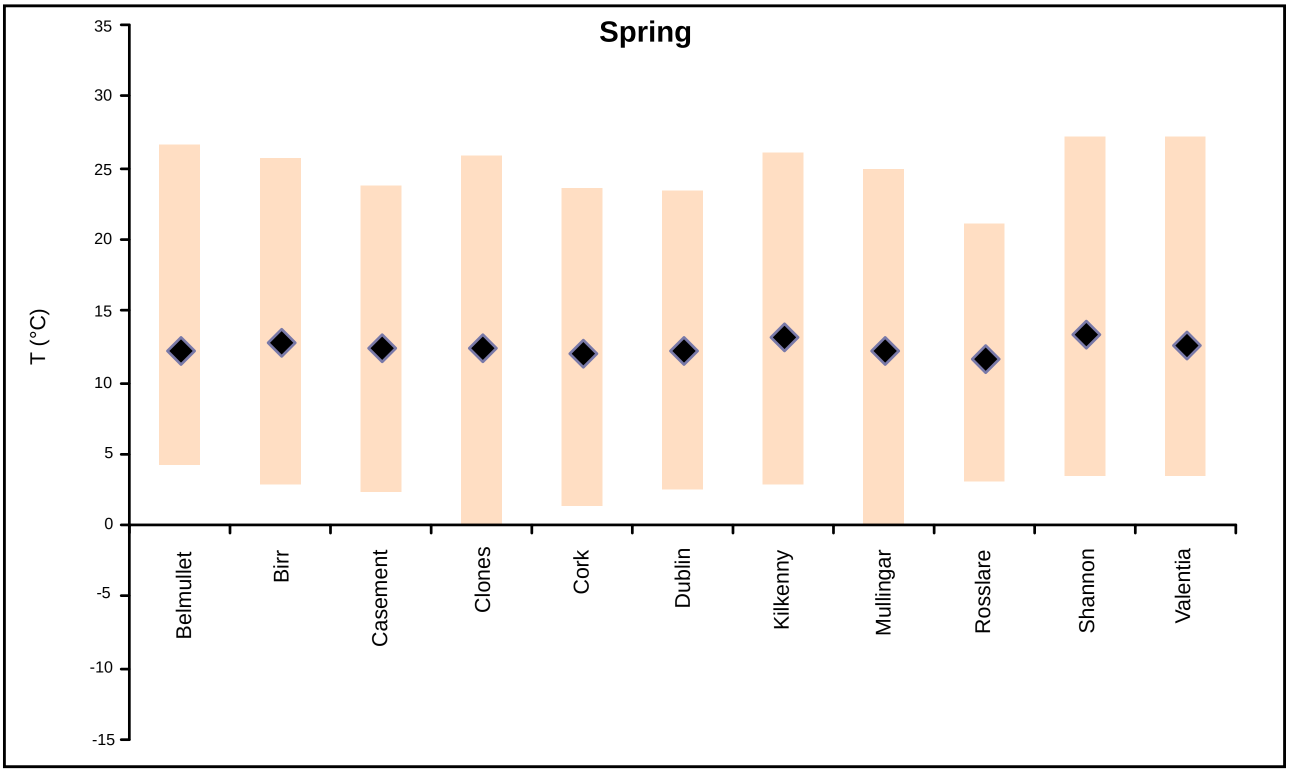


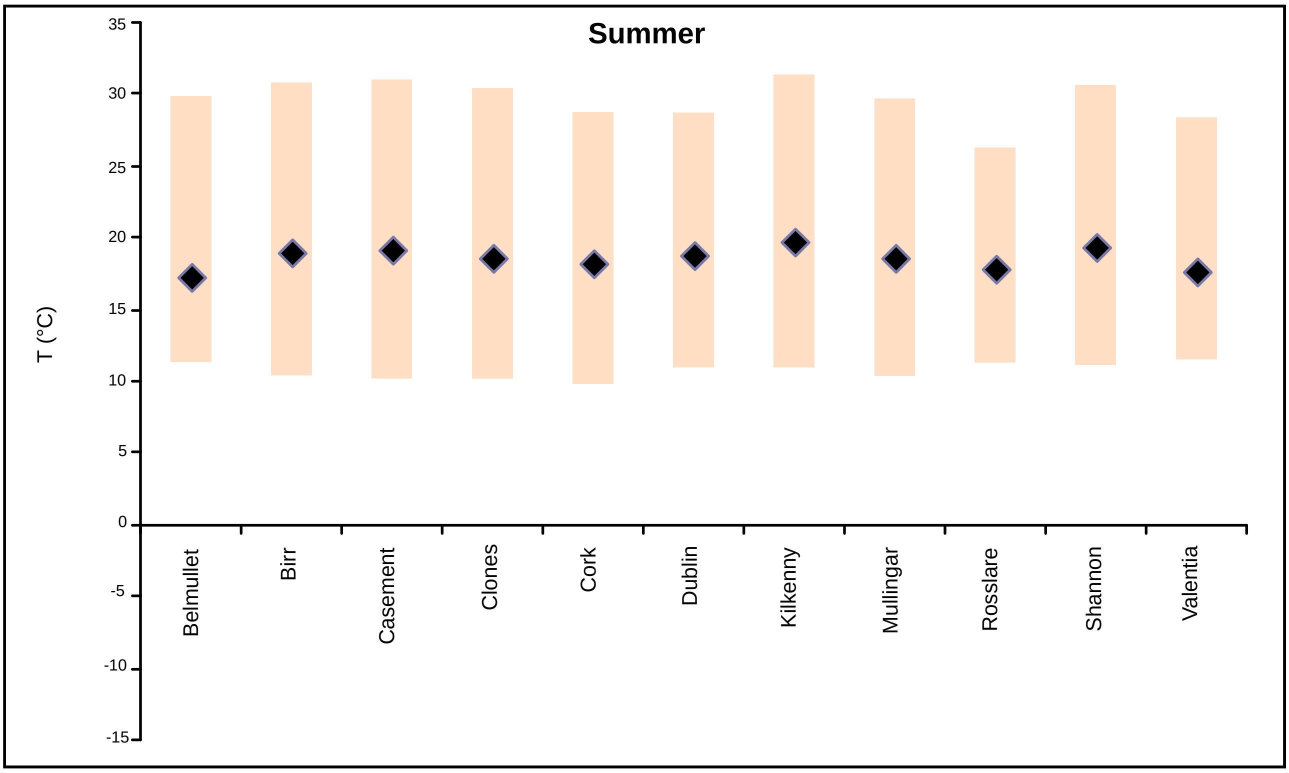


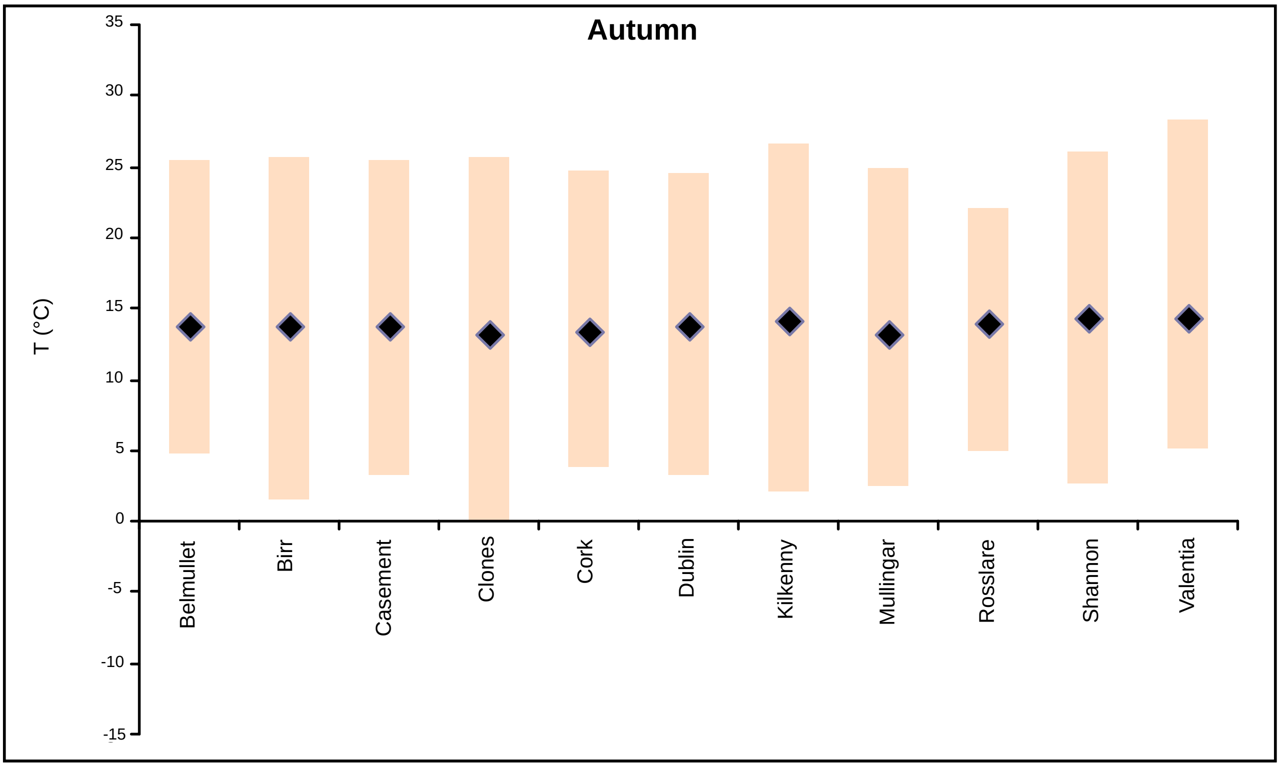

Autumn
T (°C)
35
30
25
20
15
10
5
0
-5
-10
-15
Belmullet
Birr
Casement
Clones
Cork
Dublin
Kilkenny
Mullingar
Rosslare
Shannon
Valentia

