What determines spatiotemporal variations in cold-weather-related mortality in England?

Louise Maria Tanner

A thesis submitted in partial fulfilment of the requirements
of the degree of Doctor of Philosophy

11th October 2016

Institute of Health and Society

Newcastle University

Abstract

Mortality rates in England are higher during the winter period (December-March) compared to other seasons. Most excess winter deaths are caused by respiratory and circulatory conditions, which are exacerbated by cold temperatures. Excess winter mortality rates vary between areas and years. This research investigated spatial and spatiotemporal variations in excess mortality across small areas of England in relation to winter season, cold weather and other explanatory factors.

A systematic review was undertaken, which identified factors associated with modified risk of specific types of winter- and cold-related adverse health and social outcome, and assessed the effectiveness of interventions on reducing these adverse impacts. Evidence-based pathway models were developed of associations between winter season or cold exposure and circulatory and respiratory health outcomes, in relation to explanatory factors.

Secondary data were identified to represent variables from the pathway models in analyses. Poisson regression models were implemented using a Bayesian approach to evaluate spatial and spatiotemporal variations in observed-to-expected mortality ratios from circulatory and respiratory conditions in relation to covariates, across English Local Authorities and between: winter seasons, periods of cold and warmer weather and months of the year.

Climatic factors were associated with spatiotemporal variations in mortality ratios between winter periods, but were less important determinants of excess mortality across the year. This supports the use of weather forecasting services to alert health and social care providers to predicted adverse weather conditions, in order to support individuals with circulatory and respiratory conditions during the winter period. The effects of social factors were similar for circulatory and respiratory conditions and were predominantly non-seasonal. Thus, interventions could be developed to reduce spatial variations in excess mortality from both condition groups on a year-round basis. Further research using morbidity outcome data could provide information to reduce spatial variations in excess medical consultation rates across England.

Table of contents

List of Tables

List of figures

Acknowledgments

I would thank my supervisors, Doctor Suzanne Moffatt and Professors Eugene Milne, Martin White and Steve Rushton, for enabling me the opportunity to undertake the PhD and for their feedback on my work.

Special thanks to Dr Alasdair Blain, who provided advice and support throughout the period when I formatted and linked the data and enabled me to prepare the scripts that I used for the analyses (chapters six-eight). Also, Kate Best provided helpful information about Poisson regression analysis and proof-read chapter eight of this thesis.

The ESRC funded my PhD. Professor Judith Rankin allowed me access to funding from Newcastle University's Applied Epidemiology research theme to obtain the mortality data for this project.

I would like thank all of the organisations and individuals who provided data, as well as those who shared their knowledge regarding my research topic and methods. Although too numerous to name individually, the information and insights that they provided were crucial for my learning and enabled me to complete this research.

I am grateful to my mock-viva examiners, Doctors Colin Muirhead and Suzanne Moffatt, for their advice which enabled me to prepare for my viva exam. Also, thank you to my viva examiners, Professors Christine Liddell and Mark Pearce, for taking the time to read and examine my thesis and for their comments on how my thesis could be improved.

Finally, and very importantly, I would like to thank my wonderful parents, Marie and Ken Tanner, for their love, friendship and support, without which I would not have reached this stage in my PhD. Also, I would like to thank my nephew, Alexander, and my niece, Isabelle, for the joy and laughter that they bring to me.

Statement of contributions

Funding for this project was obtained via a research proposal that was developed and submitted to the ESRC by LM Tanner, EMG Milne, M White, S Moffatt and S Rushton. The proposal described the research context, specified the original research questions to be addressed, identified organisations from which the mortality, morbidity and meteorological data were requested and identified the types of method that were used to address each research question.

LM Tanner drafted the thesis, undertook the systematic reviews (chapters two-three), developed the evidence-based pathway models (chapter four) and identified, obtained, selected, formatted and linked the data for the analyses (chapters five-seven). AP Blain provided advice to LM Tanner throughout the period when she undertook data formatting and linkage (chapter six). The scripts used to produce variables from the air pollution and meteorological data were created by AP Blain and adapted by LM Tanner to the ecological level used for the analyses. AP Blain identified the text book containing the scripts that LM Tanner used to implement the disease risk maps and regression analyses and enabled LM Tanner to adapt these for her data. Decisions regarding which analyses to perform were made by LM Tanner, with advice from AP Blain and S Rushton. LM Tanner analysed the data and interpreted the results from the analyses. Comments on all chapters of the thesis were provided by S Moffatt, EMG Milne and M White. SR provided feedback on chapters six-eight.

Declaration

I declare that the work presented in this thesis is my own, except where explicitly stated in the text or statement of contributions.

Abbreviations and acronyms

Term	Abbreviation
Accident and emergency	A&E
Bayesian credible interval	BCI
Body Mass Index	BMI
Cardiovascular disease	CVD
Critical Appraisal Skills Programme	CASP
Chronic obstructive pulmonary disease	COPD
Coefficient of seasonal variation in mortality	CSVM
Comma-separated value	CSV
Confidence Interval	CI
Department for Environment, Food and Rural Affairs	DEFRA
Department of Energy and Climate Change	DECC
Deviance Information Criterion	DIC
Diastolic blood pressure	DBP
Energy Performance Certificate	EPC
European Union	EU
Evidence-based medicine	EBM
Excess Winter Mortality	EWM
Excess Winter Mortality Index	EWMI
General Practitioner	GP
Government Office Region	GOR
Health Protection Agency	HPA

Abbreviations and acronyms (continued i)

Term	Abbreviation
Hospital Episode Statistics	HES
Influenza-like-illness	ILI
Integrated Laplace Approximation	INLA
International Classification of Diseases, version 10	ICD-10
Intra-cerebral haemorrhage	ICH
Ischemic heart disease	IHD
Local Authority District	LAD
Low density lipoprotein	LDL
Lower layer super output area	LSOA
Micrograms	μg
Middle layer super output area	MSOA
National Institute for Health and Care Excellence	NICE
National Health Service	NHS
North Atlantic Oscillation	NAO
Nitrogen dioxide	NO_2
Odds ratio	OR
Particulate matter	PM
Primary Care Trust	PCT
Quality-adjusted life year	QALY
Randomised controlled trial	RCT

Abbreviations and acronyms (continued ii)

Term	Abbreviation
Relative Risk	RR
Royal College of General Practitioners	RCGP
Rural-Urban Classification for LADs	RUCLAD
Standard Assessment Procedure	SAP
Standard Deviation	SD
Square Kilometre	sq km
Standardised Mortality Ratio	SMR
Systolic Blood Pressure	SBP
Tapered Element Oscillating Microbalance	TEOM
The English Indices of Multiple Deprivation	IMD
Ultraviolet	UV
United Kingdom	UK
United States of America	USA
Variance Inflation Factor	VIF

Chapter One.

Winter- and cold-related excess adverse health and social outcomes in England: Introduction and Contextual Overview

1.1 Background

1.1.1 Introduction

Morbidity (disease occurrence) and mortality rates are higher during the winter period (generally defined as December-March in the Northern Hemisphere and June–September in the Southern Hemisphere), compared to other times of year in England and many other countries (1, 2). Excess winter mortality (EWM) rates vary across England and between winter seasons. However, the causes of these variations are not fully understood. Political interest in addressing the causes of winter- and cold-related adverse health and social outcomes has increased over recent decades, particularly in England and other UK countries. Knowledge regarding the causes of spatial (between areas) and temporal (time-related) variations in excess winter deaths and illnesses could enable the development of interventions to reduce geographical inequalities in, and the overall magnitude of, these adverse health outcomes.

In this introductory chapter, I explain key terms used to describe and measure winter- and cold-related excess mortality and illnesses. I also provide descriptive information about the spatial and temporal characteristics of EWM and the proportional contribution of different medical condition groups to this outcome. I then describe the English legislative framework in relation to addressing winter-and cold-related excess adverse health and social outcomes. Subsequently, I outline the aims and research questions for this PhD. Finally, I provide an outline of the structure of this thesis.

1.1.2 Defining excess winter morbidity and mortality

Excess winter morbidity is usually measured and defined in relation to healthcare utilisation, as the number of increased hospital admissions and general practitioner consultations during the winter period, compared to other seasons (3, 4). Excess Winter Mortality refers to the number of deaths that occur during the winter months minus the average number of deaths occurring during the preceding and subsequent four months (5). The definition of the winter period as the months December to March (in the Northern Hemisphere) was introduced in the

late 1800s. This was based on historical observations that mortality rates tend to be highest during this period (5), which led to a recommendation by the Statistical Society of London in 1881 to aggregate the four months starting in December to assess the seasonality of mortality (6). However, the use of excess winter morbidity and mortality to measure the adverse health impacts of cold weather is problematic. This is due to the fact that extreme cold weather can occur outside of the winter period, particularly in countries like the UK, comprising England, Wales, Scotland and Northern Ireland, which experiences variable climatic conditions throughout the year due to geographic and meteorological factors. Consequently, the months from December to March are often not the coldest (4). In addition, extreme climatic events that occur at other times of the year, including summer heat-waves, artificially reduce excess winter morbidity and mortality rates. Predicted future climate change, potentially causing uncharacteristic weather patterns throughout the year, is likely to further reduce the validity of seasonal measures of cold-weather-related adverse health outcomes (7).

1.1.3 Spatial and temporal variations in EWM rates

Excess winter mortality rates vary spatially, within and between countries (8). The '*paradox of Excess Winter Mortality*' refers to the positive trend for the association between mean winter temperatures and EWM rates (8). An example of this paradox is the generally higher rates of EWM in the UK compared to other countries that are located at the same and more northerly latitude and experience colder mean winter temperatures (8). In addition, Southern European countries generally have higher EWM rates than the UK. Figure 1.1 shows the positive association between mean winter temperatures and coefficients of seasonal variation in mortality, calculated as the number of excess winter deaths divided by the average number of non-winter deaths, across 14 European countries (8).
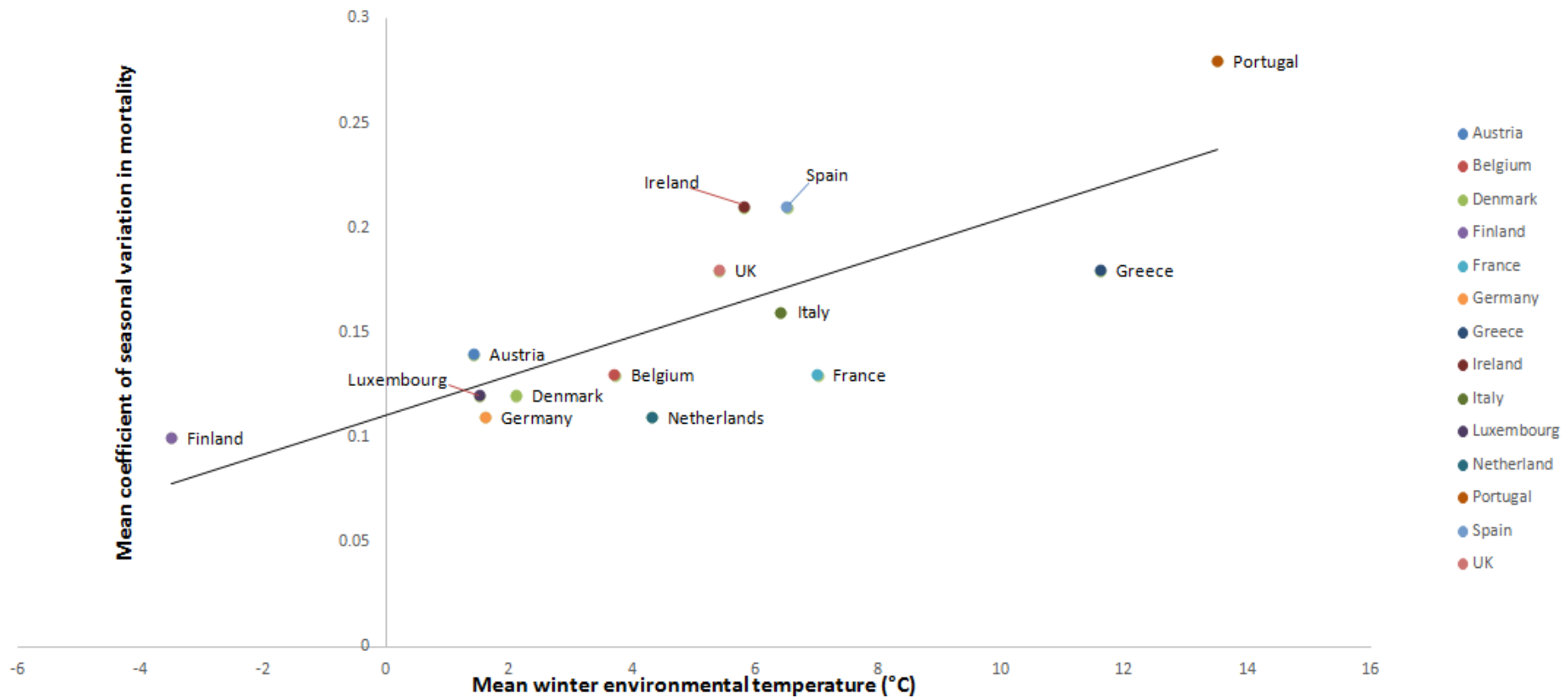
Figure 1.1: *Mean coefficients of seasonal variation in mortality in relation to mean winter environmental temperatures (${}^{0}C$) across 14 European countries with best fit line, based on data from 1988-97. Graph produced using data from (8).*

3

A more recent analysis calculated Excess Winter Mortality Indices (EWMIs), by multiplying coefficients of seasonal variation in mortality by 100, using data from thirty-one European countries (9). The results indicated that the mean Excess Winter Mortality Index (EWMI) for the period 2002/2003–2010/2011 in the UK was 15.8% (9). This was the highest out of ten Northern European countries that were included in the analysis. It was also the sixth highest out of thirty-one European countries for which data were obtained in this study. The average EWMI across all countries in the analysis during the period 2002/2003–2010/2011 was 13.9%.

Variations in EWM rates also occur within countries, including between English regions, and through time. The mean number of excess winter deaths in England is approximately 28,642, based on data from 1991/2-2014/15 (5)[*]. However, the actual number of excess winter deaths varies between years, for example, from 21,740 in the winter of 1997/98 to 45,650 in winter 1999/2000 (5). Figure 1.2 illustrates spatial and temporal variations in the EWMIs between English regions and across winter seasons from 1991/2-2014/15.