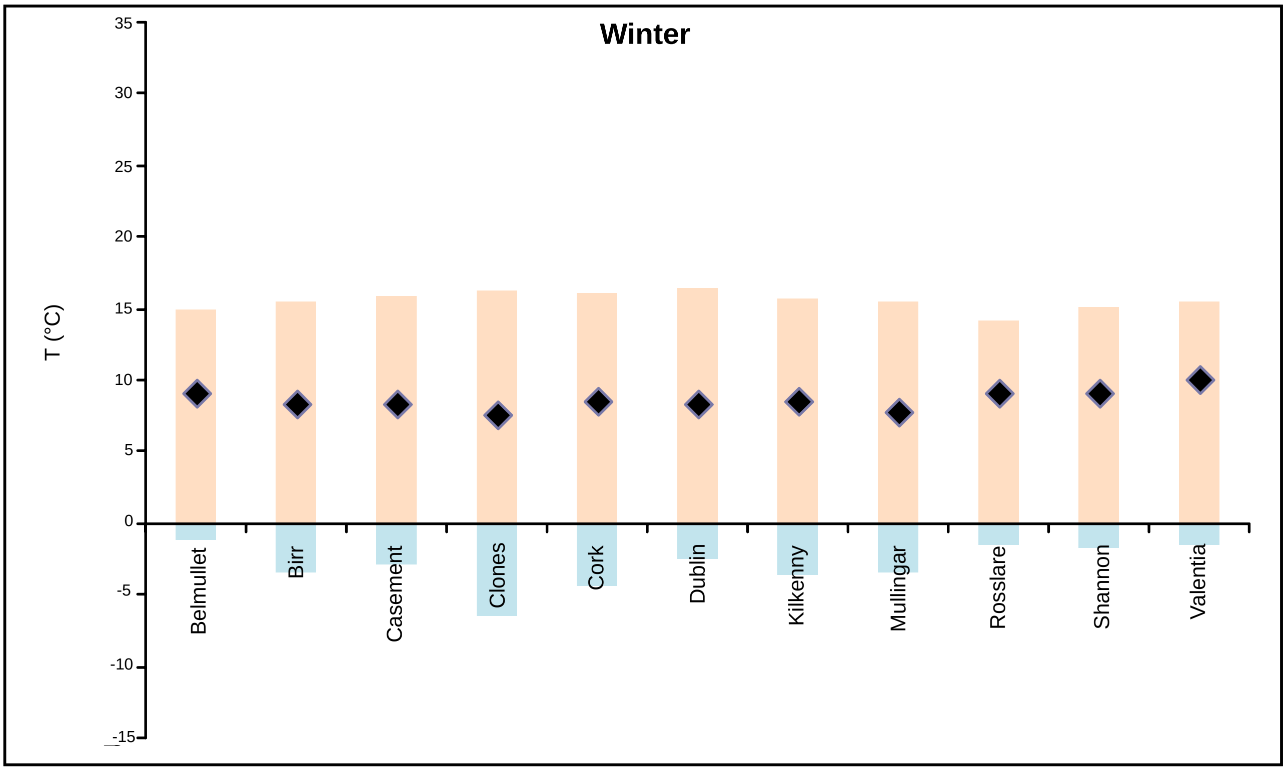

Winter
T (°C)
35
30
25
20
15
10
5
0
-5
-10
-15
Belmullet
Birr
Casement
Clones
Cork
Dublin
Kilkenny
Mullingar
Rosslare
Shannon
Valentia

Appendix 3 Ranges of Maximum Temperature per Station and Season

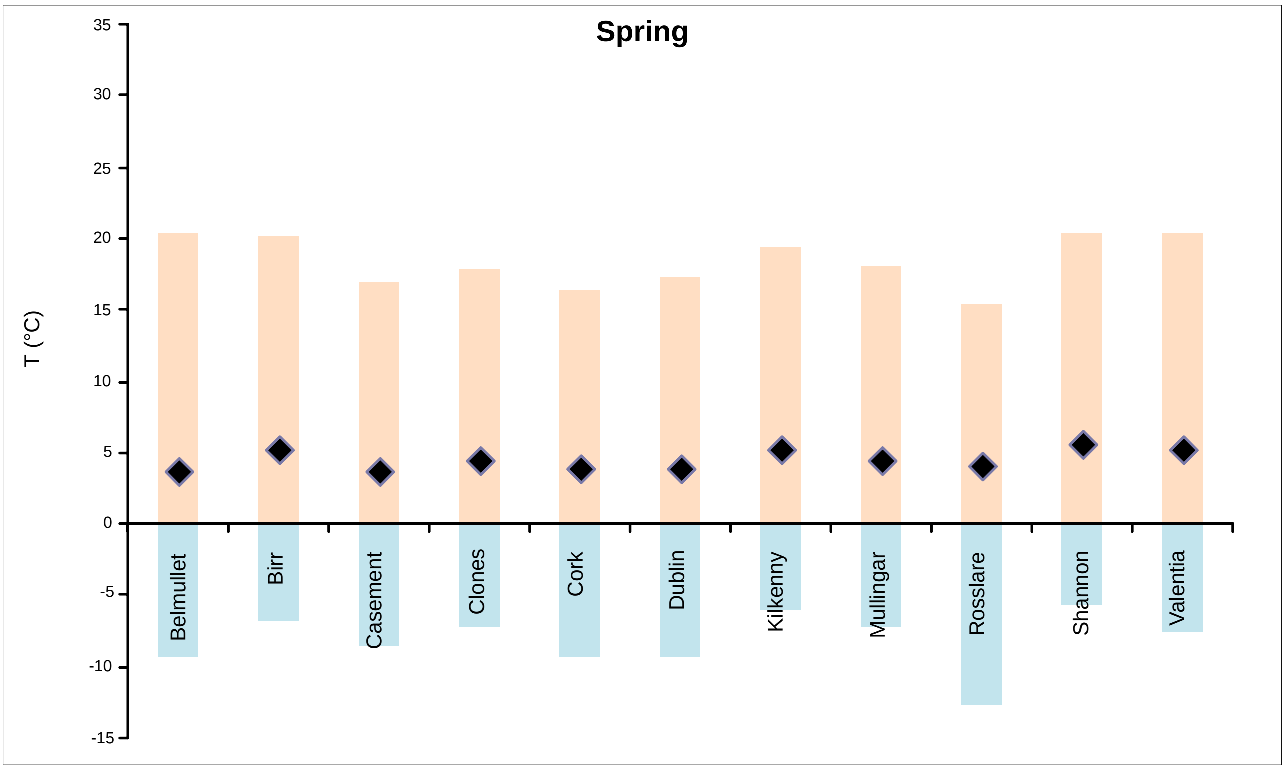


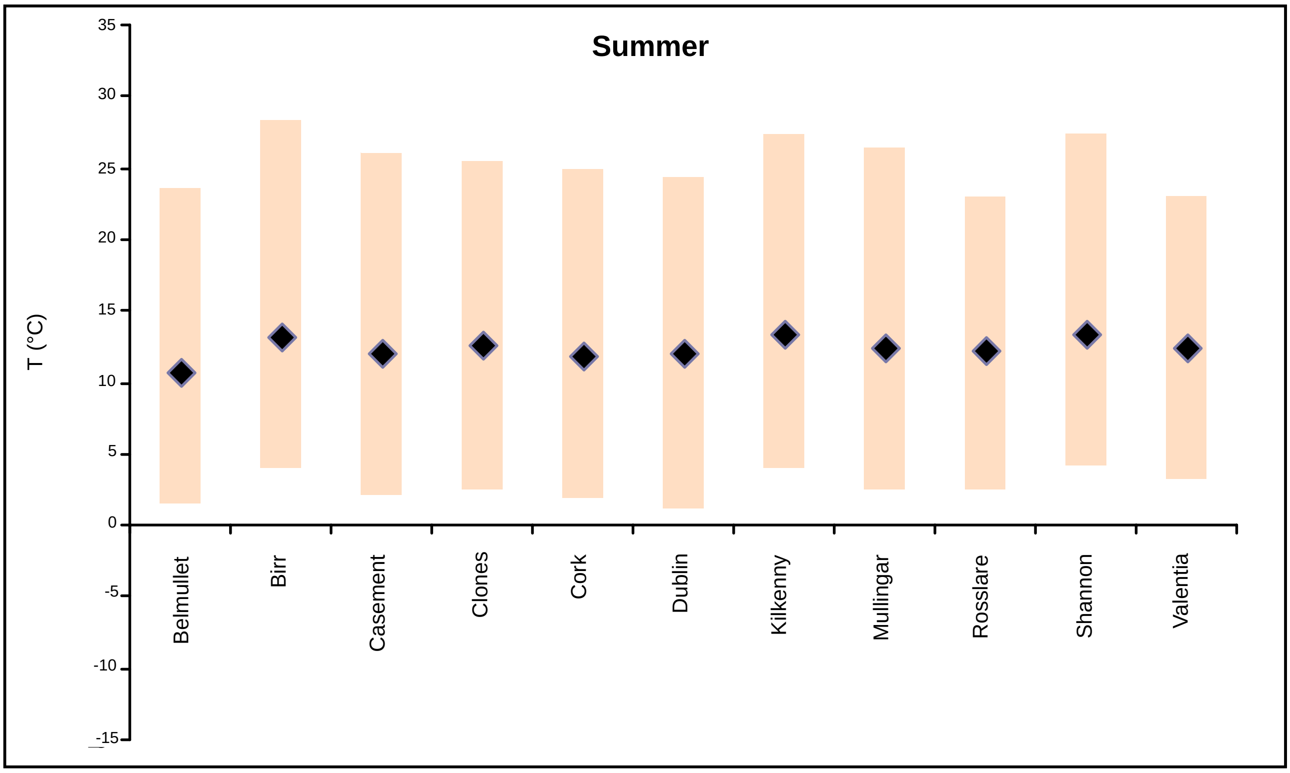


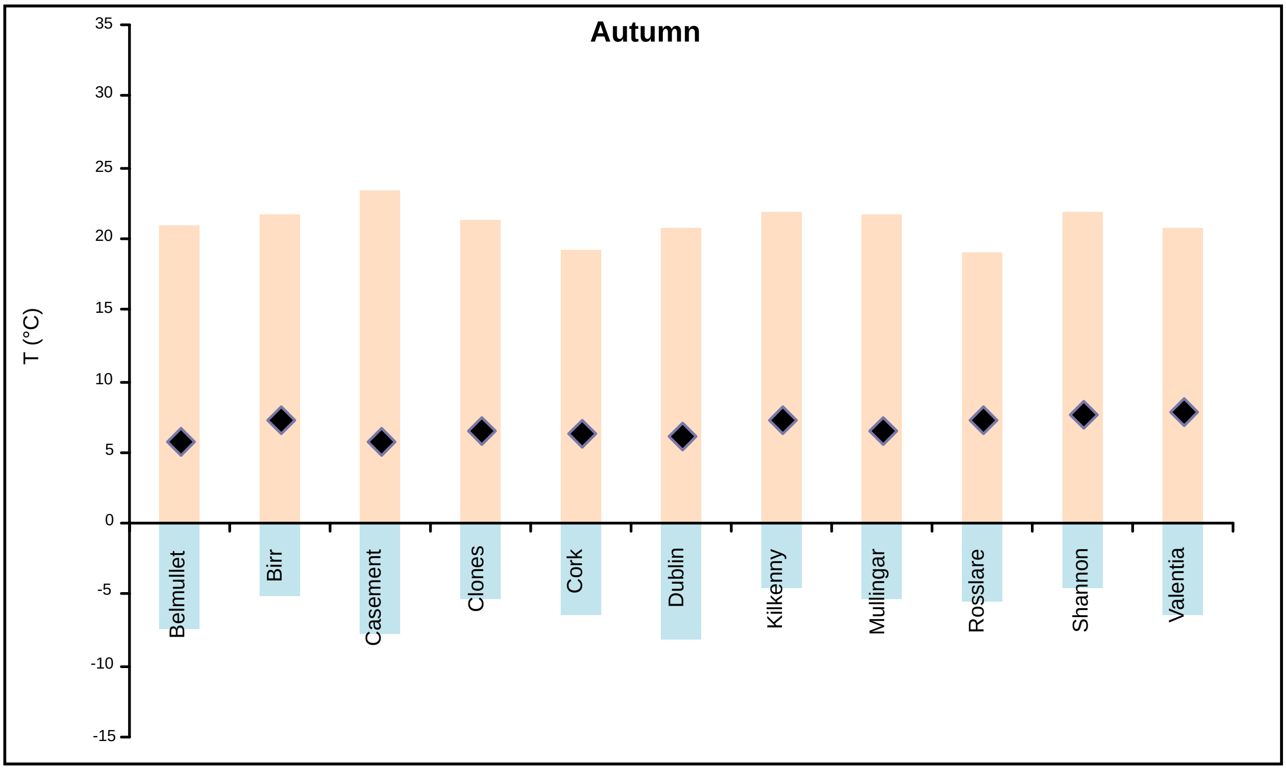

Autumn
T (°C)
35
30
25
20
15
10
5
0
-5
-10
-15
Belmullet
Birr
Casement
Clones
Cork
Dublin
Kilkenny
Mullingar
Rosslare
Shannon
Valentia