---

[*] Note that the excess winter mortality data for the winter season 2014/15 are provisional and were adjusted by the Office for National Statistics to account for late death registrations between April and July 2015.
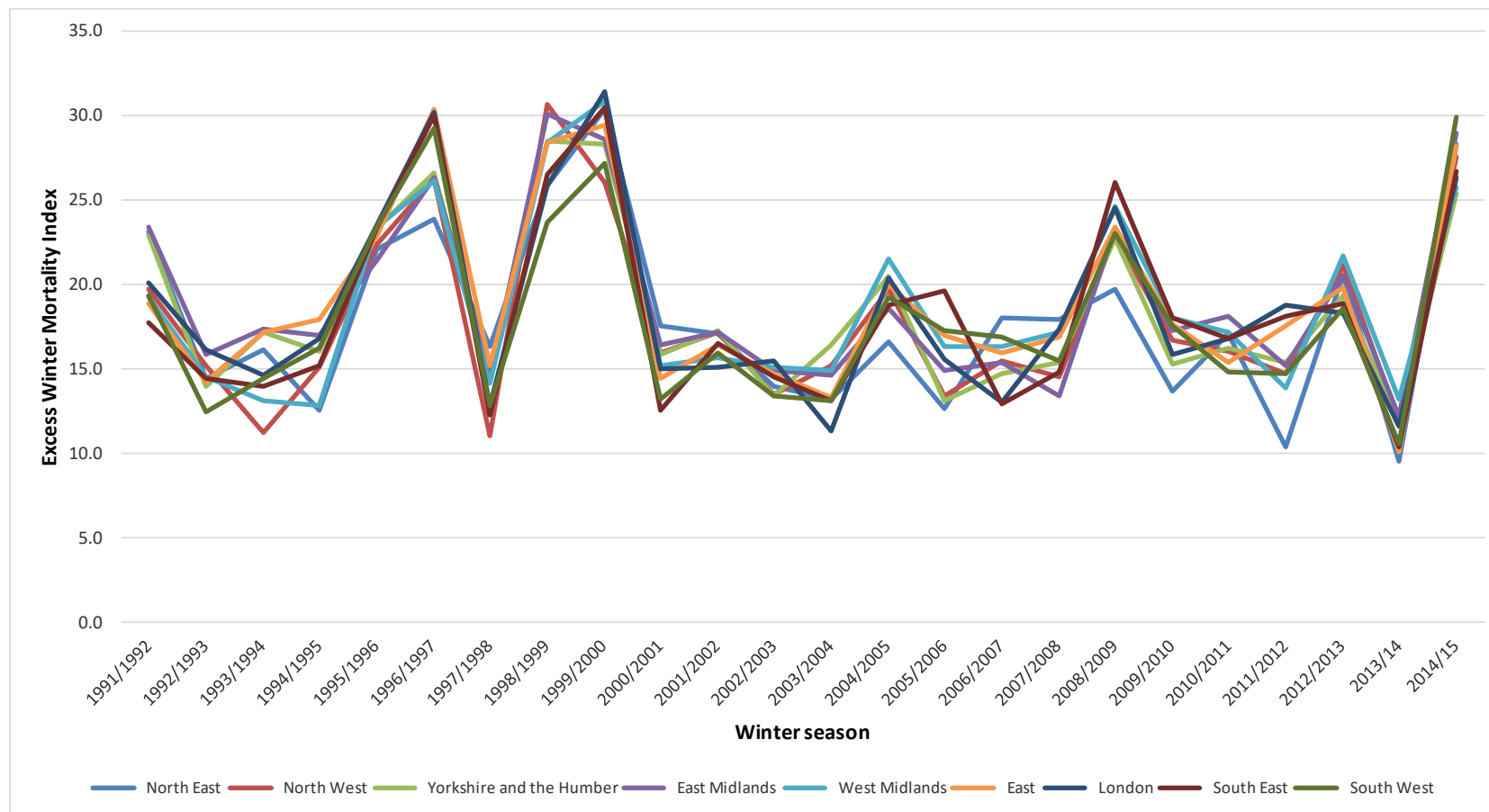
Figure 1.2: *Graph to illustrate spatial and temporal variations in excess winter mortality indices across English regions and winter seasons from 1991/2-2014/15. Graph produced using data from (5)*.*

1.1.4 Nature of winter- and cold-related adverse health and social outcomes

Most deaths that occur during the winter period in the UK are caused by conditions of the cardiovascular and cerebrovascular systems, which are subdivisions of the circulatory system and transport blood and nutrients to the abdominal organs and the brain, respectively. However, heart disease is currently the biggest single cause of death in the UK on a non-seasonal basis (7). In terms of their proportional contributions to EWM from all causes, most excess deaths that occurred in England and Wales across the winter seasons 1991/2-2014/15* were attributed to respiratory diseases (mean proportional contribution 40%), followed by circulatory diseases (mean proportional contribution 37%) and Dementia and Alzheimer's (mean proportional contribution 7%) (5). In relation to mortality from specific condition groups, mean average EWMIs across the winter seasons 1991/2-2014/15* indicated that there was greatest seasonality with a winter peak for respiratory conditions (average EWMI 55.8), followed by Dementia and Alzheimer's (average EWMI 31.1), circulatory conditions (average EWMI 18.3) and Injury and poisoning (average EWMI for the winter seasons 1991/2-2013/14 was 6.9). However, these are primary, direct causes from death certification, which tend to hide underlying and contributory causes in some cases. For example, seasonal influenza is acknowledged to be major contributor to EWM, even outside of epidemic periods. However, the effects of seasonal influenza on EWM rates are underestimated due to the fact that influenza-related deaths may be recorded on patient records as being caused by respiratory or circulatory diseases without identification of, or reference to, the influenza infection (10).

Cancer causes approximately 25% of annual deaths in England and Wales, but research suggests a lack of seasonal pattern for these deaths (5). In addition, official statistics indicate that less than 1% of excess winter deaths in developed countries are caused by clinical hypothermia (11), where body temperature drops below 35^0C (12). Hypothermia deaths are likely to be under-reported due to difficulties diagnosing the condition, because the temperature of a deceased individual has often changed by the time that the body is discovered and also due to the fact that hypothermia can cause other illnesses, which are more likely to be recorded as the primary cause of death (13). One percent of excess winter deaths across the winter seasons 1991/2-2013/14 in England and Wales were attributed to injuries and poisoning (5).

Indirect health impacts that have been associated with exposure to cold housing include impaired child development, exacerbation of allergies, nutritional deficiencies and mental health problems (14). Spatial and temporal variations in EWM rates do not occur equally

across demographic or medical condition groups (5). In addition, the prevalence of various winter-and cold-weather-related adverse health impacts varies between geographical areas, through time and between population sub groups, particularly in relation to age groups, sex and income level (1). Cold weather could therefore contribute to health inequalities, which are defined as differences in health status or the distribution of health determinants between individuals or groups (15).

The physiological pathways that mediate associations between cold weather, illnesses and deaths, are not well understood (7). The key mechanisms by which cold weather is considered to increase the risk of circulatory illnesses and deaths are through increased blood clotting potential, leading to heart attack and stroke (16). In relation to respiratory conditions, cold exposure causes constriction of air passages, a condition called bronchospasm, which can cause breathing difficulties, particularly amongst individuals with existing respiratory diseases (16).

Excess deaths from injuries during the winter period are likely to be caused by increased slips and falls indoors amongst older persons due to reduced mobility in relation to cold exposure. Outdoor slips and falls on cold and icy surfaces occur most commonly amongst individuals below pensionable age, and result in injuries rather than deaths. Increased deaths due to poisoning over the winter period generally occur because of carbon monoxide poisoning attributable to poorly maintained boilers, stoves and heaters, which are used more over the winter compared to other seasons (17).

A plausible explanation for the increased number of deaths from dementia and Alzheimer's disease over the winter period is that increased blood pressure in relation to cold exposure increases the risk of vascular dementia. However, there is evidence that less than 25% of excess winter dementia deaths are caused by the vascular sub-type (18). It has been suggested that the use of psychotropic drugs by individuals with dementia can diminish thermal perception, in terms of one's ability to detect coldness, and subsequent energy behaviours (18) (e.g. in terms of heating usage).

Wider social impacts of exposure to cold weather and housing include economic costs associated with increased healthcare utilisation and reduced economic productivity, caused by work absenteeism due to cold-related illnesses (19). Exposure to cold housing has also been associated with social exclusion, truancy, educational under-attainment (14, 20) and criminal and anti-social behaviour (21). However, the extent and nature of the associations between exposure to cold housing and many adverse social outcomes are not well understood (21).

1.1.5 Historical overview of legislation, policies and guidelines to address winter- and cold-related adverse health and social outcomes in England

The four nations of the UK have relatively well developed legislative frameworks to address social factors associated with excess cold-weather-related adverse health and social outcomes, compared to other countries. Political interest on these issues gained prominence during the 1970s, when fuel poverty, broadly definable as the inability to afford adequate warmth at home, came to be recognised as a distinct social issue rather than simply as an aspect of general deprivation (22). This change in political thinking occurred in relation to the oil crises of 1973 and 1979, when Western countries experienced severe oil shortages due to political tensions with the Middle East (22). This impacted on the ability of households to afford adequate home heating (23). These events highlighted the potentially limited nature of fossil fuels, and energy conservation policies were subsequently developed by the UK government. It was at this time that the government officially recognised the inferior insulation standards of UK housing compared to other European countries. The government set out plans to introduce basic levels of insulation in public sector homes where it was lacking and new homes were required to conform to specified standards of loft insulation (24). In addition, home insulation grants were provided for the first time, to older people (aged over state pension age), individuals with disabilities and long term health problems, and low income households, funded by central government (25).

Christmas Bonus payments were introduced in 1972, under Edward Heath's Conservative Government. These one-off tax-free payments, made just before Christmas, were intended to help pensioners and individuals who claim certain welfare benefits to cope with increased fuel costs over the winter period. These payments are still made today but have not increased in line with inflation (26).

The UK experienced several exceptionally cold winters during the 1980s. It was during this decade that '*Exceptionally cold weather payments*' were introduced to help offset increased heating costs of people over state pension age during periods of severe cold weather. However, these payments were administered at the discretion of local government, which meant that the payments were being sanctioned in some areas but not in other, sometimes colder, areas (27). An amendment to the Supplementary Benefit Regulation in 1986 led to the introduction of a new system, in which exceptionally cold weather payments of £5 per week were made to householders aged ≥65 years, where average local temperatures fell below -1.5°C (28). Cold weather payments of £25 are now paid more widely, to individuals who are in receipt of certain welfare benefits, when local temperatures are recorded or forecast to be

an average of ≤0°C for seven consecutive days during the period between 1st November and 31st March (29).

Interest in fuel poverty increased from the early 1990s. In 1991, Oxford University graduate, Dr Brenda Boardman, published her book entitled '*Fuel Poverty*', based on her doctoral research (30). In her book, Dr Boardman distinguished between general poverty, caused by low income, and fuel poverty, which, she presented evidence to suggest, is additionally driven by high energy prices and thermally inefficient housing (30). Based on data from the 1988 Family Expenditure Survey, Dr Boardman defined fuel poverty as the situation where a household needs to spend more than 10% of its income after tax on fuel to maintain a satisfactory heating regime (30). Also during the early 1990s, the South East Public Health Observatory started to investigate fuel poverty, before other Public Health Observatories expressed an interest (31).

Fuel poverty policies have developed in England and elsewhere alongside environmental policies, which are aimed at reducing greenhouse gas emissions, including carbon dioxide, which are generated from sources including household energy use. In 1992, the United Nations held its second conference on Environment and Development in Rio de Janeiro, Brazil, at which discussions took place in relation to the impact of international economic development on environmental degradation (32). It was at this time that an international convention was developed to address climate change (32). This convention was extended in 1997, in the Kyoto protocol, which specified legally binding targets for member states of the United Nations to reduce carbon emissions (33). Household thermal inefficiency was recognised as contributing the most to greenhouse gas emissions. Consequently, improving the thermal efficiency of domestic housing in the UK was recognised as fulfilling a dual aim of reducing fuel poverty and carbon emissions.

The extent to which government policies can balance climate change and fuel poverty is subject to debate. This is due to the fact that climate change is associated with greenhouse gas emissions arising from the use of non-renewable forms of energy, whereas fuel poverty is often associated with the underuse or excessive cost of household energy (34). However, climate change mitigation policies that were later established in the UK, during the initial years of the twenty-first century, specified a requirement to have regard to '*the desirability of alleviating fuel poverty*' (cited in 35, p.3).

Following the election of the Labour Government in 1997, the Health Secretary, Frank Dobson, invited England's former Chief Medical Officer, Sir Donald Acheson, to produce recommendations on reducing health inequalities in the UK, including recommendations

relating to fuel poverty. Following the lead of the Black Report in 1980, a second review on health inequalities (the "Acheson" Report) was published in 1998 (36). The Acheson report concluded that health inequalities were fundamentally socioeconomic in nature and should be addressed across government departments by tackling the social determinants of health, in relation to income, education, housing, diet, employment and working conditions. Acheson identified the link between poor quality housing and poor health, and recommended "*Policies to improve insulation and heating systems in new and existing buildings in order to reduce the prevalence of fuel poverty*" (36, p.78). Subsequently, the UK Department of Health issued a white paper '*Saving Lives: Our Healthier Nation*', which identified two overarching goals for public health, namely to improve health and reduce health inequalities (37).

In 1999, the Winter Fuel Payment was introduced as a non-means-tested, tax-free annual cash payment, made usually in December, to households containing a person over state pension age to help with heating costs. The Winter Fuel Payment is currently worth about £169 per case on average (6) and is paid to households containing individuals aged ≥62.5 years. A recent economic evaluation attributed almost half of the reduction in EWM since 1999/2000 to the Winter Fuel Payment (6).

Following the recommendations of the Acheson Report on reducing fuel poverty, the Warm Homes and Energy Conservation Act 2000 was passed (35), which formally defined fuel poverty using the definition proposed by Boardman in 1991. The Warm Homes and Energy Conservation Act 2000 made it a legal requirement for the UK Government to publish and implement a strategy to eliminate fuel poverty and to set targets for the implementation of that strategy in England (35). The first official UK Fuel Poverty Strategy was released in 2001, and set a target of ending fuel poverty, based on the definition developed by Dr Boardman in 1991, in "vulnerable" households, defined as those containing elderly persons, young children or individuals with long term sickness or medical problems, in England by 2010, and the eradication of fuel poverty in all households by 2016 (38).

The UK Fuel Poverty Strategy 2001 aimed to achieve its fuel poverty reduction targets and to contribute to government goals relating to climate change, using national and area-based measures. These measures aimed to tackle the three underlying causes of fuel poverty that Dr Boardman identified in 1991, namely high energy prices, low household income and thermally inefficient housing (20).

The Warm Front Scheme was the main tool through which the UK Government aimed to eradicate fuel poverty in England. This was a tax funded programme that provided home maintenance grants to increase thermal efficiency in low income households. Additional

measures to reduce fuel poverty included increasing the accessibility of natural gas supplies to off-grid communities and negotiating fuel tariffs with energy suppliers (38).

Various additional climate change and energy policies were introduced during the decade from 2000-10, all of which were supposed to have regard for the alleviation of fuel poverty (35). In 2008, the Climate Change Act set a target of reducing greenhouse gas emissions by 80% by the year 2050 (39).

In 2007, the UK economy was affected by the global financial crisis and entered an economic recession in 2008. Between 2008 and 2010, the impact of the recession on household incomes was initially offset by factors including increased social welfare payments (40). However, after initial buffering from the impacts of the economic recession on household incomes in 2008 and 2009, household incomes started to fall, by 0.8% in 2010 (40). This was due to the impacts of austerity, which involved public sector job cuts and withdrawal of financial benefits amongst certain demographic groups, including working families and working-aged individuals with disabilities and long term health problems, and a rise in the 'working poor'(40). Reduced access to borrowing and high inflation also reduced income spending power. The associated fall in national household incomes was the first since 1981 and the largest since 1977 (40).

Despite a reduction in fuel poverty levels that occurred between 1996 and 2003, the number of fuel poor households subsequently increased and the government target to eradicate fuel poverty in vulnerable households by 2010 was not attained. This was attributed to increased energy prices from 2004/05 and reduced household incomes associated with the current recession (41).

In 2011, the Secretary of State for Energy and Climate Change, Chris Huhne, commissioned a review of fuel poverty. The Hills review (2012) concluded that the widely used definition of fuel poverty was inadequate, due to factors including that it included many wealthier households that could afford to spend ≥10% of their income on fuel without experiencing financial hardship (20). Subsequently, fuel poverty was officially re-defined in England in 2012, as a situation where a household's income falls below the official poverty threshold, or below 60% of median national household income, after having fuel bills of above the national median level, based on household composition and size (42). The Government argued that this would enable resources to be targeted where they are most useful. However, National Energy Action, a national fuel poverty charity, identified that this would reduce the number of households officially defined as being in fuel poverty without improving their circumstances (43).

Also in 2011, The Warm Homes Discount Scheme was introduced, which required domestic energy suppliers to provide £1.13 billion support for fuel poor customers over four years (44). The 'core group' who automatically receive this intervention are financially less well-off pensioners (45). However, low income non-pensioner households, including working age individuals with disabilities and chronic health problems, are assisted to a lesser extent under this scheme (45).

In 2012, the Warm Front Discount Scheme was phased out and replaced by the Green Deal, which aimed to reduce carbon emissions through improving thermal efficiency of private housing. Home improvements which are made under this scheme are paid for through household energy bills. It has been argued that this initiative will have adverse impacts on individuals from vulnerable households, as it involves the removal of non-repayable tax funded grants that were provided by the Warm Front Discount Scheme to improve thermal efficiency in low income households (46).

The Energy Company Obligation was introduced in 2013 and sets out an obligation for large energy suppliers to deliver energy efficiency measures to domestic energy users. This operates alongside the Green Deal and is intended to focus on low income and vulnerable households and hard-to-treat homes (47). However, there is lack of guaranteed support for low income households under this scheme (48).

The Fuel Poverty Regulation (England) 2014 set out a legal commitment to address fuel poverty, by improving the energy efficiency ratings of domestic properties. Energy performance of domestic and commercial properties in the European Union is measured using Energy Performance Certificate (EPC) ratings. This gives an energy efficiency rating from A (most efficient) to G (least efficient) (49). The Fuel Poverty Regulation (England) 2014 also specifies that all domestic properties will achieve a minimum energy efficiency standard of band C by 2030. This regulation also includes interim targets to ensure that as many homes as practicable attain energy efficiency standards E and D by 2020 and 2025, respectively.

In March 2015, the Conservative and Liberal Democrat Coalition Government published '*Cutting the Cost of Keeping Warm: A Fuel Poverty Strategy for England'* (50). This includes plans for implementing The Fuel Poverty Regulation (England) 2014. Reflecting the target specified in The Fuel Poverty Regulation (England) 2014, the current fuel poverty strategy specifies that '*as many homes as reasonably practicable will be improved to an [EPC] E rating by 2020, to a D rating by 2025 and to a C rating by 2030'*(50, p.6). Criticisms of the new legislation include lack of clarity over the meaning of the term '*reasonably practicable'*, in relation to the targets for improving thermal efficiency of domestic properties. In addition,

concerns have been raised about how the programme will be resourced in this period of reduced public spending. Also, it has been highlighted that thermal efficiency improvements are not keeping pace with energy prices increases; and that opportunities for incentives to improve thermal efficiency performance of households (e.g. the Renewable Heat Incentive) are not available to everyone.

Recent policy changes around fuel poverty have occurred in the context of government plans to reduce carbon emissions in line with the Climate Change Act 2008, in relation to the Energy Market Reform 2013(51) by switching to renewable energy sources.

In addition to the economic and political events that have occurred since 2007, climatic factors have influenced guidelines for addressing the health and social impacts of cold weather since 2011. After Europe experienced two excessively cold winters between 2009/10 and 2010/11, the UK Department of Health developed a Cold Weather Plan for England in 2011 (52), which has subsequently been published on an annual basis. The structure and scope of the Cold Weather Plan for England is similar to that of the Heat Wave Plan for England, which has been published annually since 2004, following the 2003 European heat wave.

The Cold Weather Plan for England aims to increase resilience against the adverse health and social impacts of extreme cold-weather conditions, by increasing public awareness and providing guidelines on how members of the public and relevant organisations should prepare for, and respond to, cold-weather events. The plan includes activities that should be completed on a year-round basis, during the winter period, in relation to predicted cold weather events and when cold weather events actually occur. The plan was developed in collaboration with the Met Office, and different levels of cold weather alert are cascaded down through relevant organisations (53). A preliminary evaluation of the Cold Weather Plan for England has suggested that the plan has the ability to reduce adverse health impacts and the burden on the English NHS of cold weather events (54). A more informative assessment can be delivered in the future, when data from more years are available to evaluate the effectiveness of the Cold Weather Plan for England.

The Cold Weather Plan for England is subject to an annual review by Public Health England and the Department of Health, including using information including data from the Public Health Outcomes Framework. This provides data on various public health indicators, including excess winter deaths and fuel poverty prevalence for England as a whole and for English Local Authority areas. It can be used to compare performance of English Local Authorities for reducing these cold-weather-related adverse outcomes (52).

In March 2015, the National Institute for Health and Care Excellence (NICE) published guidelines for health and other public sector staff to identify and support vulnerable children and older people from excess winter mortality and illness (17). Also, in March 2015, NICE published a quality standard, to prioritise areas for preventing excess winter deaths and illness associated with cold homes.

Most policy interest around risk factors for cold-weather-related adverse outcomes has occurred in England, Scotland, Northern Ireland and Wales. International policies have been developed by the European Commission and members states of the European Union (EU) to tackle fuel poverty, although implementation of the recommendations from these policies has varied between countries (55). A report that was recently published by UK Fuel Poverty Charity National Energy Action, set out proposals to develop an EU-wide understanding about the nature of fuel poverty, changes to the current EU-legislative framework to support the long term eradication of fuel poverty and for binding targets for energy efficiency standards in low income households across the EU (56).

In New Zealand, research interest around EWM and fuel poverty began in the early 1990s. Despite having a temperate climate, like the UK, New Zealand has high levels of EWM, excess winter morbidities and fuel poverty (57). This has been linked to the thermally inefficient housing stock of the country, caused by a history of poor housing regulations. Also, the main heating source for housing in New Zealand is electricity, a relatively expensive fuel, and the country has a largely unregulated energy market which has led to rising electricity prices (57). Political interest around the problems associated with thermally inefficient housing began in 2004 and this issue has also been identified in subsequent government documents, but unlike in the UK and the EU, there has been no legal commitment to reducing fuel poverty in New Zealand (57).

1.2 Study rationale, aims and research questions

Despite having a relatively well developed and evolving legislative framework for reducing excess adverse health and social outcomes compared to other countries, average EWM indices across winter seasons remain high in England compared to other Northern European countries (5, 9). Excess winter mortality indices are also highly variable from one year to the next, although relative geographical synchrony in EWMIs between English regions each year indicates that systematic factors drive variations in EWM (see figure 1.2). Increased knowledge regarding mechanisms that influence health and social outcomes in relation to winter season and cold weather, could improve interventions to reduce EWM and other

adverse impacts, including cold-related health and social inequalities between geographical areas and population sub-groups.

The aims of the research presented in this thesis are (i) to identify a comprehensive range of factors associated with adverse health outcomes in relation to winter season and cold exposure, (ii) to investigate pathways between cold weather and adverse health outcomes in relation to these explanatory factors and (iii) to define and explore the nature of associations between cold weather, other explanatory factors and spatial and temporal variations in winter- and cold-weather-related excess morbidity and mortality rates.

 Specific research questions are:

1. What are the key social factors that affect vulnerability to excess winter- and cold-related adverse health and social outcomes, according to current research?
2. What are the mechanisms by which the factors identified from the answer to question one moderate winter- and cold-weather-related morbidities and mortality?
3. Which of the factors identified from question one are associated with spatial and temporal variations in winter- and cold-weather-related morbidity and mortality rates?
4. Does the same combination of variables drive spatial and temporal variations in cold-weather-related morbidity and mortality rates?
5. What are the implications of the answers to questions 1-4, for policy interventions to reduce winter- and cold-weather-related morbidity and mortality?
6. What further research is needed to identify ways to reduce winter- and cold-weather-related morbidity and mortality?

1.3 Geographical scope of the research

The current research will focus on the situation in England. This is because the nature of excess adverse health outcomes that occur in relation to cold weather and winter season is likely to differ between countries to a greater extent than within countries as a result of international differences in factors including climatic conditions, policies and adaptation to prevailing weather. Focusing on one country may therefore produce more accurate and useful information about the potential causes of excess winter- and cold-weather-related adverse health outcomes and of ways to reduce them. However, the outcomes of this research may have relevance to the other devolved nations of the UK as well as internationally.

1.4 Outline of the thesis

This thesis comprises nine chapters. In this first, introductory chapter, I have provided a contextual overview of the nature of winter- and cold-weather-related excess adverse health

and social outcomes in England and described social policies and guidelines to address this issue. I also identified the aims, research questions and scope of the project. In chapter two, I present the first part of a systematic literature review, which synthesises evidence from studies that identify factors associated with increased vulnerability to different winter- and cold-related adverse health and social outcomes. Subsequently, in chapter three I identify evidence from studies that evaluated the effectiveness of interventions for reducing the adverse health and social impacts of cold exposure. In chapter four, I consider the mechanisms by which factors identified from the systematic review in chapters two and three influence cold-related morbidity and mortality. In chapters five, six and seven, respectively, I present the methods to identify, link and analyse health and social data, to explore associations between aspects of cold weather, other exploratory factors and spatial and temporal variations in adverse circulatory and respiratory health outcomes. I present the results from these analyses in chapter eight. Finally, in chapter nine, I discuss the results and examine the extent to which is has been possible to address the research questions posed and the extent to which it is possible to make recommendations for policy interventions and further research in this important field of study.

Chapter Two.

Social moderators of associations between winter season, cold exposure and adverse health and social outcomes: a systematic literature review of aetiology studies

2.1 Introduction

Cold weather is associated with various adverse health and social outcomes. There is a positive association between mean winter temperatures and EWM rates, between English regions and internationally (5, 9) (see section 1.1.3). This indicates that factors in addition to low environmental temperatures modify the risk of winter- and cold-related adverse health outcomes.

Research has identified various demographic (e.g. age), clinical (e.g. pre-existing illnesses), environmental (e.g. meteorological parameters), biological (e.g. circulating infections), socioeconomic (low income) and housing (thermal inefficiency) factors associated with increased risk of winter- and cold-related adverse health and social outcomes (1). Behavioural factors, including active smoking, have shown less consistent associations with illnesses and deaths in relation to cold weather and the winter season (1).

In recent years, two systematic reviews (1, 58), have been published, one of which was my own (1), which summarise the current state of knowledge in relation to the potential causes of winter- and cold-related adverse health and social outcomes. However, the evidence presented in these reviews was limited in terms of the range of study designs from which evidence was included, risk factors investigated and time periods of study. A more comprehensive review was completed by researchers from the London School of Hygiene and Tropical Medicine in 2014, to support the development of guidelines to reduce excess winter deaths and illnesses in elderly and vulnerable persons, commissioned by NICE (59). However, this did not consider evidence in relation to the aetiology of specific outcomes.

The aim of the systematic literature review in this chapter is to present a comprehensive summary of the literature on the aetiology of different winter- and cold-related adverse health and social outcomes. This information, and the results from the systematic review of intervention evaluation studies presented in chapter three, is used to conceptualise the mechanisms by which explanatory factors can influence the risk of morbidity and mortality from specific medical condition groups, in chapter four.

2.2 Methods

Systematic methods were used to locate, evaluate and synthesise evidence from quantitative and qualitative observational studies that explored the potentially modifying effects of socioeconomic, housing or behavioural factors on health or social outcomes in relation to cold exposure or winter season.

2.2.1 Search strategy

Electronic searches were conducted in October 2012 in Medline, PsychInfo, PubMed, Scopus and Web of Science, using combinations of Medical Subject Headings and keywords relating to climatic, socioeconomic, housing and behavioural exposures and outcomes of interest. Searches were restricted to human studies published in English language, where this facility was available (See appendix A for the electronic search strategies used to locate literature). No geographical, date or other restrictions were placed. Search alerts were created, which enabled new literature to be integrated into the review up until May 20th 2014. At this point, it was decided that a sufficiently large number of studies had been retrieved. Expert advisors from UK and international universities and third sector organisations provided additional references. Reference lists from relevant systematic reviews were also searched to locate additional, relevant studies (1, 3, 58, 60).

2.2.2 Inclusion and exclusion criteria

Figure 2.1 shows the flow of studies at each stage of the review process. Included studies had to be conducted on human participants, published in English and to quantify or qualify the effects of behavioural, socioeconomic or housing factors of contemporary relevance to England, on winter or cold-related health or social outcomes. Full details of the inclusion and exclusion criteria, including details of exposures and outcomes considered relevant to this review, are specified in appendix B. Titles and abstracts (where available) of located references were screened against the review inclusion criteria. The full texts of any references considered potentially eligible for inclusion were obtained in full. Exclusion reasons were recorded during the second screen. Unobtainable references were excluded.

Included studies were then separated based on whether they: i) investigated the effects of factors which influence vulnerability to winter- or cold-related health and social outcomes or ii) evaluated the effects of interventions on winter- or cold-related health and social outcomes. The current chapter includes evidence from vulnerability studies only. A review of the evidence from intervention evaluation studies is presented in chapter three.