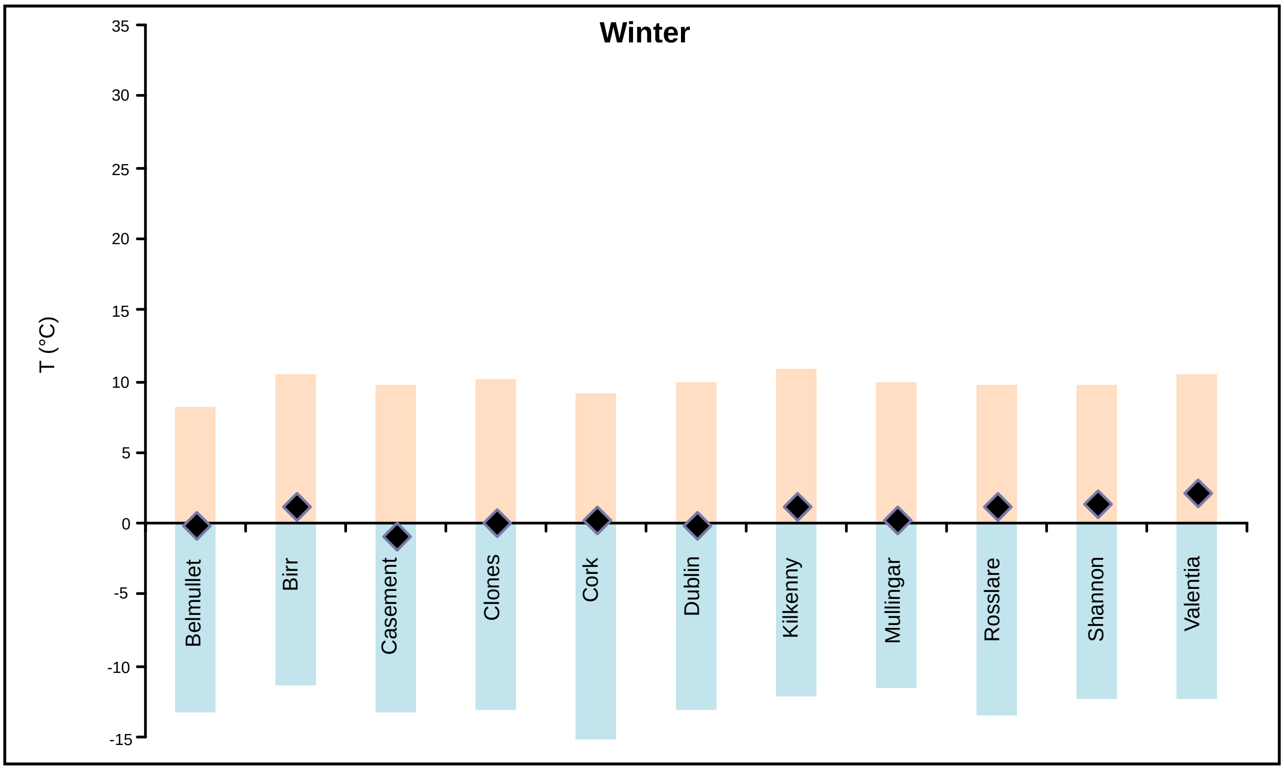

Winter
T (°C)
35
30
25
20
15
10
5
0
-5
-10
-15
Belmullet
Birr
Casement
Clones
Cork
Dublin
Kilkenny
Mullingar
Rosslare
Shannon
Valentia