2.2.3 Data extraction and appraisal

Details about the characteristics of each included study and their results were extracted onto standardised summary tables. The following data were extracted: author names and date of publication, country of origin and dates during which the study took place, study design, participant characteristics and study setting, exposures of interest, outcomes investigated, confounders and effect modifiers that were controlled for in the study design or analysis, name of the tool used to assess study quality and associated appraisal score.

Most of the studies in the review had a quantitative epidemiological design. These studies were appraised using the Quality Assessment Tool for Quantitative Studies (61). This is a generic tool for assessing the risk of bias of quantitative epidemiological studies in relation to the following dimensions: selection bias, study design, confounders, blinding, data collection methods, withdrawals and drop-outs. This tool has been found to have good inter-rater and test-retest reliability (62, 63); this is likely to be due to provision of a dictionary, which enhances robustness of the appraisal process (64). This is particularly important given that the systematic literature review presented in chapters two and three of this thesis, was undertaken by one person (the author). A limitation of this appraisal tool is the lack of questions pertaining to specific research designs, due to its generic nature. However, there is no well-designed and validated tool to appraise all study designs in this review, including cross-sectional studies (65) and case-series. Consequently, I was unable to use different tools to appraise studies that employed specific methods. Use of the Quality Assessment Tool for Quantitative Studies tool enabled broad comparability of study quality in relation to aspects that are likely to affect the ability to make causal inferences regarding associations between exposure and outcome variables, across the heterogeneous studies in this review.

A wide number of tools exist to appraise qualitative research, although the application of quality criteria to these studies is widely debated (66). In particular, there is a lack of agreement over which criteria can be used assess the quality of qualitative research (66). The Critical Appraisal Skills Programme (CASP) tool for qualitative studies was used to appraise the four qualitative studies in this review (67). This tool is recommended by the Cochrane Collaboration Qualitative Methods group for reviewers with little experience of qualitative research (Hannes, 2011 cited in (68)). CASP appraisal tools contain sub-questions, which enable the reader to assess the degree to which each study meets each specific criterion (69).

2.2.4 Data synthesis

A narrative approach was used to synthesise data from included studies. Meta-analysis was not possible nor would yield meaningful findings due to heterogeneity in study designs,

populations, risk factors and outcomes. However, quantitative results are reported in the narrative synthesis, in section 2.3.3.
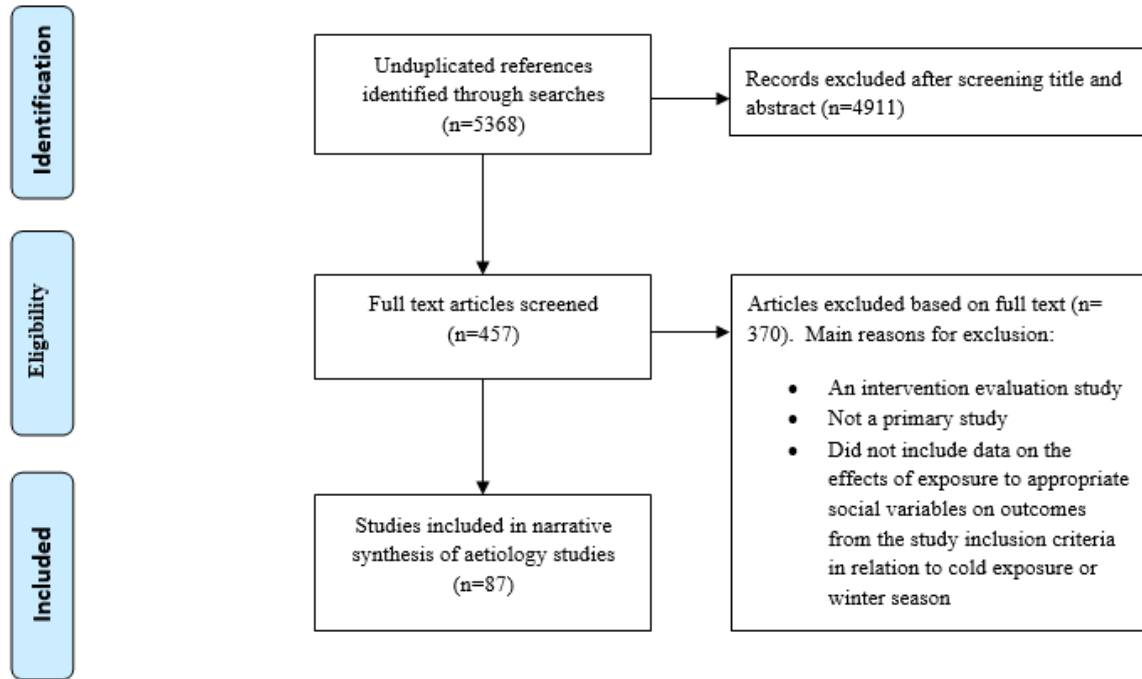
Figure 2.1: Flow of included and excluded studies. Diagram source: (70).

2.3 Results

2.3.1 Number and characteristics of studies

The number of unduplicated studies identified from searches was 5368. Eighty-seven met the inclusion criteria for this systematic literature review of aetiology studies. Thirty studies came from the UK, eleven from the USA, six were from Finland, five from Ireland, four each from Sweden and Australia, three each from New Zealand and China, two pan-European studies and two studies from each of Austria, Brazil, Canada, the French territories, South Korea, Taiwan and one each from Estonia, Germany, Israel, Japan, Norway, Portugal and Romania. Study designs included twenty-six ecological studies, twenty-two cross-sectional studies, twenty-one cohort studies, ten case-series, four qualitative studies, three case-control studies and one case-cross-over study.

2.3.2 Study quality

Eighty three studies used quantitative epidemiological designs. Forty three of these studies received a weak global rating using the Quality Assessment Tool for Quantitative Studies, thirty five were rated as being of moderate quality and five were rated as being strong. Scores for qualitative studies, assigned using the appropriate CASP tool, ranged from six to nine out of ten.

2.3.3 Study results

The main results from the eighty seven studies investigating associations between exposures and winter- or cold-related adverse health or social outcomes are presented in this section, in a narrative synthesis. The evidence is grouped by outcome. Many of the included studies examined the impacts of multiple exposures, often each in relation to more than one outcome, and therefore appear multiple times in the narrative synthesis below.

i. *Studies investigating factors associated with modified risk of winter- or cold-related mortality from all causes*

The following information summarizes the evidence in relation to the effects of socioeconomic, housing and behavioural factors on non-condition-group-specific mortality, in relation to winter season and cold exposure.

Effects of socioeconomic factors

Six studies examined associations between composite deprivation indices, which are used to assess the level of deprivation at area level, and all-cause mortality. Two of these were ecological time series analyses from England, conducted at small area-levels, which found non-significant associations between EWM rates and Townsend Deprivation Index scores across census super output areas (71) and enumeration districts (72). The Townsend Deprivation Index assigns a normally distributed deprivation score based on an equal weighting of the proportions of the population who are: unemployed, non-car owners, non-home owners and live in over-crowded accommodation, from UK Census data.

Another study, also from England, investigated the association between Carstairs Deprivation Index and risk of winter death (73). The Carstairs Deprivation Index assigns deprivation scores to small areas using census data on household overcrowding, male unemployment, belonging to social classes 4 or 5 and non-car ownership. Participants were a cohort of people aged 75 years and over who were registered with one of 106 general practitioner (GP) practices in England. A deprivation score was assigned to each participant, based on the enumeration district in which they lived. The risk of winter death was not significantly higher for participants from the most socioeconomically deprived areas compared to those from the least socioeconomically deprived areas when taking the 95% CI into account (winter to non-winter mortality ratio: 1.02, 95% CI 0.87-1.19). The assignment of area level deprivation scores to study participants involves making the assumption that individuals conform to the average level of deprivation for their area of residence. This is particularly problematic when

the areas of interest are known to be socially heterogeneous, which is the case for census enumeration districts.

Townsend and Carstairs deprivation indices were developed during the 1980s, using census data, and may no longer be accurate predictors of socioeconomic deprivation. There is evidence, for example, that car ownership may be a stronger indicator of socioeconomic deprivation in urban compared to rural areas (74). This is likely to reflect the increased reliance on cars amongst individuals from geographically remote areas, regardless of socioeconomic position, in order to increase their access to facilities. In support of this, data from the 2010 UK National Travel Survey indicated that 90% of rural households had access to a car compared with 57% of households from London (75). In addition, the right to buy scheme was introduced during the 1970s, which enabled social housing tenants across the UK to purchase their home at a discounted price (76). This potentially reduces the validity of non-home ownership as an indicator of socioeconomic deprivation because home ownership has increased amongst the more socioeconomically deprived groups.

Two ecological time series studies from New Zealand found non-significant associations between small area level score on the New Zealand Deprivation Index, which comprises two measures of income and one measure of each of the following variables: employment, transport, support, qualifications, home ownership and household occupancy level, based on data from the New Zealand Census, and EWM (77, 78). As with other deprivation indices, the New Zealand Deprivation Index has been criticised for its simplicity, as it provides a measure of 'deprivation', which is a complex issue, across a small number of domains in relation to theoretical considerations as to what constitutes appropriate measures of this construct (79).

One of the studies from New Zealand (77) used data from four Regional Health Authorities (North, Central, Midland and South) and found a lack of seasonal variation in mortality between regions (p = .93). The analysis of geographic variations in seasonal mortality is valuable in studies that use data from a country with significant climatic variations between constituent areas. New Zealand, for example, comprises North and South Islands, which have mean annual temperatures of 16°C and 10°C, respectively (80). Variations in topography and altitude within New Zealand also create temperature differences across the country. However, as noted by the authors of study (77), the use of four Regional Health Authorities is a relatively insensitive way of assessing the impact of geography on seasonal mortality, as this approach does not account for climatic variations within regions, or potential urban-rural differences. The second study from New Zealand (78), assessed urban-rural variations in EWM, but did consider additional sources of geographical variations in temperature.

Another ecological time-series study analysed potential modifiers of cold-weather-related-mortality in administrative districts of Sao Paolo, Brazil, using daily counts of deaths from 1991-94 (81). The results of this study indicated a small effect of socioeconomic deprivation on warm-weather-related deaths, but not on cold-weather-related deaths. A composite, area-level measure of socioeconomic deprivation was used in this study, which comprised data on mean income level, average level of education and percentages of homes with an adequate sewerage system, with piped treated water services and of overcrowded households. The study authors did not discuss the validity of these measures as being the most suitable available indicators of socioeconomic deprivation in the study area.

An ecological time-series study from Japan (from 2002-7) investigated income as a potential modifier of the temperature-mortality association, using data from six cities that are located from the North to South-West of the country. In relation to exposure to cold weather, an increased risk of mortality of 3.47% (95% CI 1.75%–5.21%) was found, based on comparisons between the first and tenth temperature percentiles (82). Evidence of acclimatisation was also found, with populations from the climatically colder north of the country appearing to adapt more effectively to low temperatures. However, average income did not significantly modify the association between cold weather and mortality risk in this study (p>.10).

Three studies from the UK, including two ecological time series studies and one cohort study, investigated occupational measures as potential risk factors for cold-weather-related mortality (83-85). None of the studies found significant associations between occupational group and seasonal mortality risk.

Another ecological time series study examined education as a potential modifier of the association between temperature and all-cause mortality across seven cities in the USA, from 1986-93 (86). The following cities were included in the analysis: Denver, Colorado; Detroit, Michigan; Minneapolis and St. Paul, Minnesota; New Haven, Connecticut; Pittsburgh, Pennsylvania (for 1986–1993); Chicago, Illinois, and Seattle, Washington (for 1988– 1993). Mean temperatures in these cities across the study period ranged from 7.4-10.3°C. Pooled results across all cities showed an increased rate of heat and cold-related deaths in areas with higher proportions of black (African American) (compared to white) people and in areas where educational attainment was lower. City-specific effects also showed increased effects of cold weather on mortality in relation to black compared to white racial groups, except in Detroit and Minneapolis, where effects were approximately equal. The generally increased effects of cold weather on mortality rates in areas with higher proportions of black persons

may reflect health and social inequalities between racial groups in the USA, with black people having lower average educational attainment and worse health outcomes overall (non-seasonally), compared to white Americans. Interestingly, the study found higher cold-weather-related death rates amongst individuals aged <65 years compared to persons aged ≥65 years. This is contrary to most evidence, which suggest that older people are most susceptible to cold- weather-related mortality. However, the association between older age and reduced cold-weather-related mortality in this study may have been due to confounding of the association between age and mortality by medical access. This is because the USA does not have a nationalised healthcare system, but most individuals aged ≥65 years are eligible for free national healthcare insurance.

Another ecological time series study, which used data from eleven large metropolitan cities in the Eastern USA, examined the proportion of houses with air conditioning in the south and heaters in the north, which are indicative of socioeconomic status of the city populations in the study area, as potential modifiers of the association between cold weather and mortality risk (87). Data from the following areas were included in the analyses: Chicago, Illinois; Boston, Massachusetts; New York; Philadelphia, Pennsylvania; Baltimore, Maryland; Washington DC; Charlotte, North Carolina; Atlanta, Georgia; Jacksonville, Tampa and Miami, Florida. These areas were selected for the analyses as they incorporate a broad geographical coverage, with climatic variations between areas. It was found that older age (percentage of the population aged ≥65years) was associated with a significantly increased mortality risk in relation to cold weather. The temperature-mortality association varied in relation to latitude, as the effects of cold weather on mortality risk were stronger in generally warmer cities, which are located further south, whereas climatically colder cities, located further north, had an increased risk of mortality in relation to warmer temperatures. This may reflect biological and / or cultural adaptations to cold temperatures amongst populations from more northern, colder areas. In relation to cultural adaptations to cold weather conditions, the percentage of the population with heaters in the north was associated with a non-significant reduction in the steepness of the cold-weather-related mortality slope.

Two ecological time-series studies investigated independent associations between multiple indicators of socioeconomic deprivation and mortality risk. One of the studies, from the UK, found that older people, particularly those in nursing and care homes, were most vulnerable to the effects of temperature (88). The study also found that vulnerability to either heat or cold was generally not modified in relation to individual area-level measures of deprivation,

including employment, income, housing and health. However, in rural populations, adverse cold effects were slightly stronger in more deprived areas.

A different study, from the USA, found increased susceptibility to cold-weather-related mortality amongst older people and that vulnerability to either heat or cold was not modified by indicators of deprivation (89). This study used data from 107 communities, which comprised individual counties and groups of adjacent counties, across the following seven regions of America: industrial Mid-West, North-East, North-West, Southern California, South-East, South-West and Upper Mid-West. Indicators of deprivation that were used in the study included median household income and percentages of the population who were (i) unemployed, (ii) did not have a high school degree or (iii) commuted using public transportation. Communities with a higher percentage of Black/African Americans had higher cold-weather-related mortality rates. It was also found that the effects of cold weather on mortality were increased in Southern (climatically warmer) compared to Northern (climatically colder) regions. Conversely, the effects of heat on mortality rates were generally larger in the Northern compared to Southern regions. This may reflect biological and / or cultural adaptations of the study population to their regional climate.

Effects of housing-related factors

A small area level ecological time series study (electoral ward level, 1986-96) from England found no significant associations (based on 95% CIs) between EWM and (i) the proportion of owner-occupied homes containing one or more residents of pensionable age (OR 0.995, 95% CI 0.987-1.003), and (ii) the proportion of privately rented households containing one or more residents of pensionable age (OR 1.003, 95% CI 0.995-1.010) (90).

A study from New Zealand found that compared to home owners, people living in rented accommodation were at significantly higher risk of winter death (OR 1.05, 95% CI 1.01 to 1.10) (78). However, this study did not compare winter mortality between tenants of privately and socially rented housing. In addition, this study did not consider potential geographical variations in relation to the effects of explanatory variables, including housing tenure, on winter mortality rates across the country.

Two ecological time-series studies from the UK did not find significant associations between rural dwelling and cold-weather-related deaths (88) or EWM (91). However, one study found slightly stronger effects of deprivation on cold-weather-related mortality rates in rural, compared to urban areas (88). A study from New Zealand, found that urban dwellers were at

increased risk of winter mortality compared to rural populations (OR 1.056 (95% CI 1.015-1.097)) (78). It is likely that different factors increase the risk of cold-weather-related mortality between rural and urban locations. For example, rural areas generally have increased cold exposure and higher rates of fuel poverty; whereas urban areas have higher levels of air pollution, which can cause and exacerbate cardiovascular and respiratory conditions.

Effects of lifestyle-related factors

The aetiology of obesity is complex. Genetic and metabolic issues have been identified as causes of obesity (92). However, lifestyle factors, including an energy imbalance between calorific intake and expenditure, are considered to be major contributors to obesity prevalence (92). Body Mass Index (BMI), which is a ratio of weight to height, is the most widely used indicator to classify individuals as being underweight, normal weight, overweight or obese. Obesity is defined by the World Health Organization as the situation where a person's BMI is greater than or equal to 30 (93). An ecological time series analysis found a borderline significant association between national obesity rates and coefficients of seasonal variations in all-cause EWM between 14 European countries (regression coefficient=0.30, p=0.05) (8). Obesity could increase the risk of cold-weather-related cardiovascular mortality, due to increased blood pressure and strain on the heart amongst obese individuals. However, ecological studies provide weak evidence of causal associations between exposures and outcomes due to the ecological fallacy, whereby associations that exist between exposures and outcomes at area level are wrongly assumed to exist for individuals within the population under investigation. For example, where obese individuals are assumed be at high risk of dying during the winter due to living in a country where obesity and EWM are correlated. Also, like other observational (non-experimental) studies, ecological investigations are prone to confounding, which refers to a situation whereby a third (extraneous) variable is independently related to an explanatory and dependent variable in a statistical model, potentially causing misinterpretation of the nature of association between them. For example, countries with higher obesity rates may have increased rates of general deprivation and associated risk factors for adverse health outcomes.

Two studies investigated smoking as a potential risk factor for all-cause mortality during the winter season (8, 84). One of the studies was a pan-European ecological analysis, which found no significant association between smoking rates and relative EWM across 13 countries (8). The other study found no significant association between a multivariable risk score,

which included data on the participants' smoking status, and seasonal mortality; however, the independent effects of smoking status were not assessed in this study (84).

Summary of evidence – studies investigating factors associated with modified risk of winter- or cold-related mortality from all causes

Composite and most individual measures of socioeconomic deprivation were not independently and significantly associated with mortality in relation to cold weather or winter season. There was some evidence that socioeconomic deprivation is associated with a slight increased risk of cold-related mortality in rural populations (88). Rented housing tenure and urban dwelling were associated with significantly increased risk of winter mortality in a study from New Zealand (78). Vulnerability factors, including older age (81, 87-89); younger age (<65 years) and black ethnicity in the USA (86), and the presence of medical complications (73), were independently and significantly associated with increased risk of cold-weather-related mortality. Lifestyle-related factors, including active smoking and obesity, were not significantly (at p<0.5 level) associated increased risk of all-cause mortality in relation to winter season or during periods of cold weather.

ii.   Studies investigating factors associated with modified risk of circulatory illnesses and deaths in relation to winter season or cold exposure

In this section, I present evidence pertaining to the effects of socioeconomic, housing and behavioural factors on winter- and cold-related risk of illness and mortality from circulatory conditions.

Effects of socioeconomic factors

Two ecological time series studies examined associations between composite deprivation indices and cold-weather-related cardiovascular risk (94, 95) One of the studies found that health regions of Quebec with a significant excess of winter Ischemic Heart Disease (IHD) hospitalisation rates had higher social or material deprivation index scores (p<0.01), calculated using census variables (94). Smoking and other behavioural factors could have mediated the association between aspects of deprivation and IHD hospital admissions. The other study (95), which included data from 349 townships located across mainland Taiwan (i.e. excluding Taiwanese islands), found that a composite measure of 'social disadvantage', comprising percentages of uneducated population, single-parent families and aboriginal population, was associated with a significantly increased risk of cardiovascular mortality following extreme cold-days (social disadvantage OR 1.038, 95% CI 1.112-1.075). However, a second indicator termed 'lack of economic opportunity', which included unemployment rate

28

and percentage of labourers working outside the county of residence, was not significantly associated with cardiovascular mortality rates after extreme cold days (OR 0.996, 95% CI 0.977, 1.016) (95). Taiwan is a country with relatively mild winters, although geographical variations in temperature exist between urban and rural areas. Study (95) used data from townships across Taiwan. However, the effects of rurality on cardiovascular mortality were assessed (see section on the effects of housing-related factors on circulatory health outcomes, below).

An ecological study from the UK found no clear association between socioeconomic deprivation, which was measured using 'A classification of Residential Neighbourhoods', and excess winter rates of finished consultant episodes for IHD. The data for this study were collected for the summer and winter (defined as May-August and November-February, respectively) periods of the years 1990-91 and 1991-92 (96). However, summer morbidity rates were higher amongst less affluent groups. The authors of this study attributed these findings to the seasonality of differences in healthy lifestyles between socioeconomic groups. For example, more affluent individuals are likely to have increased opportunities for outdoor recreation and associated cardiovascular health benefits during the summer months, compared to less affluent groups. During the winter months however, individuals from more affluent population groups have more restricted opportunities for outdoor exercise due to adverse climatic conditions; this reduces their health advantage over individuals from more deprived areas.

A classification of Residential Neighbourhoods assigns a 5-point deprivation index to UK postcodes based on associated social and lifestyle characteristics of different types of housing based on census and other administrative data (96). However, as with other indices, the socioeconomic classification of areas over a limited range of categories fails to capture social heterogeneity within areas.

Four other studies, from England (including data from all English regions), Sweden, the USA (Massachusetts) and rural Northern China, found non-significant effects of the following variables on cold-weather-related cardiac risk: occupational group (83); prevalence of manual workers, unemployment rates and proportion of low income earners (97); income poverty (98) and educational attainment (99).

Effects of housing-related factors

Seven studies examined associations between aspects of housing and winter- or cold-related cardiovascular outcomes. A small area level ecological time series study from England, linked

cardiovascular deaths that occurred from 1986-96 with data from the 1991 English House Condition Survey (83). The results showed that older age group, female gender, private rented or owner occupied housing tenure, housing region (no obvious north-south trend was observed), older property age, housing dampness, lack of central heating, low household thermal efficiency rating and colder hall temperature were associated with significantly increased risk of excess winter cardiovascular mortality (p values for trend all ≤0.05).

A cohort study from England found that living room temperature was significantly inversely associated with winter total cholesterol concentrations, based on a sample of 96 community living participants aged between 65-74 years (regression coefficient -0.03, CI -0.04 to -0.008, p = 0.005) (100). A cross-sectional survey from the UK found that residing in an area with colder climatic conditions plus indicators of worse quality housing, based on measures of age and condition of properties, were associated with significantly increased risk of diastolic hypertension (OR 1.25, 95% CI 1.01-1.53), using data from the Health and Lifestyle Survey (101). A case-series of 18,388 cardiac hospital inpatients during a winter period in Portugal found that high proportions of patients reported being exposed to cold housing conditions prior to admission (102).

An ecological study found that relative excess winter mortality from cardiovascular disease in Ireland was 2.1 times that in Norway, despite the fact that Ireland has a warmer climate (103). The study authors attributed this to better household thermal efficiency standards in Norway compared to Ireland. However, the two countries differ in terms of other factors which are likely to influence EWM rates, potentially including biological and cultural adaptation to cold weather conditions, a stronger social welfare system and generally superior housing standards in Norway compared to Ireland.

A pan-European cross-sectional survey found that out of four measures of cold-housing, only a measure of indoor damp and mould, which is caused by cold indoor environmental conditions, was related to self-reports of doctor diagnosed cardiovascular conditions in older people (104). An ecological study which included data from townships across mainland Taiwan, found that rural dwelling was a significant predictor of post-cold-surge cardiovascular mortality (4.8% average increase in risk per one quartile increase in rurality score) (95). This is possibly attributable to reduced healthcare access in rural compared to urban populations of Taiwan.

Effects of fuel poverty

An English cross-sectional study found that using less fuel due to worry about fuel costs was significantly associated with the presence of cardiovascular disease (CVD) (p≤0.05), after standardising for various factors, based on 7,461 interviews (105).

Effects of lifestyle-related factors

An ecological study from Quebec, Canada, described in the section on socioeconomic deprivation and circulatory health outcomes, found hospital admission rates for IHD during the winter season were higher in health regions that had higher smoking rates (94). However, these areas may also have had higher levels of other deprivation-related risk factors for cardiovascular disease (e.g. obesity, diabetes and hypertension), which were not included in the analyses. In addition, the study also found excess IHD hospital admissions in some regions with moderate or low levels of smoking.

A cohort study from California, the USA, investigated the effects of exposure to tobacco smoke on sympathetic nerve activity using the cold-pressure test, in which the hand of active, passive and non-smokers were submerged in ice cold water for a short period of time in order to stimulate sympathetic nerve activity (106). It was found that mean sympathetic nerve activity (total activity per minute) responses to the cold-pressure test were significantly greater, by approximately 100%, in passive smokers compared to current, former or never smokers (all p<0.01). This was regardless of menstrual phase in women, which influences sympathetic nerve activity. The authors of this study suggested that exposure to tobacco smoke could increase cardiac risk through altered sympathetic nerve activity. However, sympathetic nerve activity response to the cold-pressure test did not differ significantly in current smokers compared to past smokers and never smokers, possibly due to physiological tolerance to the effects of nicotine amongst active smokers.

Four studies, which came from rural Northern China, Finland, Norway and South Korea, and investigated the potential modification effects of smoking on cold-weather related cardiovascular health outcomes, found only non-significant associations (99, 107-109). Four additional studies found that a high proportion of cold-weather-related cardiac hospital admissions were active smokers, but significance was not assessed due to the small number of cases examined and the lack of control groups in these studies (98, 110-112).

The inconsistent associations between tobacco cigarette smoking and measures of cardiac risk between studies may reflect a lack of seasonality in relation to the adverse cardiovascular health impacts of smoking.

A cross-sectional study from rural Northern China found that alcohol consumption was significantly, positively associated with diastolic blood pressure response to the cold pressure test (regression coefficient = 1.810, p = 0.04) (99). Another study found no significant association between alcohol consumption, assessed using information on patient medical records, and IHD hospitalisations during cold-periods (107); however, data on alcohol consumption were missing for 12% of participants in this study.

Five studies investigated synergistic associations between cold weather or winter season, dietary intake and cardiovascular disease risk (99, 100, 109, 113, 114). One of these was a case-control study, from South Korea (109). It was found in this study that that older age, cold-exposure severity and self-reported milk intake were associated with significantly increased risk of hypertension in cold-exposed workers, whose odds ratios were 5.204 (95% CI 1.440-18.812), 2.674 (95% CI 1.080-6.618) and 0.364 (95% CI 0.141 – 0.942), respectively.

A cohort study from Israel found that a winter increase in dietary intake of saturated fat was significantly correlated with an increase in serum total and low density lipoprotein cholesterol and body mass index (BMI) during the winter period (p<0.05), in a sample of 94 male industrial employees (113). Serum cholesterol and BMI are both risk factors for cardiovascular disease.

A cohort study from Austria found that cardiovascular disease risk profiles improved with seasonal change (from winter to summer) in women who had Polycystic Ovary Syndrome after a 20-week lifestyle intervention, which included a low calorie diet with and without physical activity (114). However, this improvement was also found in a group that started the intervention during the summer and finished in the winter, which indicates a lack of seasonality of the effectiveness of the intervention. An English cohort study found that participants had an increased intake of saturated fat during the winter (100). However, this did not contribute significantly to increased serum cholesterol level, which is a risk factor for heart attack.

Five studies investigated measures of physical activity as potential modifiers of the association between cold-exposure and cardiac risk (99, 110-112, 115). A cohort study from Quebec, Canada, investigated associations between physical activity and seasonal blood pressure changes in a sample of individuals with type 2 diabetes (115). Results of the study showed that step counts averaged at a sedentary level in fall (autumn)/winter (mean 4,901 steps per day) and at a low active level in spring/summer (mean 5,659 steps per day). Also, systolic blood pressure was higher in fall/winter than spring/summer. However, the fall/

winter increase in systolic blood pressure could have been caused by other seasonal factors, including exposure to winter climatic conditions and seasonal weight increase during the winter period. Physical activity is known to have beneficial effects on the cardiac system. However, intensive physical activity amongst unfit individuals could increase cardiac risk, especially when exposed to cold-environments.

Three case-series found that intense physical activity in cold weather conditions was associated with increased cardiac risk. One study, from the French Alps, found that 76.3% of patients hospitalised after experiencing a heart attack experienced this outcome within one hour of heavy physical activity, mainly during or after skiing (110). Two other studies, one from Virginia and the other from Detroit, both located in the USA, which investigated risk factors in patients hospitalised for cardiac events after snow shovelling, found that patients tended to have multiple cardiovascular risk factors. These included previous occurrence of acute myocardial infarction, family history of heart disease, smoking, obesity, having high cholesterol, hypertension, diabetes mellitus, being habitually sedentary and shovelling between 6 and 8am (the coldest time of day) (111, 112). This research indicates that cold exposure and strenuous physical activity could trigger cardiac events, especially amongst individuals with other cardiac risk factors. However, significance of the association between strenuous physical activity and cardiac risk in cold weather conditions was not assessed, due to the small number of cases in each study and the absence of control groups. Also, the effect of cold exposure was unclear from these studies as there was a lack of comparison between heart attack rates for individuals in relation to physical activity in warm environments.