Appendix 4 Ranges of Apparent Temperature per Station and Season

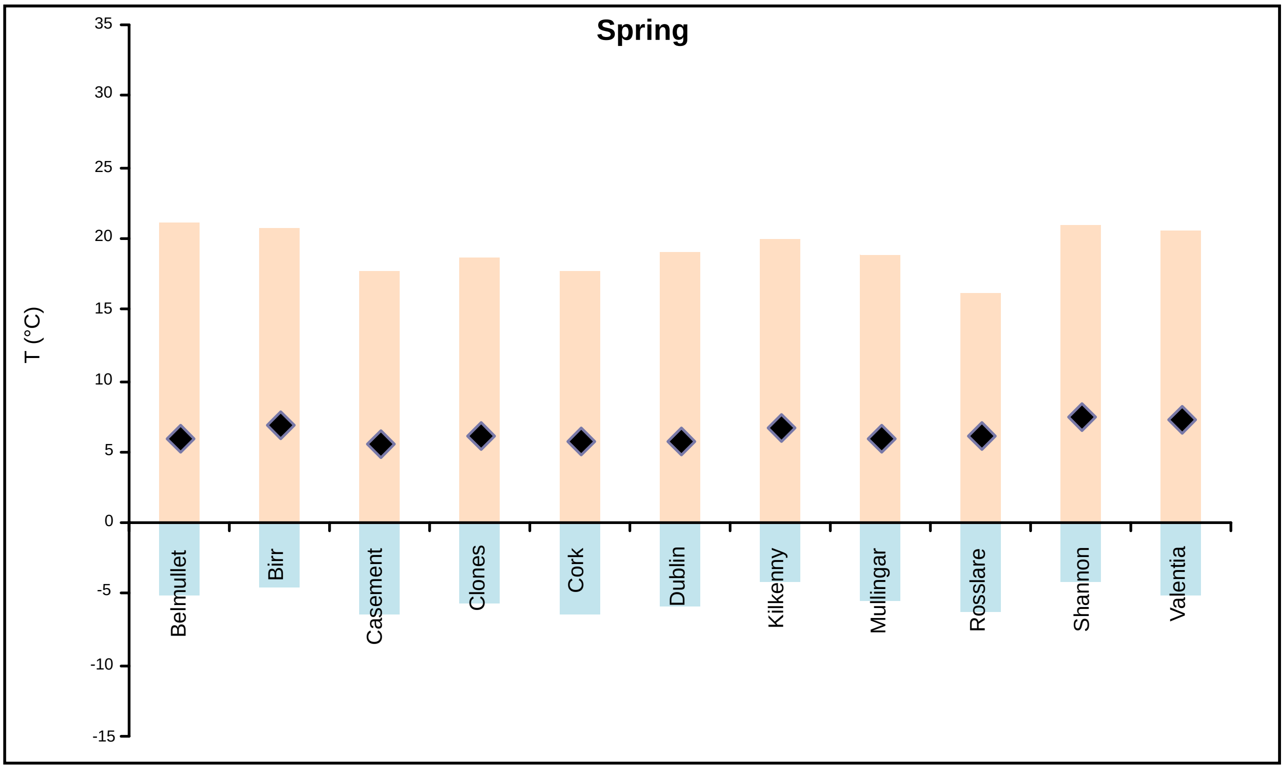


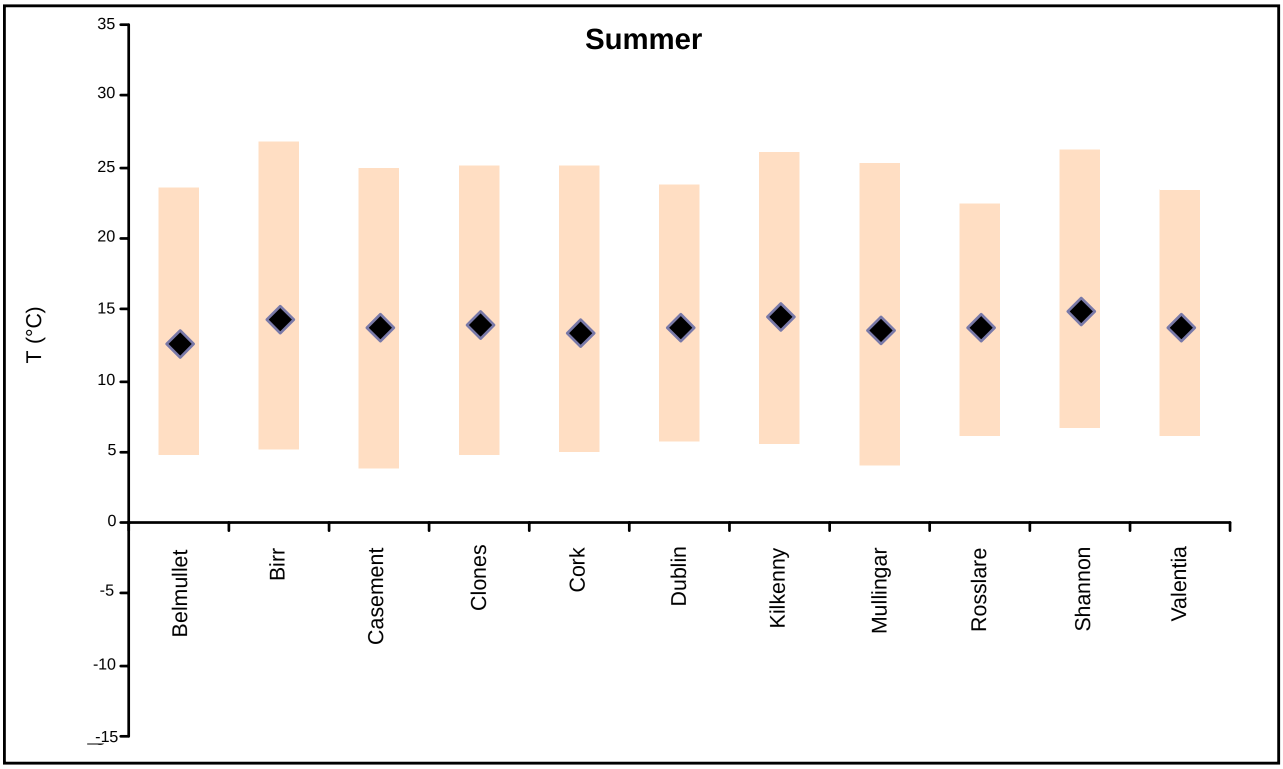


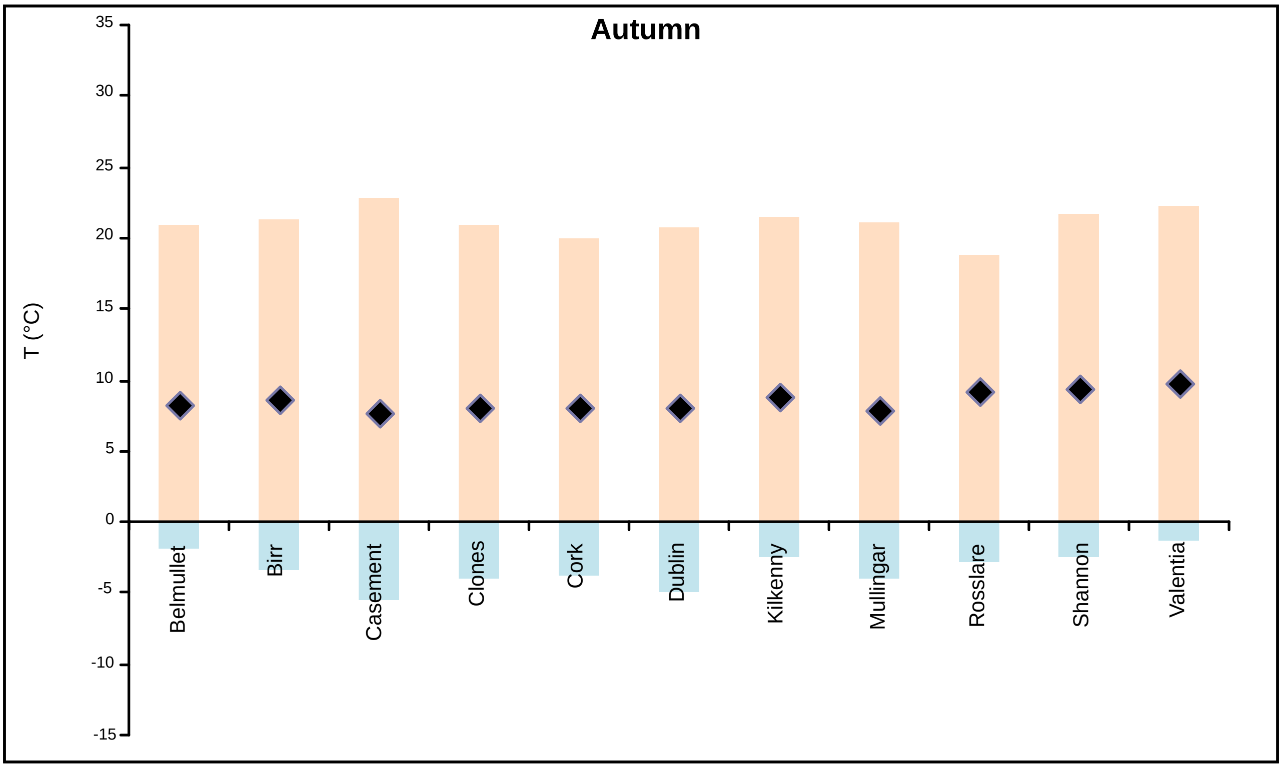

Autumn
T (°C)
35
30
25
20
15
10
5
0
-5
-10
-15
Belmullet
Birr
Casement
Clones
Cork
Dublin
Kilkenny
Mullingar
Rosslare
Shannon
Valentia

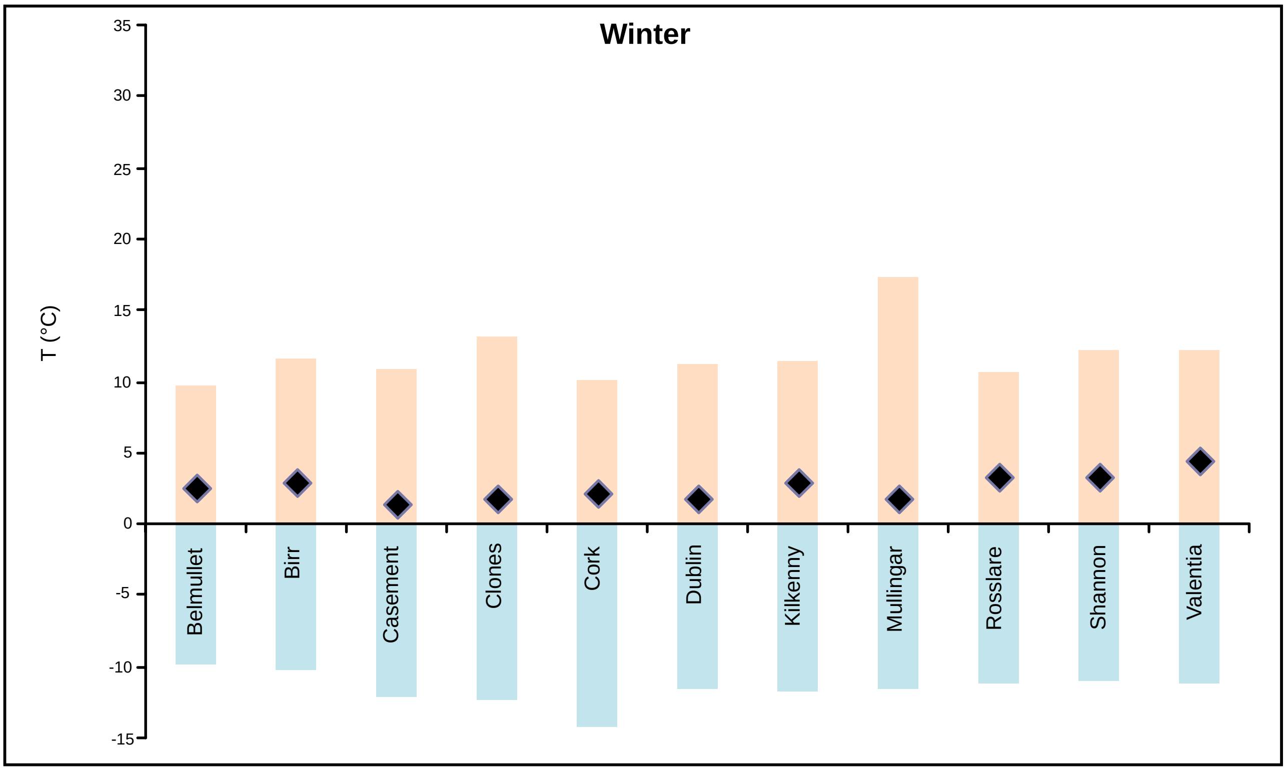

Winter
T (°C)
35
30
25
20
15
10
5
0
-5
-10
-15
Belmullet
Birr
Casement
Clones
Cork
Dublin
Kilkenny
Mullingar
Rosslare
Shannon
Valentia