A cohort study from rural Northern China found that self-reported level of physical activity was significantly, inversely associated with systolic blood pressure response to the cold pressure test (regression coefficient -0.101, $P = 0.01$) (99). This study also found that higher BMI was associated with higher maximum systolic blood pressure responses to the cold pressure test (regression coefficient $= 0.132$, $P = 0.04$) (99).

A study from Finland, described in the section on alcohol consumption and cardiac risk, investigated risk factors associated with intra-cerebral haemorrhage (ICH) hospitalisations amongst patients treated at the same hospital (107). Untreated hypertension was associated with a 3.6-fold increased risk of ICH hospitalisation during the cold-period (OR 3.60, 95% CI 1.27-10.21, $P = 0.016$). Other factors, including having diabetes, medication use, alcohol consumption, sex and age, were not associated with significantly increased risk. However, data on smoking and alcohol consumption were missing for 15% and 12% of participants, respectively.

A cross-sectional study from Finland investigated associations between cold exposure, measured using the number of cold days where mean daily temperature fell below zero degrees centigrade in the respondents' locality and weekly number of hours spent in the cold during the winter period, and coronary symptoms (116). This study found a significant increase in chest pain by 6% for every additional 10 cold days (risk ratio 1.06, 95% CI 1.02-1.09), weighted in relation to the number of hours spent outdoors; and a significant increase in chest pain by 7% for every additional 10 hours spent outdoors (risk ratio: 1.07, 95% CI = 1.05-1.09). Both of the analyses included age and sex as explanatory variables. It was also found that men and younger subjects experienced less chest pain compared to women and older subjects, after adjustment for the level of cold-exposure. However, younger participants and males tended to have more cold-exposure than females and older persons, which meant that they tended to experience the most chest pain compared in analyses where level of cold exposure was not controlled for.

Summary of evidence - Studies investigating factors associated with modified risk of circulatory illnesses and deaths in relation to winter season or cold exposure

Socioeconomic deprivation was inconsistently associated with cold- related circulatory risk. Various housing factors, including private rented or owner occupied housing tenure, housing region, older property age, housing dampness, lack of central heating, low household thermal efficiency rating and colder hall temperature, were associated with increased risk of cardiac mortality (83). Low living room temperature was also significantly associated with total cholesterol concentrations during the winter (100). Using less fuel due to worry about fuel costs, was significantly associated with the presence of cardiovascular disease (105). However, the associations between these measures of cold housing and circulatory disease risk and occurrence may have been confounded by other aspects of deprivation (e.g. smoking). Rural dwelling was a significant predictor of post-cold-surge cardiovascular mortality according to one study from Taiwan (95).

Untreated hypertension was associated with significantly increased risk of hospitalisation for intra-cerebral haemorrhage (107). Several behavioural factors, including active smoking (106), alcohol consumption (99), dietary factors (99, 100, 109, 113, 114), physical inactivity (115) and outdoor exposure (116), were associated with cardiac risk factors, or symptoms, in relation to cold weather. Older age was associated with increased risk of cardiovascular mortality (83) and with cardiovascular problems amongst individuals who were exposed to household mould, which is associated with cold and damp housing (104). This indicates that

factors which modify the effects of cold weather on adverse cardiovascular health outcomes may vary between age groups.

iii.   *Studies investigating factors associated with modified risk of respiratory illnesses and deaths in relation to cold exposure or winter season*

The following section integrates evidence from studies investigating the effects of socioeconomic, housing and behavioural factors on winter- or cold- related respiratory health outcomes.

Effects of socioeconomic factors

Five studies investigated possible associations between composite measures of deprivation and cold-weather-related respiratory health outcomes (4, 72, 117-119), based on several different small area-based indices. Townsend Deprivation Index scores were not associated with a significant increase in winter respiratory hospital admissions at individual (117) or area (4, 72, 117, 119) levels.

A small area level ecological time series (2001-11) study from Scotland found that hospital admission rates for Chronic Obstructive Pulmonary Disease (COPD) were highest during the winter season in small (Census Super Output) areas located in the most deprived quintile of the Scottish Index of Multiple Deprivation (118). This deprivation index includes measures of employment, income level, crime, housing, health, education, and access to services. The study found that 19.4% (95% CI 17.3% to 21.4%) of admissions were attributable to season/deprivation interaction, 61.2% (95% CI 59.5% to 63.0%) to deprivation alone, and 5.2% (95% CI 4.3% to 6.0%) to winter alone. In addition, this study found that lower average daily minimum temperatures over a month were associated with higher admission rates, with stronger associations evident in the more deprived quintiles. However, the significance of these Scottish Index of Multiple Deprivation -cold-weather effects on COPD hospital admissions were not assessed and climatic data were based on national, rather than local measurements.

Three studies investigated associations between household income and respiratory health outcomes in children. A cohort study from Connecticut, the USA, found that overall mean annual incidence of paediatric influenza-associated hospitalisation was significantly higher in high versus low poverty census tracts (p<0.05) for six out of seven seasons studied (120). However, overall mean annual incidence of paediatric influenza-associated hospitalisation was also found to be significantly higher in neighbourhoods with high versus low levels of household crowding. This may indicate that the association between poverty and influenza

incidence could be mediated by increased potential for infections to spread between children whom live in crowded households and therefore have more contact with other children.

A study from Southern Brazil found a significant association between middle ear infection, which is associated with the aftermath of respiratory infection, and low income, with a winter peak (121). This association between low income and middle ear infection could also be explained by household crowding, which increases the potential for infections to spread. Exposure to second hand tobacco smoke is a risk factor for respiratory infections and may have confounded the association between household income and middle ear infection for children in this study, as smoking prevalence is higher in low income communities (122).

A cohort study from Melbourne, Australia, found a higher winter rate of Influenza-like-Illness (ILI) episodes, based on subjective reporting by parents, amongst children from higher income families (annual household income $\geq$\$56,000 = 0.57 rate of ILI episodes per month compared to 0.36 in the reference group with annual household income $\leq$\$56,000; rate ratio for the association between annual household income and ILI episodes = 1.57 (0.98-2.53)) (123). However, this study also found that younger age was a risk factor for ILI in children, which is likely to be due to the reduced maturity of the immune systems of younger children. Age was not controlled for when analysing the association between income level and childhood ILI incidence in this study. Consequently, it could have been that children in the high income group had a younger age profile, which caused higher paediatric ILI incidence in this group, compared to the lower income group. This study also found that fewer people residing in a household and structured exposure to other children outside the home were also risk factors for ILI. In relation to this finding, the study authors hypothesized that children from higher income households may have less contact with other children at home, due to living in less crowded households. Consequently, these children may have had less immune stimulation and therefore, subsequent exposure to infections carried by unrelated children in structured childcare settings, may increase the susceptibility of these children to contracting ILIs. Alternatively, it could be that parents with higher incomes were more likely to report episodes of ILI, as a result of recall or reporting bias.

Three studies investigated potential associations between educational attainment and respiratory health outcomes. A cross-sectional study from Northern Taiwan found that parental education ($\geq$13 years or <13 years) was non-significantly, inversely associated with allergic rhinitis (nasal allergy) in children (winter subtype) (124). A cross-sectional study from Finland found marginal increased risk of respiratory symptoms during the winter period in relation to lower educational attainment (and active smoking, a possible confounder of this

association) in an adult population (125). An ecological study from the USA, which included data from Denver, Colorado; Detroit, Michigan; Minneapolis and St. Paul, Minnesota; New Haven, Connecticut; Pittsburgh, Pennsylvania; Chicago, Illinois, and Seattle, Washington, found an increased respiratory mortality rate amongst individuals with less education in hot and cold temperatures. In addition, stronger adverse effects of cold weather on mortality rates occurred in individuals aged <65 years (86).

Effects of housing-related factors

A cross-sectional study from Scotland examined the association between indoor temperatures and respiratory health in COPD patients (126). The study found that poorer respiratory health status was significantly associated with fewer days with nine hours of warmth at 21^0C in the living room, independently of age, lung function, smoking status and outdoor temperatures, (p = 0.01). A sub-group analysis conducted in the same study found that patients who smoked experienced significantly more adverse respiratory health effects compared to non-smokers (P<0.01). A pan-European cross-sectional study found that self-reported respiratory problems in seniors aged ≥65 years were more prevalent if their house was cold in winter (OR 1.97, 95% CI 1.03 – 3.76) and if the individual was dissatisfied with the level of insulation in their household (104). No significant associations were found between self-reported respiratory problems in adults (aged <65 years) and problems with housing, which indicates that the association between cold housing and adverse respiratory health outcomes may be stronger with increasing age. A cohort study from South Auckland, New Zealand, found that cold housing was significantly associated with increased incidence of asthma (adjusted OR 1.73, 95% CI 1.10–2.71), based on self-reported exposure and outcome data (127).

Three studies examined associations between central heating access and respiratory health outcomes. An ecological time series study (enumeration district level, 1993-6), which modelled factors associated with number of hospital admissions for respiratory diagnoses in the London Borough of Newham, did not find proportion of houses with central heating to be significantly associated with the number of respiratory admissions (128). An English case-control study found that self-reported home heating status (fully heated, partly heated or not heated) had little effect on risk of hospital admission for respiratory disease in a univariable analysis (p = 0.130) (117). However, the drop-out rate in this study was high, which may have introduced bias into the results. A pan-European cross-sectional survey found self-reported problems with central heating were associated with increased prevalence of respiratory problems in children (OR 2.1 95%, CI 1.0-4.38), but not in adults (104).

Two studies examined associations between measures of household thermal efficiency and respiratory health outcomes (103, 128). An ecological study from Ireland modelled risk factors associated with emergency respiratory hospital admissions amongst older people in the London Borough of Newham between 1993 and 1996 (128). The best fitting model for being an emergency respiratory hospital admission in this study included winter season (defined as November–February), fuel poverty risk, older age, male sex, being a pensioner and low household thermal efficiency, measured using SAP ratings (128). Another ecological study, previously described in the section on general mortality, and which was conducted at national level, found that relative excess winter mortality from respiratory disease was 1.4 times higher in Ireland compared to Norway, despite the fact that Norway has a colder climate than Ireland (103). The study authors attributed this finding to superior insulation standards in Norway, but the authors did consider the various other social and environmental factors which differ between countries and are likely to influence EWM rates.

Three studies, involving the same authors, assessed the association between composite measure of fuel poverty and respiratory health outcomes (4, 119, 128). All three of the studies had ecological designs and were conducted in England, based on data from the population of the London Borough of Newham who were aged ≥65 years. The authors of two linked studies developed a Fuel Poverty Risk Index, comprising enumeration district level Census data on percentage of households with low energy efficiency (based on 1991 standards), receipt of council tax benefit (a measure of low income), proportion of households with householders of pensionable age and proportion of under-occupied households. The first study, which acted as a pilot for the second, found that fuel poverty risk was significantly positively related to winter respiratory disease morbidity counts for two of four years studied (1993: OR 1.7, 95% CI 1.1-2.7; 1996: OR 1.6, 95% CI 0.9-2.8) (4). The second study also found that morbidity counts rose with increasing fuel poverty risk in winter (defined as November – February, because this was deemed to be the coldest period of the years of study), with a notably large effect in December. Morbidity counts in winter were 2.0 times higher for the 75-84 year old age group and 4.8 times higher for 85+ years, compared with ages 65-74 years (119).

Another investigation, described in relation to the effects of household thermal efficiency on respiratory health, found that winter season (also defined as November to February) and fuel poverty risk score was included in a best prediction model of being a respiratory hospital admission amongst older people in the London Borough of Newham, based on data for the period between 1993 and 1996 (128). Analyses also showed that the combined effects of winter season and fuel poverty risk were over and above the effects of winter season alone.

Fuel poverty could modify the association between cold-weather and respiratory health outcomes by exposing individuals, who are unable to maintain sufficiently warm housing conditions, to cold and damp indoor environments.

A pan-European cross-sectional survey found that self-reported respiratory problems in children were four times less prevalent in households where the respondent reported being dissatisfied with draughts (OR 0.25, 95% CI 0.13 – 0.49) (104). This could attributable to reduced spreading of infectious respiratory agents in households with increased ventilation.

Two studies investigated associations between household occupancy and the occurrence of respiratory illnesses in relation to cold housing or winter season. One study, from Connecticut, the USA, found that the overall mean annual incidence of paediatric influenza-associated hospitalisations was significantly higher in high versus low poverty and high versus low crowding census tracts (p<0.05) for six out of seven seasons studied (120). A different study, from Melbourne, Australia, found that children from households containing fewer other children had more ILI episodes, but this was based on self-reported data (123). These contradictory findings between studies may indicate that different mechanisms mediate associations between cold-weather and adverse respiratory health outcomes between population groups with different levels of socioeconomic deprivation.

Effects of lifestyle-related factors

The authors of a study from Scotland investigated whether specific health outcomes, including wheezing, were significantly related to the extent and duration of domestic heating usage, either directly, or indirectly, via the possible mediating effect of internal environmental conditions (129). Heating usage was not directly significantly associated with any respiratory health outcomes at the p≤0.01 level (the significance threshold of p≤0.01 was selected to reduce the probability of making a type 1 error, due to the large number of significance tests performed in this study). However, significant associations were found between reduced heating usage and internal environmental problems relating to dampness, mould and condensation in the home and between internal environmental problems and wheezing at the p≤0.01 level (129).

Six studies, described in the following five paragraphs, investigated the impacts of active smoking on cold-weather-related respiratory outcomes in adult populations and one study investigated the effects of passive smoking on respiratory health in children.

One study found active smoking was significantly associated with cold-weather-related adverse respiratory outcomes, including COPD hospital admissions amongst respiratory

patients aged ≥65 years (OR 3.2, 95% CI 1.8 to 5.8 for current relative to non-current smokers) (117).

Two linked large scale cross-sectional surveys that were undertaken during winter periods, one of which included data on the adult populations of Northern and Southern Finland, the other included data only on the population of Southern Finland, investigated associations between smoking status and respiratory symptoms and morbidities. The first study found that current or ex-smokers were at significantly increased risk of chronic productive cough (ORs 2.44 and 1.38 for current and ex-smokers relative to never smokers, respectively) (130). The second study found that prevalence of shortness of breath was significantly higher among current smokers than for ex-or non-smokers (131). Other vulnerability factors identified by these studies included older age, having a family history of obstructive airway disease or allergy, and working outdoors.

A different cross-sectional study of cold-related respiratory symptoms in 6591 adults aged 25-74 years from six areas of Finland, found only marginal effects of smoking status on cold-related respiratory symptoms (125). Unlike the two linked studies described in the last paragraph (130) and (131), this investigation asked participants about symptoms experienced in relation to the temperatures at which the symptoms started. A limitation of this method, acknowledged by the study authors, was that it may have been difficult for participants to remember or accurately estimate the temperature of onset for each self-reported respiratory symptom.