Appendix 5 Ranges of Wind Chill per Station and Season

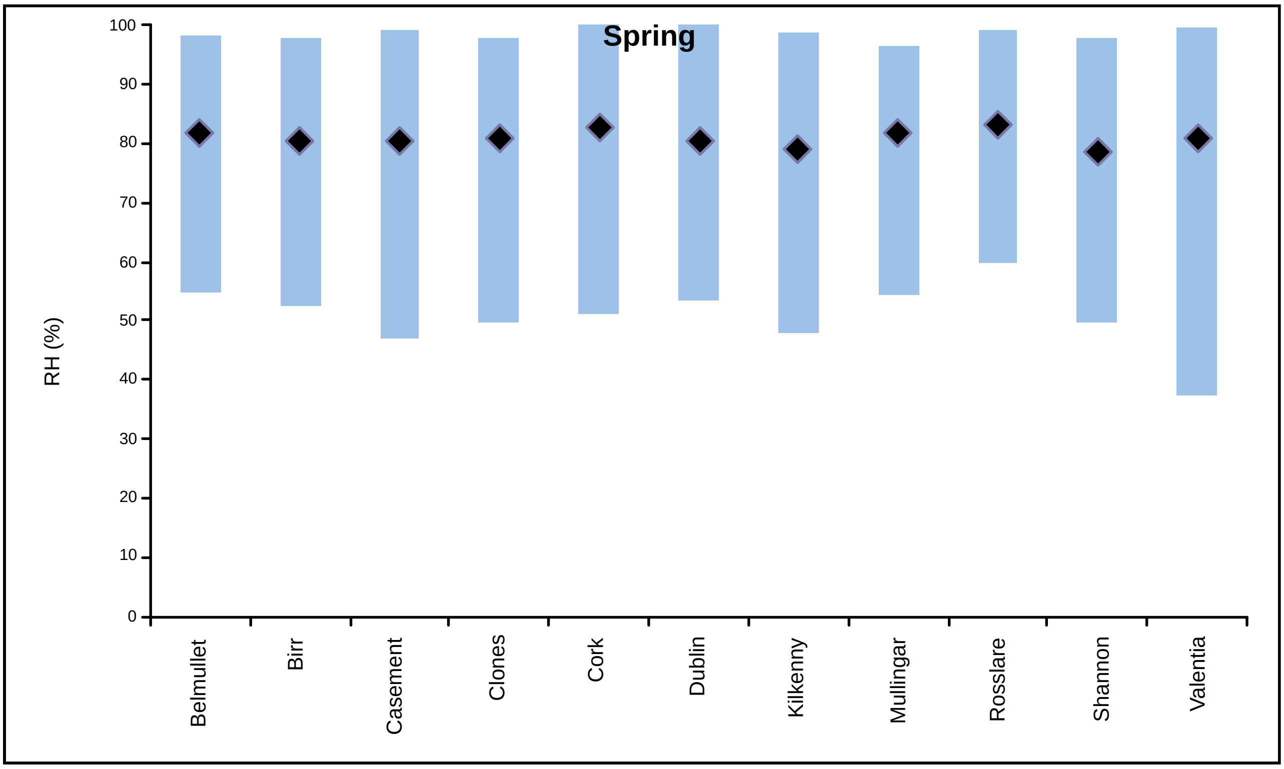


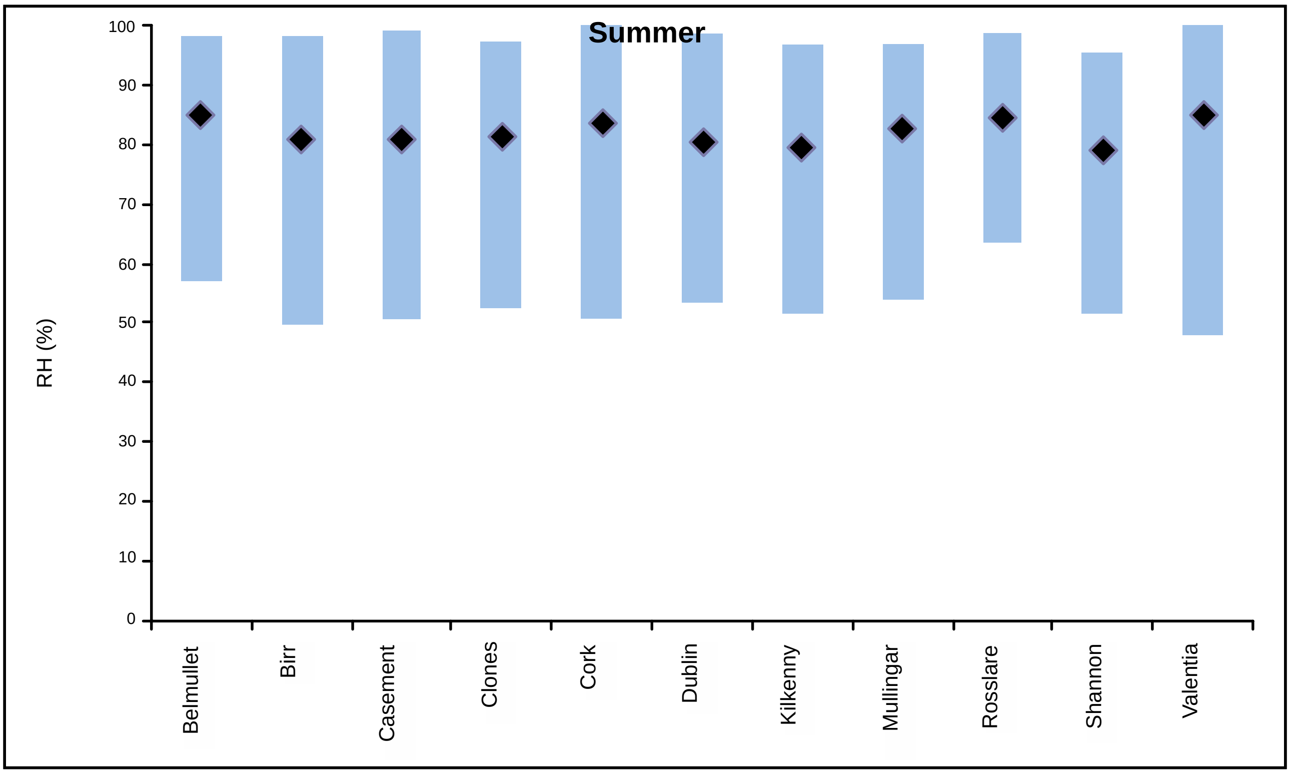


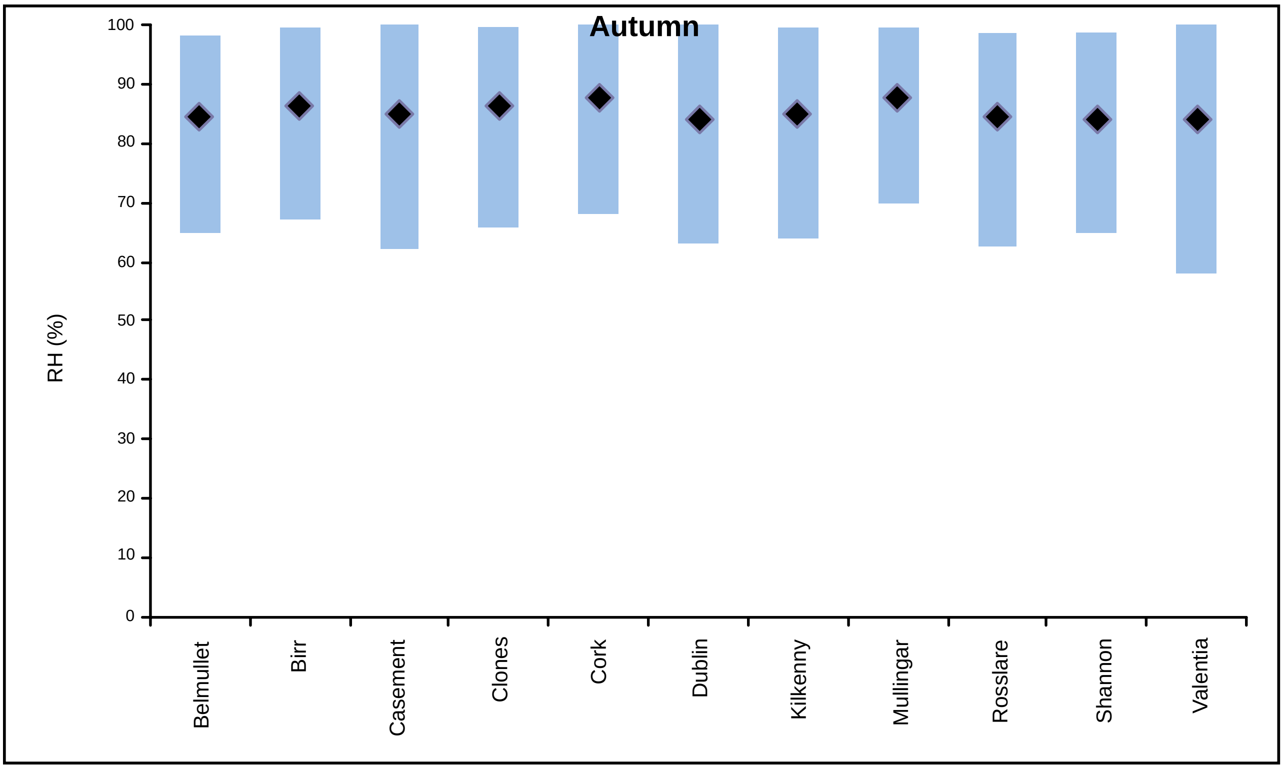

Autumn
T (°C)
35
30
25
20
15
10
5
0
-5
-10
-15
Belmullet
Birr
Casement
Clones
Cork
Dublin
Kilkenny
Mullingar
Rosslare
Shannon
Valentia


Winter
T (°C)
35
30
25
20
15
10
5
0
-5
-10
-15
Belmullet
Birr
Casement
Clones
Cork
Dublin
Kilkenny
Mullingar
Rosslare
Shannon
Valentia

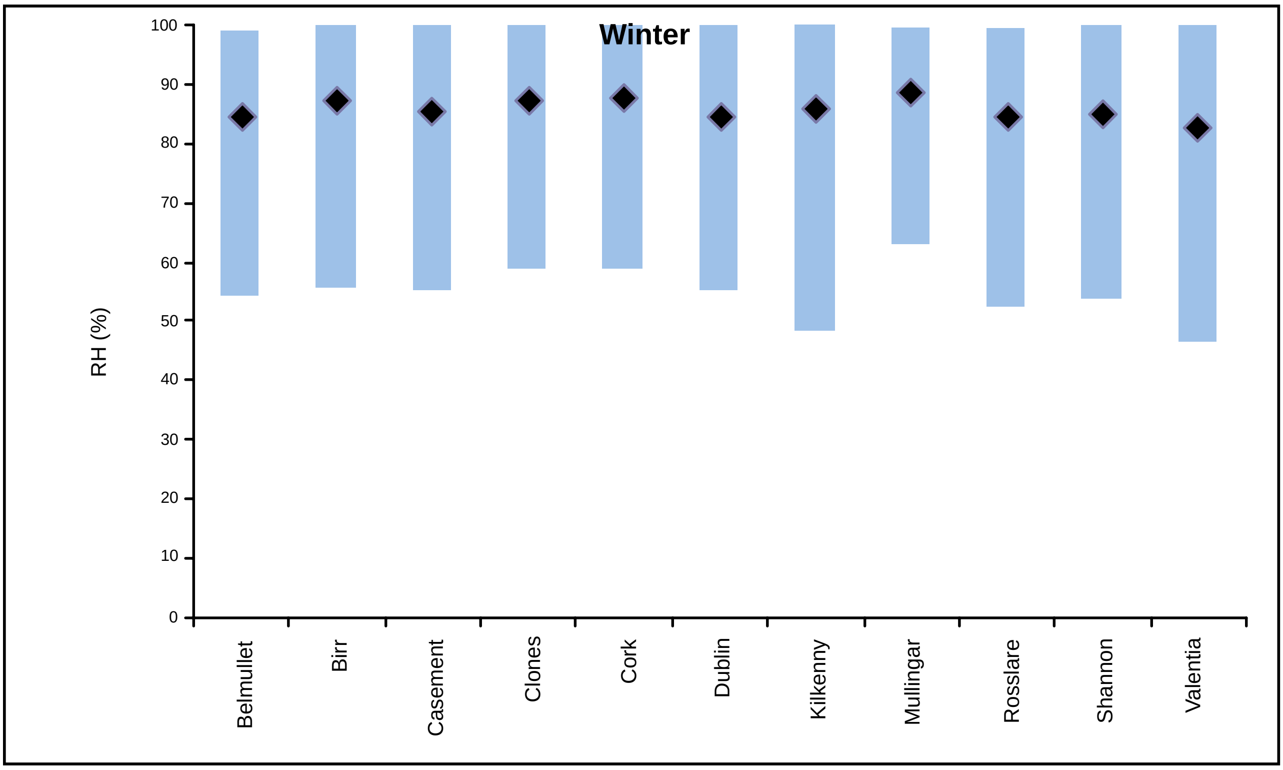
Appendix 6 Ranges of Relative Humidity per Station and Season





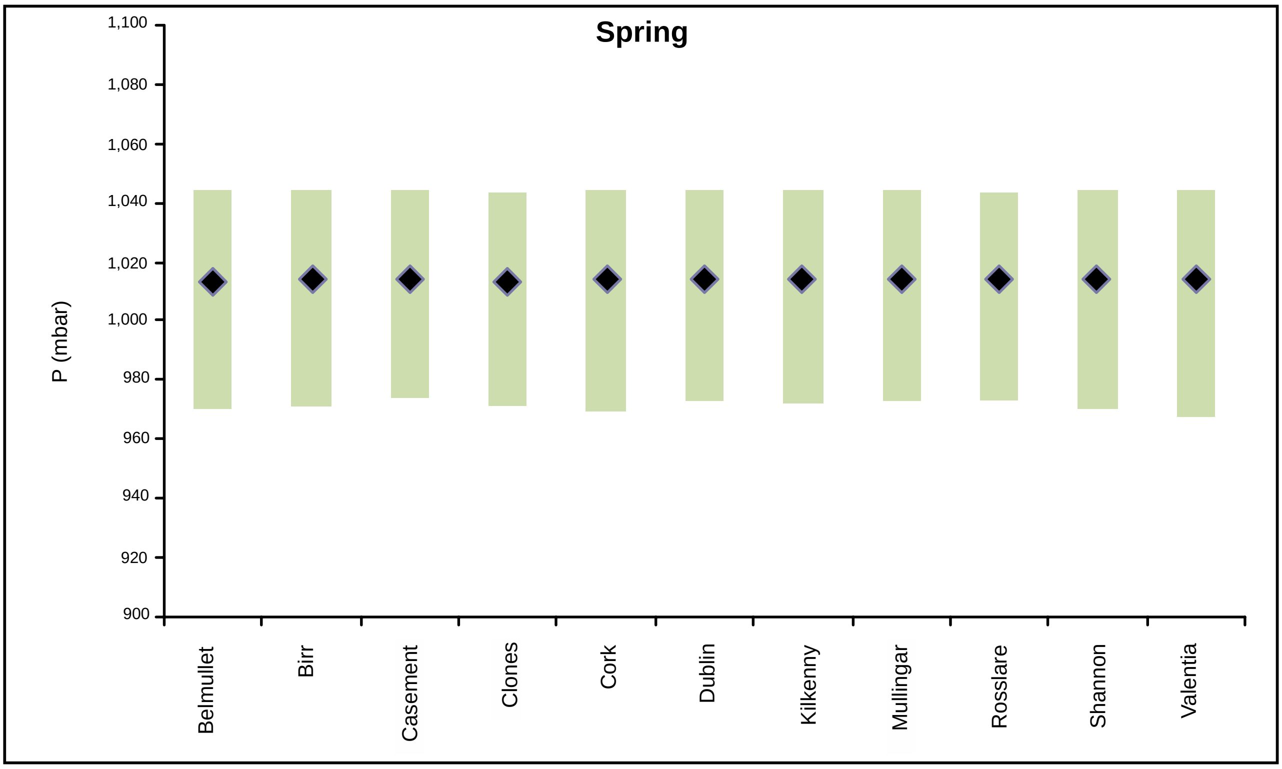


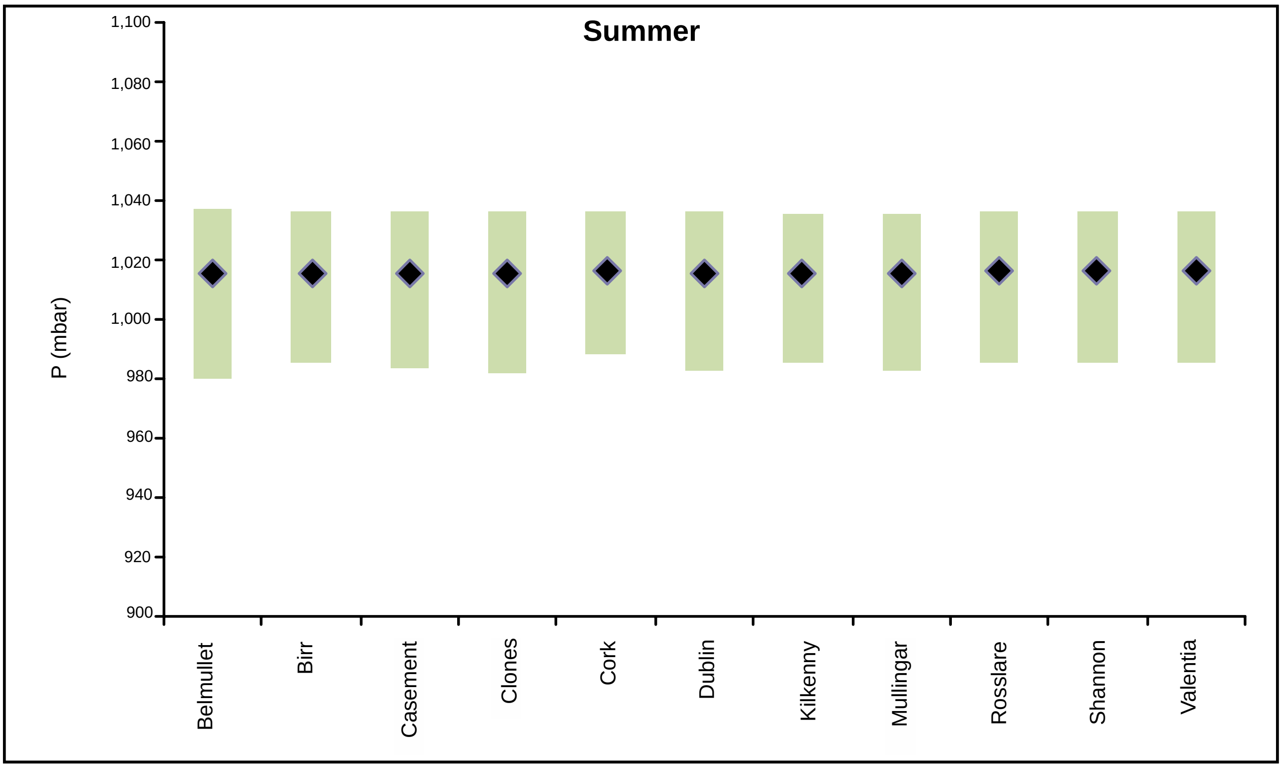
Autumn
RH (%)
100
90
80
70
60
50
40
30
20
10
0
Belmullet
Birr
Casement
Clones
Cork
Dublin
Kilkenny
Mullingar
Rosslare
Shannon
Valentia

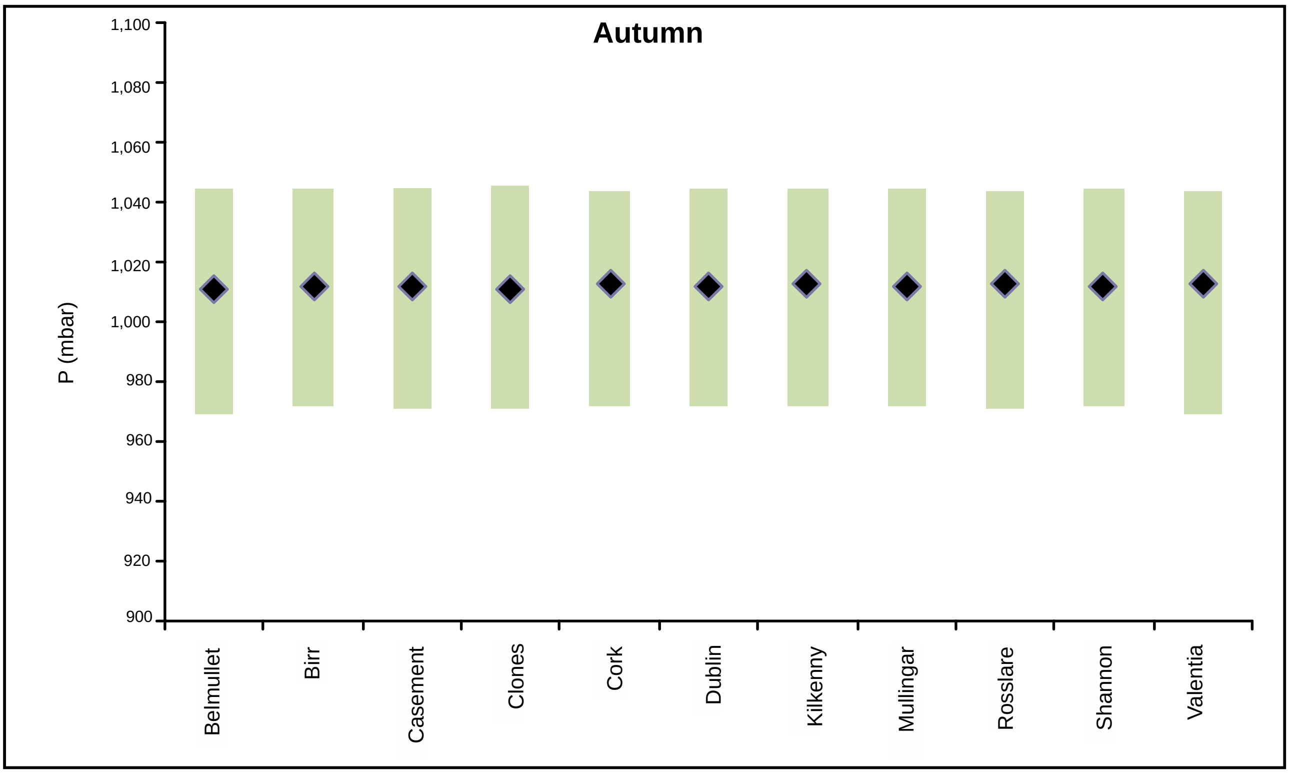


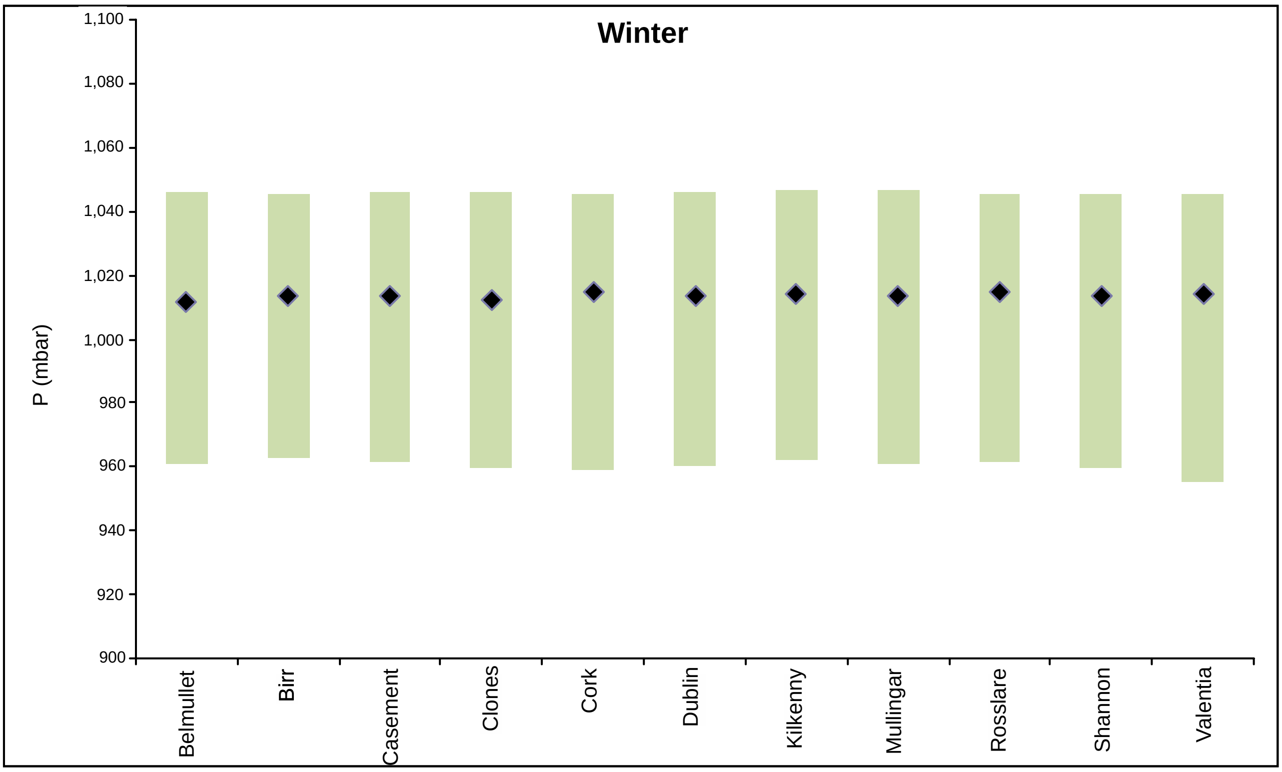
Winter
RH (%)
100
90
80
70
60
50
40
30
20
10
0
Belmullet
Birr
Casement
Clones
Cork
Dublin
Kilkenny
Mullingar
Rosslare
Shannon
Valentia

Appendix 7 Ranges of Atmospheric Pressure per Station and Season






Autumn
P (mbar)
1,100
1,080
1,060
1,040
1,020
1,000
980
960
940
920
900
Belmullet
Birr
Casement
Clones
Cork
Dublin
Kilkenny
Mullingar
Rosslare
Shannon
Valentia