A cross-sectional survey from Northern Taiwan found passive smoking was not a predictor of seasonal allergic rhinitis (winter sub-type) in children (124). The effects of second hand smoking on risk of adverse respiratory health outcomes in asthmatic children during the winter season was investigated in a cohort study from the USA (132). The study, which included participants from eight asthma research centres that were located in major urban areas with similar climatic conditions from the North-Central and North-East regions of the United States, found no seasonal effects of environmental tobacco smoke exposure, based on subjective and objective measures, on the incidence of asthma symptoms (P >.86).

Three case-series investigated a potential association between obesity and severe complications of influenza (133-135). One of the studies, from Romania, found that the following factors were significantly associated with fatal outcomes in severe acute respiratory infection patients: pregnancy (OR 7.1, 95% CI 1.6-31.2), clinical obesity (OR 2·9, 95% CI 1·6-31·2), and having an immune-compromising condition (OR 3.7, 95% CI 1.1-13.4) (134). However, a study from China that used national data, found no statistically significant

difference in the proportion of obese individuals between severe and moderately ill cases of H1N1 influenza (17.9% versus 16.9%, respectively) (133). A study that assessed risk factors for influenza in three French Territories found that obesity in adults, as well as medical and an ethnic factors, were frequently observed in severe cases and deaths from influenza A (H1N1), but significance was not assessed (135).

Possible mechanisms by which obesity could increase the risk of severe or fatal influenza include mechanical impairment of lung function caused by abdominal adiposity and possible immune dysregulation caused by obesity. However, obesity related medical complications are likely to be a major contributor to the association between obesity and the occurrence of severe and fatal influenza.

Summary of evidence - Studies investigating factors associated with modified risk of respiratory illnesses and deaths in relation to winter season or cold exposure

Composite deprivation indices were not significantly associated with adverse respiratory health outcomes in relation to cold weather or winter season. Low household income was associated with adverse paediatric health outcomes linked to the respiratory system in two studies (120, 121). This association may be due to aspects of socioeconomic deprivation, such as exposure to second hand smoke and overcrowded housing conditions, which are associated both with low income and respiratory morbidities. Another study found that higher household income was associated with paediatric influenza symptoms reported by parents (123). This may have been due to confounding by reduced immunity, caused by younger age or lack of exposure to other children, amongst children from high income households. A study from the USA found that lower educational attainment was a significant predictor of cold-related respiratory mortality (86).

The effects of cold housing on respiratory health outcomes varied between age groups (104) and in relation to factors including smoking status (126). Fuel poverty, which is associated with factors including low household income, high fuel prices and thermally inefficient housing, predicted respiratory hospital admission risk amongst individuals aged ≥65 years in three studies (4, 119, 128).

Household dampness and condensation relating to under-usage of central heating, was found to be significantly associated with respiratory illness in one study (129). Active smoking was inconsistently associated with adverse respiratory health outcomes (124-126, 130-132). Obesity, pregnancy and having a compromised immune system were significantly associated with increased risk of fatality in patients with severe acute respiratory infection (134).

Studies investigating factors associated with modified risk of hypothermia in relation to cold exposure or winter season

The following section integrates evidence from studies investigating the effects of socioeconomic, housing and behavioural factors on hypothermia occurrence.

Effects of socioeconomic factors

Two studies investigated associations between socioeconomic deprivation and hypothermia incidence. One of these was a case control study from Ireland (136). This study found that the interaction between lower local mean air temperature on the day of admission and higher deprivation level was a significant predictor of hypothermia in individuals aged ≥65 years, who were admitted to a large hospital in Dublin between 1st January 2002 and 31st December 2010 (OR 1.03, 95% CI 1.01-1.06, P=0.033). Deprivation was measured in this study by allocating individuals a score on the 2006 Irish National Deprivation Index, which comprises weighted scores for unemployment, social class, housing tenure and car ownership, based on the electoral ward in which each participant lived.

A study from Scotland found that patients aged ≥65 years who attended an accident and emergency department over a 2 month period between October and December 2009 were more likely to be hypothermic (with a core body temperature of ≤35^{0}C) if they lived in a relatively deprived area (79% of hypothermic patients lived in a relatively deprived area), based on Carstairs Deprivation Category Score (137). However, significance was not assessed in this study.

It is possible that an association between deprivation and hypothermia could be mediated by factors including increased rates of fuel poverty, lack of adequate clothing protection and possibly greater harm attributed to alcohol, amongst the most deprived population groups.

Effects of housing-related factors

A cohort study compared the incidence of symptoms of cold stress in response to exposure to an identical cold environment between healthy young males from two areas of China. Thirty-one participants were from Beijing, Northern China, where indoor heating facilities are available during the winter, and 26 were from Shanghai, Southern China, where indoor heating facilities are not available during the winter. The study found that the participants from Beijing were more likely to complain about thermal discomfort and to display physiological indications of cold-stress compared to participants from Shanghai (138). This was interpreted by the study authors as indicating that the participants from Shanghai were

more acclimatised to cold-exposure; however, climatic temperature differences between the two Chinese cities were not controlled for in the analysis.

A case-series from Ireland found that low population density (i.e. rural dwelling) was associated with an increased risk of hypothermia (139). This may be explainable in terms of the fact that rural areas are generally colder than urban locations and housing in rural areas tend to be less thermally efficient, which increases exposure to cold indoor and outdoor environments.

Effects of fuel poverty

A cross-sectional study from Ireland found that fuel poor households were more likely to display behavioural risk factors for ill health relating to diet, smoking, physical activity and indoor and outdoor cold-exposure leading to shivering. This indicates that behavioural factors could mediate associations between deprivation, fuel poverty and cold-weather-related adverse health outcomes (140).

Effects of lifestyle-related factors

Alcohol and drug consumption are acknowledged risk factors for hypothermia, due to their widening effects on blood vessels which encourages heat loss. Five studies investigated associations between alcohol or drug consumption and hypothermia symptoms, incidence or death (139-143). However, none of the studies assessed significance of these associations, due to the small number of hypothermia cases and lack of control groups.

A study from Finland found that outdoor occupation and inadequate clothing protection were associated with reduced manual dexterity, increased risk of frostbite and body cooling (144). A study from Ireland also found an association between outdoor cold exposure and shivering (140).

Summary of evidence - Studies investigating factors associated with modified risk of hypothermia in relation to winter season or cold exposure

There was some evidence that deprivation is associated with significantly increased risk of hypothermia incidence (136). Other factors that were found to be associated with hypothermia were rural dwelling (139), alcohol and drug consumption (139-143), indoor and outdoor cold exposure (140, 144). However, significance of the associations between potential vulnerability factors and hypothermia were generally not assessed due to the small number of cases in each study. One of the studies found that older age was associated with hypothermia incidence (139), which is possible due to declining thermal perception with increased age.

Other factors associated with hypothermia included being single (139), dietary factors and reduced physical activity (140), possibly due to increased risk of fuel poverty amongst single people, and amongst individuals with poor diet and who are physically inactive who are likely to have reduced household income.

v.   Studies investigating factors associated with modified risk of arthritis in relation to cold exposure

One study investigated the association between cold housing and the occurrence of arthritis. This was a cross-sectional, pan-European analysis which found that self-reported arthritic problems were 1.92 times more prevalent in houses reported cold by older people (OR 1.92, 95% CI 1.16-3.16) (104).

vi.   Studies investigating factors associated with modified risk of slips and falls in relation to cold exposure or winter season

Slips and falls are more prevalent in cold weather conditions. This is likely to be largely attributable to slippery outdoor surfaces and stiffness caused by cold exposure, which reduces mobility and increases the risk of falls.

A study from Sweden examined the association between footwear protection and tendency to slip or fall during the winter / cold period October-April (145). Based on results from a self-reported questionnaire completed by 52 outdoor workers in Sweden, the study reported that a high proportion of the participants did not think that their professional footwear provided enough protection against slips and falls (145).

A longitudinal study from Australia found significant variations in a measure of blood serum levels of vitamin D, physical activity levels, ankle strength and hours spent outside over the course of a year ($p<0.001$), with the highest values for each of these variables occurring in January and February (mid-summer) (146). Low mean ankle strength was associated with increased incidence of falling ($p = 0.047$). This indicates that reduced vitamin D, due to factors including reduced sunlight exposure and reduced physical activity, could mediate the association between winter season and increased incidence of falls. Although the area within Australia in which this study was conducted was not provided, the authors noted that the data were collected within an area located at 41° south and that the same results may not be found at alternative latitudes. Another study (147), from Sweden, found that bone mineral density levels were associated with time spent outdoors in winter, although the association was non-significant ($p = 0.079$).

Summary of evidence – Studies investigating factors associated with modified risk of slips and falls in relation to winter season or cold exposure

There is evidence from one study that low mean ankle strength is significantly associated with increased incidence of falling (146). This may be associated with reduced vitamin D synthesis during the winter period, due to factors including reduced physical activity and sunlight exposure, but more evidence is needed to support this possible association. There is a lack of strong evidence to assess the association between footwear and the propensity to slip or fall during periods of cold weather.

vii.   *Studies investigating factors associated with modified risk of vitamin deficiencies in relation to winter season or cold exposure*

Effects of socioeconomic factors

A national, cross-sectional survey from the USA, which linked monthly household expenditure data with weather data, and analysed nutritional data in relation to season, found that increased fuel expenditure during periods of cold weather were associated with significant reductions in food consumption and calorie intake by income poor families. Cold-weather-related increased fuel expenditure was also associated, non-significantly, with increased prevalence of vitamin deficiencies and anaemia during the winter for children and for adults with children in income poor families (148).

Effects of lifestyle-related factors

A nationwide cohort study from Great Britain found that the amount of time spent outdoors during winter did not influence the risk of vitamin D deficiency ($P \geq 0.18$) (149). This is potentially because vitamin D levels are affected by many different factors and because reduced sunlight hours during the winter period may reduce the protective effects of outdoor exposure on vitamin D synthesis. A cohort study from Estonia found that vitamin D supplement usage during the winter period ($p = 0.07$), along with sunbathing habits ($p < 0.0001$) and smoking ($p = 0.008$), were significant determinants of winter vitamin D levels and explained 12% of the variance in vitamin D levels in multiple regression analyses (correlation coefficient = 0.12) (150). A cross-sectional study of 125 healthy, pregnant women from Beijing, Northern China, found that the concentration of serum vitamin D was lower in women with shorter duration of sun exposure compared to women with longer duration of sun exposure during the winter season ($p = 0.003$). Women who reported taking a multivitamin supplement had significantly higher vitamin D concentrations compared with non-supplement users ($p < 0.001$) (151).

Summary of evidence – Studies investigating factors associated with modified risk of vitamin deficiencies in relation to winter season or cold exposure

There is evidence from one study that increased fuel use during periods of cold weather is significantly associated with reduced food consumption amongst low income families, but there is a lack of evidence that this reduced food consumption contributes significantly to vitamin deficiencies (148). There is some evidence that lifestyle factors, including sunbathing habits, smoking and physical activity significantly affect vitamin D levels during the winter (150).

viii. Studies investigating factors associated with general non-condition-group-specific health outcomes in relation to winter season or cold exposure

Effects of socioeconomic factors

A cross-sectional survey of 333 people from fuel poor households in the North East of England found that an income measure of poorer socioeconomic status was associated with poorer self–assessed health (increase in odds of poorer self-reported health per £100 decrease in household income = 1.00, 95% CI 1.00-1.00, p = 0.04) (152). Other measures of socioeconomic deprivation, including a wealth measure, based on the household not owning their own home or having use of a private vehicle, and occupation, were only significant predictors of worse self-rated health when income was excluded from the analysis. Additional factors that were significant predictors of poorer self-reported health in the logistic regression model were older age, being a current smoker and lower household thermal efficiency rating. A second logistic regression model showed that subjective measures, including lower mastery score, was a significant predictor of poorer respondent self-assessed health (odds 2.89, 95% CI 1.74–4.80, p < 0.001). Mastery was defined as the extent to which the individual feels in control of their life outcomes. Lower satisfaction with home heating, older age and lower household thermal efficiency rating were also predictors of worse self-assessed health. Socioeconomic measures of income, wealth and occupation were still significant when taking the subjective measures into account, but were not included in the final logistic regression model. This work provides evidence to support pathways illustrating the potential mechanisms through which socioeconomic factors may be associated with self-rated health.

Effects of housing-related factors

Three cross-sectional surveys from the UK, one of which was described in the section above on socioeconomic factors (152), investigated associations between measures of indoor temperatures and general, self-reported health (105, 152, 153). One of the studies, from

England, found that a lower household energy efficiency score was associated with significantly worse self-rated health (odds 1.03, 95% CI 1.01-1.05 per units worse in household energy efficiency score, p<0.01) (152). This study also found that demographic factors, indicators of deprivation and subjective measures were also included in the regression model of predictors of self-rated health. This indicates that complex pathways mediate associations between exposure to thermally inefficient housing and adverse health outcomes. Another cross-sectional survey of households in England found that people who reported having a doctor-diagnosed physical health condition were significantly more likely to inhabit a cold home containing mould, and to have reduced their use of domestic fuel in the past year due to worry about cost, compared to those without a physical health complaint. In a multivariable regression model, the following measures were significantly associated with poorer predicted health: presence of mould in the home, self-perceived cold-housing, cutting back on fuel usage due to cost and fuel related debt or disconnection (105). Additional factors that were significantly associated with poor physical health were: being a social renter, living in an urban (rather than rural) area, being older than 24 years, being female and being of white ethnicity. A study from Wales found that feeling cold at home and spending longer periods of time at home significantly predicted poorer self-reported health status, even when controlling for age, gender and housing tenure (153).

A cross-sectional study from Wales found that without including other housing problems in the analysis, living in private rented accommodation predicted worse self-rated health (153). However, this was no longer significant when other aspects of housing relating to energy efficiency were also included in the analysis. This supports a potential causal pathway by which living in privately rented accommodation is associated with worse self-rated health as this type of accommodation in the UK tends to be less thermally efficient compared to socially rented and privately owned dwellings.

A cross-sectional survey, already discussed in the above sections on socioeconomic deprivation and housing, found that active smoking was a significant predictor of poorer self-reported respondent health amongst individuals from fuel poor households (odds 2.34, 95% CI 1.38-3.96, p<0.002) (152). In addition to the numerous direct health impacts of active smoking and associated lifestyle behaviours that are likely to occur more commonly amongst active smokers, the association between active smoking and other forms of deprivation, including socioeconomic inequalities such as fuel poverty, are likely to provide several mechanisms which explain the association between active smoking and adverse health outcomes.