Winter
P (mbar)
1,100
1,080
1,060
1,040
1,020
1,000
980
960
940
920
900
Belmullet
Birr
Casement
Clones
Cork
Dublin
Kilkenny
Mullingar
Rosslare
Shannon
Valentia

Appendix 8 Mean Temperatures Observed during Heatwaves in Rural and Urban Stations

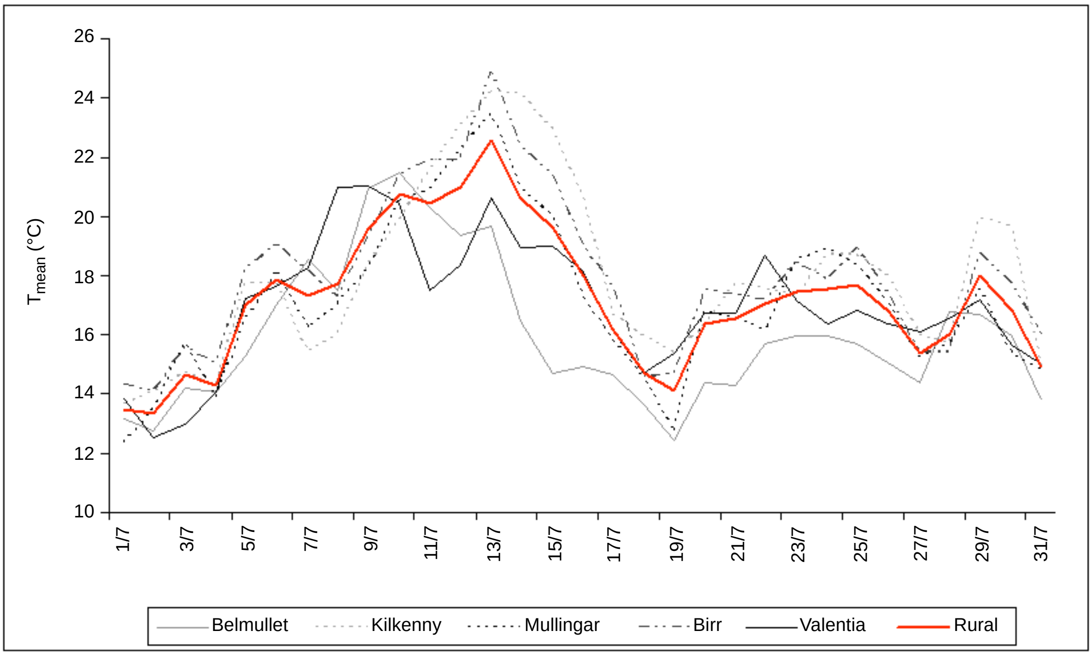


Figure A8.1. Mean temperatures observed during July 1983 in rural stations.

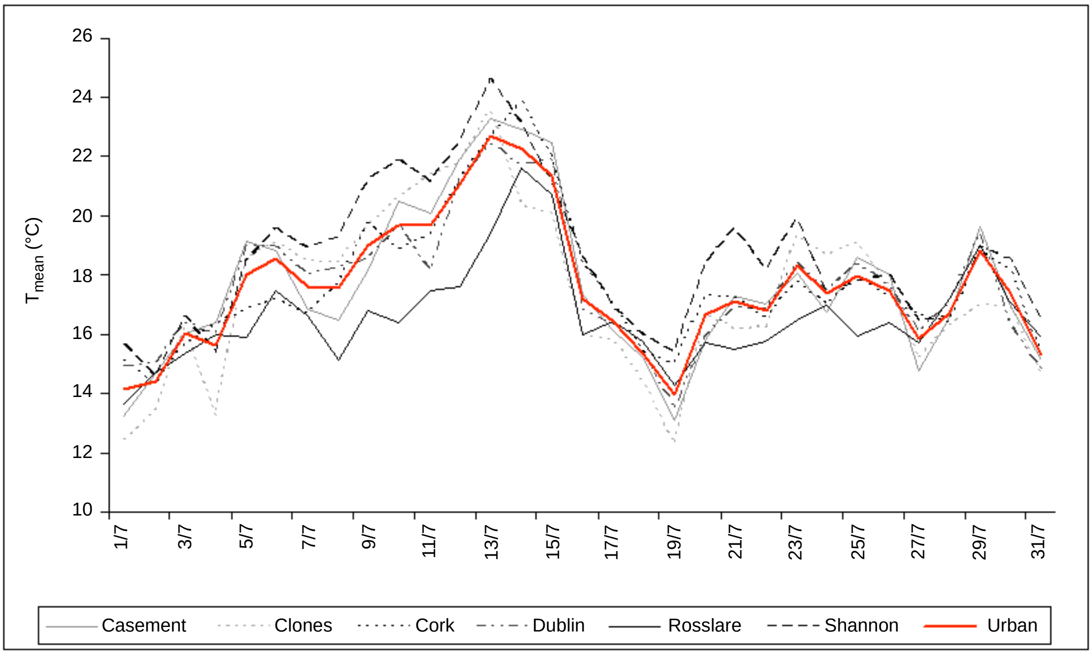


Figure A8.2. Mean temperatures observed during July 1983 in urban stations.

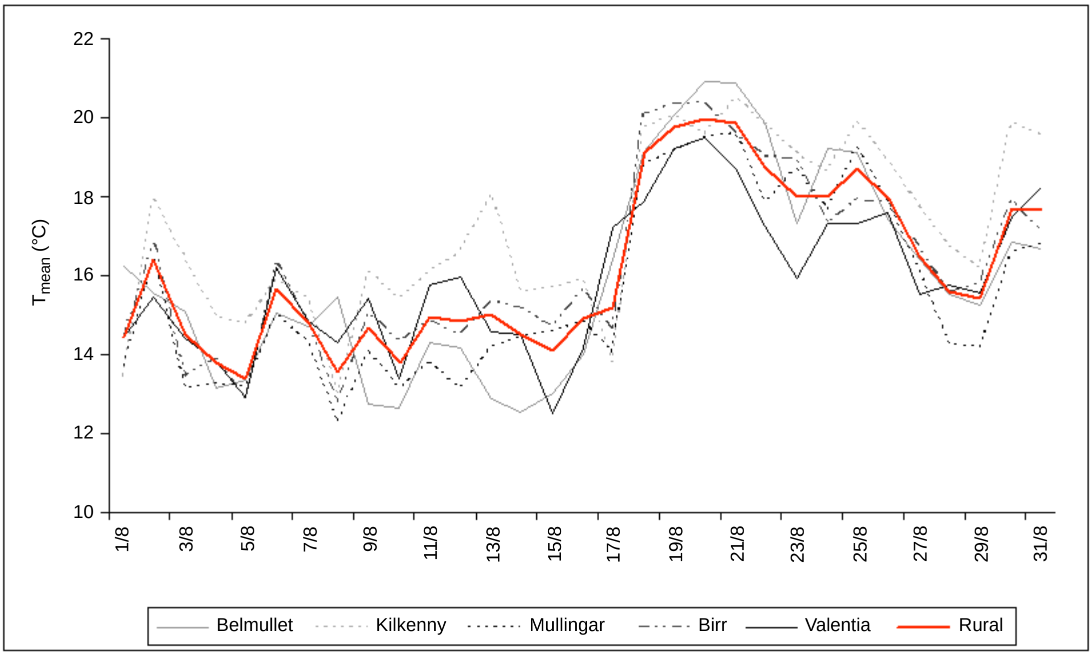


Figure A8.3. Mean temperatures observed during August 1984 in rural stations.

Figure A8.4. Mean temperatures observed during August 1984 in urban stations.

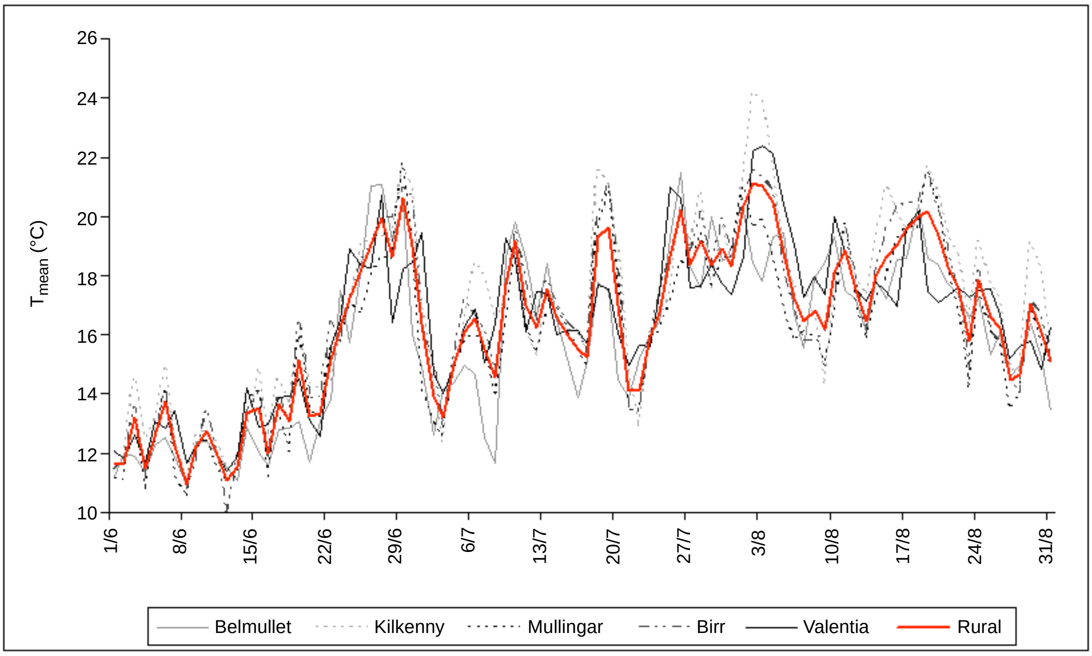


Figure A8.5. Mean temperatures observed during summer 1995 in rural stations.

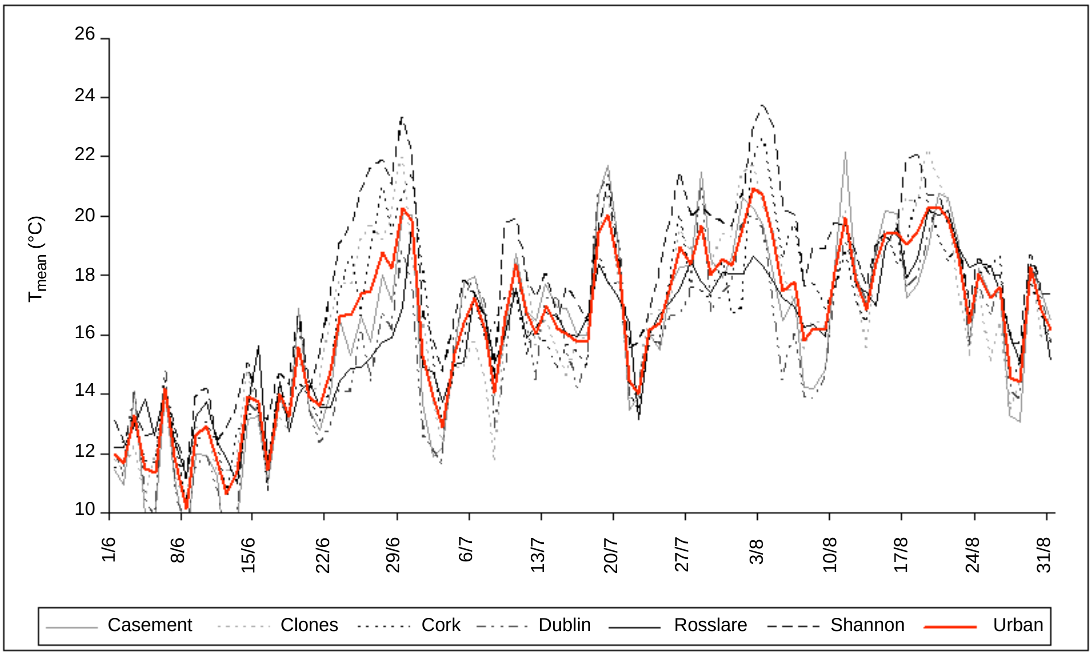


Figure A8.6. Mean temperatures observed during summer 1995 in urban stations.

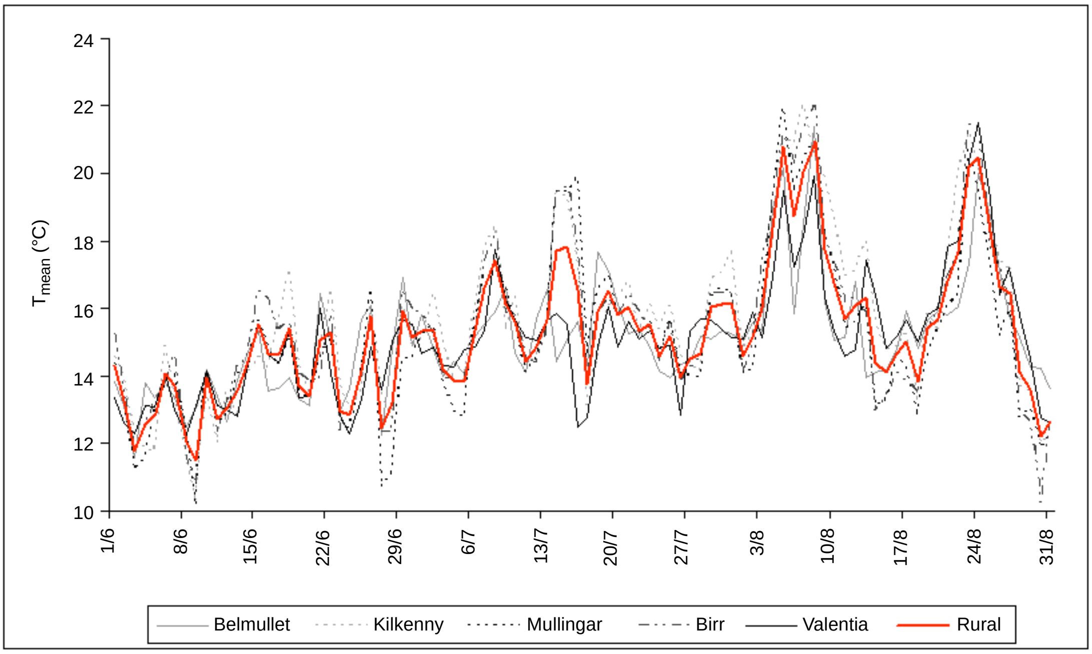


Figure A8.7. Mean temperatures observed during summer 2003 in rural stations.

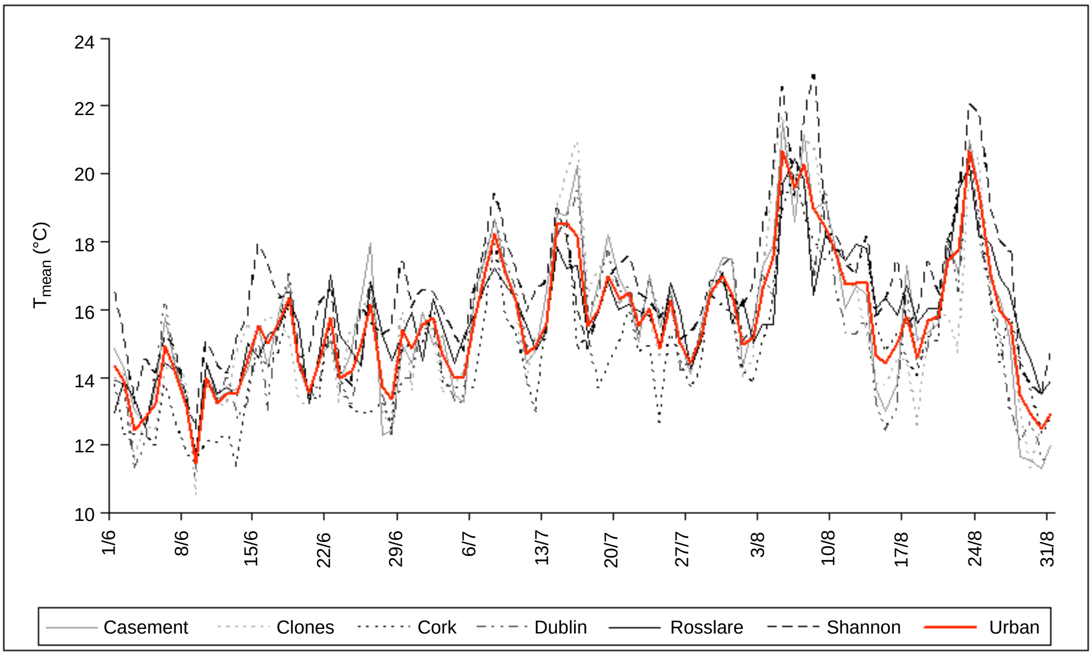


Figure A8.8. Mean temperatures observed during summer 2003 in urban stations.

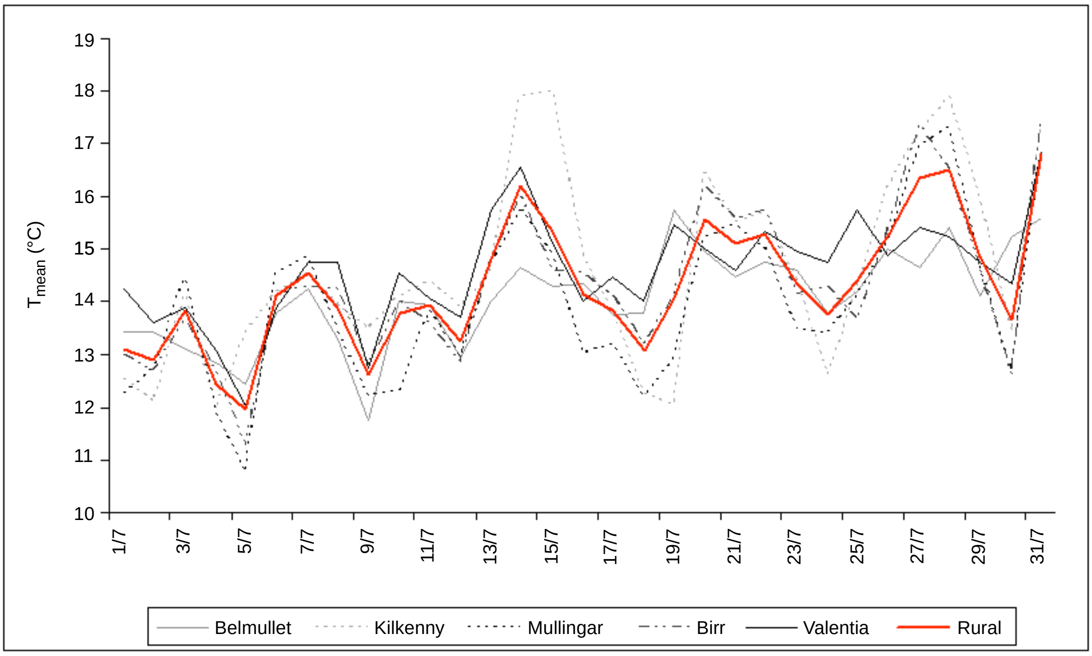


Figure A8.9. Mean temperatures observed during July 2006 in rural stations.

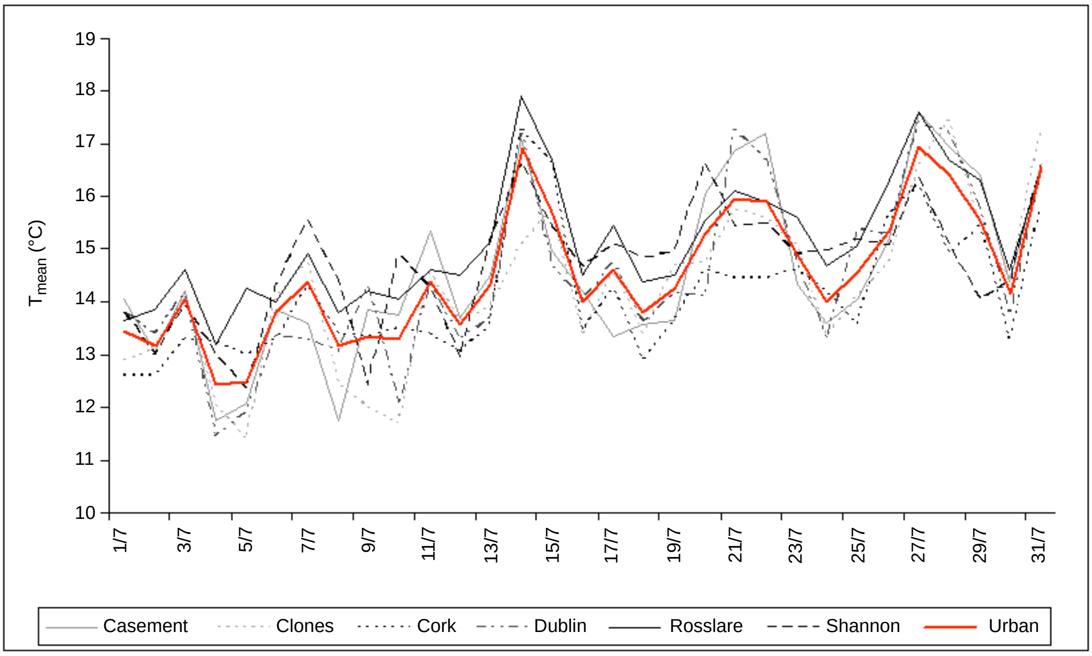


Figure A8.10. Mean temperatures observed during July 2006 in urban stations.

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil, Pobal agus Rialtais Áitiúil.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail;
- scardadh dramhuisce.

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.

epa Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

ENVIRONMENTAL PROTECTION AGENCY
PO Box 3000, Johnstown Castle Estate, Co. Wexford, Ireland
t 053 916 0600 f 053 916 0699
LoCall 1890 33 55 99
e info@epa.ie w http://www.epa.ie

SSTI Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government