Summary of evidence – Studies investigating factors associated with general non-condition-group-specific health outcomes in relation to winter season or cold exposure

There is some evidence that low self-reported income, lower household energy efficiency, older age, low self-mastery and smoking, are associated with significantly worse self-reported health amongst individuals from fuel poor households (152). This indicates that the epidemiology of self-reported health amongst individuals living in fuel poverty is likely to be complex and mediated by environmental and behavioural factors.

ix.   *Studies investigating factors associated with modified risk of adverse mental health outcomes in relation to cold exposure or winter season*

Effects of socioeconomic factors

A study from South Korea investigated educational attainment as a potential moderator of the association between daily temperature and suicide mortality (154). It was found that suicide counts for those with less education increased at temperatures $<20^0$C, but decreased at temperatures of $\geq 20^0$C.

Effects of housing-related factors

Four studies investigated associations between housing factors and cold-weather-related adverse mental health outcomes. A study from Auckland, which is located in the North Island of New Zealand, found that cold housing was significantly associated with probable depression (p <0.01; adjusted OR 1.57, 95% CI 1.14–2.15) in a cohort of 1376 mothers of 6 week old infants (127).

A cross-sectional study from England found that cold housing was consistently associated with indicators of poor psychosocial health, measured using the Short Form Health Survey (SF-36) dimensions relating to quality of life. Participants with low social functioning, a measure of mental health that refers to the extent to which an individual performs normal social activities without interference due to physical or emotional problems, were a third more likely to live in cold homes (OR 1.36, CI 0.94–1.97) as were those with a low mental-health score (OR 1.38, CI 0.96–1.99).

Another study found that cold housing was associated with high scores on the GHQ12 scale (OR 1.21, CI 0.83–1.76), which measures psychological morbidity, and with anxiety and depression, measured using the appropriate dimension on the EuroQol health outcome measurement instrument (OR 1.58, CI 1.11–2.26) (155).

A pan-European cross-sectional survey found that amongst children, beliefs that any existing mental health problems were related to their dwelling was 7.7 times less prevalent in children who reported being dissatisfied with insulation in their household (OR 1.67, 95% CI 1-2.81). Amongst adults, beliefs that any existing mental health problems were related to their dwelling were 1.79 times more prevalent if their house was cold in winter (OR 1.79, 95% CI 1.07-2.98), 1.67 times more prevalent if dissatisfied with insulation (OR 1.67, 95% CI 1-2.81) and 1.82 times more prevalent dissatisfied with heating system (OR 1.81, 95% CI 1.14-2.91). No associations were found between aspects of housing condition and mental health problems related to dwelling in seniors (104). This indicates that whereas the physical impacts of cold housing may be more prevalent in older people, younger adults may be more susceptible to the mental health impacts of living in cold housing. A cross-sectional survey from England found increased risk of common mental disorder associated with being unable to adequately heat the home in winter (OR 1.85), presence of mould in the home (OR 1.52) and for using less fuel due to worry about costs (OR 1.77) from multivariable analyses. However, the association between fuel debt and common mental disorder from the simple regression model was no longer significant in this multivariable model (105).

Effects of lifestyle-related factors

A study from Germany found that children with abnormal emotional symptoms exhibited reduced physical activity, particularly in winter (OR 0.60) (156). However, this was a cross sectional study and the direction of the association between abnormal emotional symptoms and reduced physical activity was unclear.

Summary of evidence – Studies investigating factors associated with modified risk of adverse mental health outcomes in relation to winter season or cold exposure

There was some evidence that exposure to cold housing is associated with adverse mental health impacts (104, 127, 155), particularly amongst individuals below pensionable age (104).

x.   Studies investigating factors associated with modified risk of social inequalities in relation to winter season or cold exposure

Effects of socioeconomic factors

A cross-sectional survey from England found that 63% of low-income households had cut their energy consumption in the previous winter and 47% had experienced a cold home (157). Respondents from this study also reported reduced food consumption (reduced range and quality of food). A cross-sectional, national study from the USA, which used nationally representative datasets on household expenditures and nutrition, found that poor families

significantly reduced food expenditure and calorie intake during cold temperature shocks and calorie intake during winter months, whereas richer families increased food expenditures during cold periods (148). A cross-sectional survey of 421 older persons (age 70 years+) who lived in rural Wales, found that none of the respondents with incomes >£240 per week needed extra clothing during the day to keep warm, whereas around 20% of respondents with incomes <£240 per week were unable to keep warm during the day without putting on extra clothes (correlation coefficient .177, p<0.01) (153).

Effects of housing-related factors

A cross-sectional survey of 421 older people (aged 70+) living in rural North Wales, found that the presence of roof insulation, draught proofing and double glazing were individually associated with significantly fewer reports of participants feeling cold at home or needing to wear extra clothing to keep warm (p≤0.05) (158). A different cross-sectional survey, of a representative sample of 1,500 from Ireland, found that a higher proportion of fuel poor households reported sub-optimal thermal comfort in rooms of the house compared to households not in fuel poverty. Levels of thermal discomfort were also found to be higher among the over-65s than for other households; this may be attributable to less efficient thermo-regulatory mechanisms in older people and because older people are likely to spend longer periods of time at home compared to younger people (140).

Effects of fuel poverty

Three qualitative studies, from Austria, England and Wales, found that fuel poverty was associated with adverse impacts, including reduced consumption of food and luxury items; financial concerns, social withdrawal, wearing extra clothes and only heating one room of the house (159-161).

Effects of lifestyle-related factors

A qualitative interview survey of 64 householders from England, Scotland and Wales, incorporating 58 home owners and 6 private renters who were aged over 60 years, found that frugality, in terms of not turning on heating during the day, and opening windows, were identified as contributing to living in cold homes (162). This illuminates possible pathways between cold weather and adverse health outcomes which are mediated by attitudinal and behavioural factors and may operate independently of socioeconomic status, which might explain the lack of consistent association between socioeconomic deprivation and winter mortality.

Summary of evidence – Studies investigating factors associated with modified risk of social inequalities in relation to winter season or cold exposure

Cold weather was associated significantly with reduced food consumption and calorie intake in low income families (148) and with increased clothing protection to keep warm amongst elderly persons (158). The presence of roof insulation, draught proofing and double glazing were identified as factors which protected against older persons feeling cold at home or needing to wear extra clothing to keep warm (p≤0.05) (158).

2.4 Summary

This review synthesised evidence from 87 studies that investigated associations between social factors and vulnerability to winter- or cold-related health and social outcomes. It expands the findings of previous reviews (1, 58, 59), by integrating evidence on a comprehensive range of potential risk factors and outcomes and by synthesising evidence in relation to specific outcome groups. Most of the evidence related to factors associated with all-cause mortality and with circulatory and respiratory health effects in relation to cold exposure or winter season.

In general, measures of thermally inefficient housing, low income, existing (poor) health status and age were most consistently associated with adverse health outcomes in relation to cold weather and winter season. Lifestyle factors, including smoking and aspects of diet, were least consistently associated with the adverse outcomes analysed. This is possibly due to the lack of individual level, longitudinal studies which are needed to accurately assess the long term health impacts of these factors. Also, as expected, there was evidence that certain lifestyle factors exert non-seasonal effects on health.

This review illuminates the scale of the adverse health and social impacts of cold weather and also provides information about the aetiology of each of the health and social outcomes identified. A major weakness of this review, and of the review of intervention studies presented in chapter three, is that it was completed by one person. This was due to the lack of availability of a co-reviewer to complete the required tasks, including selection, data extraction and appraisal of the large number of studies retrieved from initial search results, and from subsequent search alerts used to locate new literature during the first two years of my PhD. My decision to complete the review independently enabled a greater body of literature to be considered for inclusion. This allowed me to undertake a more comprehensive review of potential risk factors for, and interventions to reduce, winter and cold-weather-related morbidities and mortality. The lack of a second reviewer potentially introduces bias

into the review, as different results could be produced if independent researchers were to follow the described methodology for the review. Differences could arise due to subjectivity in decisions regarding which studies meet the inclusion and exclusion criteria, what data should be extracted from included studies and about study quality. However, my inclusion and exclusion criteria were explicit and I checked searches to ensure that all 'key papers' that appeared in all related systematic reviews had been identified, which reduces the risk of bias in relation to study inclusion.

Another limitation was that meta-analysis was not performed due to the heterogeneous nature of included studies, in terms of populations, exposures and outcomes of interest. Also, due to the vast amount of literature on this topic, it was not possible to broaden the search strategy to include environmental and biological factors associated with winter season, cold weather and adverse health outcomes, including air pollution and infectious diseases.

Strengths of the available evidence include the large, expanding evidence base and wide range of research designs which have been employed to investigate the epidemiology of winter and cold-weather-related adverse health and social outcomes. This is useful for the development of policies to reduce the adverse health and social impacts of cold weather.

Limitations of the available evidence include that there is less information about factors associated with outcomes other than all-cause mortality and circulatory and respiratory illnesses and deaths. Although some evidence identified factors associated with cold-weather-related slips and falls, none of the studies investigated possible risk factors for the increased prevalence of deaths from dementia and Alzheimer's disease during the winter period.

Additionally, there were relatively few individual level cohort studies which generally provide the strongest observational evidence of potential causal associations between exposures and outcomes, by indicating the correct temporal relationship between variables (i.e. the assumed exposure causes the effect, rather than vice versa). The greatest proportion of studies identified in this chapter had an ecological design, whereby associations between exposure and outcome variables are measured using aggregate data. Ecological studies provide weak evidence of causal associations between exposures and outcomes due to the ecological fallacy, whereby associations that exist between variables at area level are wrongly assumed to exist for individuals within the population under investigation.

Evidence has focused on the impacts of certain exposures, particularly measures of cold housing. Research around fuel poverty and cold housing has been stimulated by social and environmental issues within western countries. However, a broad range of factors are likely to

affect health in relation to winter season and cold weather. There is, for example, strong evidence that social isolation is a powerful predictor of adverse health outcomes, particularly amongst older people (163), but this has not been studied in relation to cold weather/temperatures or winter season.

An additional limitation is that several studies investigated seasonal or cold-weather-related health outcomes using national data (e.g. (78)). This is problematic as many countries incorporate regional and sub-regional variations in climatic conditions and it is possible that populations in climatically colder areas are biologically and culturally better adapted to cold weather conditions, compared to the inhabitants of generally warmer areas. People accustomed to warmer weather conditions may therefore be at greater risk of adverse health outcomes in relation to even temperate winters, which may have less impact on morbidity and mortality rates in colder areas.

This review supports associations between low income, fuel poverty, aspects of cold housing and personal factors, including age, sex and medical vulnerabilities and winter / cold-weather-related adverse health and social outcomes. These findings are consistent with the results from other reviews on this topic (1, 58, 59), demonstrating coherence and reliability of these conclusions across time and between different research groups. Differential impacts of cold weather and other exposures were identified between population groups, which could create cold-related health inequalities.

In chapter three, I present a systematic review of the literature which evaluates the effectiveness of interventions for reducing the adverse health and social impacts of cold weather. The information from chapters two and three will be used to conceptualise the mechanisms by which explanatory factors can influence condition-group-specific mortality and morbidities in chapter four.

Chapter Three.

Social moderators of associations between winter season, cold exposure and adverse health and social outcomes: a systematic literature review of intervention evaluation studies

3.1 Introduction

Evidence from epidemiological observational studies has identified a range of environmental, social and clinical factors that are associated with modified susceptibility to adverse health and social outcomes in relation to cold weather and the winter season.

Policies that aim to ameliorate the adverse impacts of cold weather in England and many other countries have focused on increasing the thermal efficiency of the housing stock, which also contributes to reducing greenhouse gas emissions in line with international targets. In addition, other legislation (e.g. the Winter Fuel Payment and Cold Weather Payments) has focused on reducing EWM and illnesses amongst vulnerable groups, particularly the elderly.

Policy developments that have occurred over recent decades, have led to the implementation of various interventions aiming to reduce winter- and cold-related adverse health and social outcomes. There is a growing body of literature evaluating the effectiveness of interventions for reducing the adverse health and social impacts of cold weather and housing. Elements of this evidence base have been synthesized over recent years. A Cochrane Review published in 2013, included evidence about the socioeconomic and health impacts of housing interventions, including thermal efficiency improvements (60). A different, unpublished review investigated associations between behavioural responses to severe cold weather and health risks (3) in order to develop an evidence-based intervention to reduce the health risks of severe winter weather among older people in the UK. A further systematic review was commissioned by NICE to support the development of its guidance for reducing mortality and illness amongst elderly and vulnerable persons, comprised an evidence synthesis of the efficacy of interventions aimed at reducing excess winter deaths and morbidity as well as the health risks associated with cold housing (164).

The systematic review presented in this chapter aims to extend the findings of these earlier reviews, by integrating a more comprehensive range of evidence identifying the health and social impacts of socioeconomic, housing and behavioural interventions on reducing winter- and cold-related adverse health and social outcomes. The evidence will be synthesized in

relation to different outcome groups, which could provide evidence to inform the development of interventions that are more effective for addressing specific outcomes in relation to cold exposure and during the winter period.

3.2 Methods

Systematic methods were used to locate, evaluate and synthesise evidence from quantitative and qualitative studies that evaluated the effectiveness or perceived impact of socioeconomic, housing or behavioural interventions on reducing adverse health or social outcomes in relation to cold exposure or winter season.

3.2.1 Search strategy

The same search techniques were used as in chapter two, section 2.2.1 (See appendix A for the electronic search strategies used to locate literature).

3.2.2 Inclusion and exclusion criteria

Figure 3.1 shows the flow of studies at each stage of the review. Included research had to be a primary study, conducted on human participants, published in English and which quantified or qualified the effects of behavioural, socioeconomic or housing interventions of contemporary relevance to the UK, on health or social outcomes in relation to winter season or measures of cold exposure. Full details of the inclusion and exclusion criteria, including details of exposures and outcomes considered relevant to this review, are specified in appendix B. Titles and abstracts (where available) of located references were screened against the review inclusion criteria. The full texts of any references considered potentially eligible for inclusion were obtained in full. Exclusion reasons were recorded during the second screen. Unobtainable references were excluded.

3.2.3 Data extraction and appraisal

Details of the characteristics and results from included studies were extracted into standardised summary tables. The same data were extracted as in chapter two, section 2.2.3, except that details about interventions rather than exposures were extracted in this review of intervention evaluation studies.

Quantitative intervention studies were assessed for risk of bias using the Quality Assessment Tool for Quantitative Studies (61). This appraisal tool is recommended for systematic reviews of intervention studies by the Cochrane Public Health Review Group (Armstrong et al., 2008; cited in (66)) and was also used to appraise studies in a different review, which assessed the health impacts of housing improvements (165).

The appropriate CASP tools were used to appraise economic impact studies (n=8) and qualitative (n=4) studies in this review (67).

3.2.4 Data synthesis

A narrative approach was used to synthesise data from included studies. As with the previous review of observational studies (chapter two), meta-analysis was not possible due to substantial heterogeneity in study designs, populations, risk factors and outcomes, but quantitative results are reported in the narrative synthesis, presented in section 3.3.
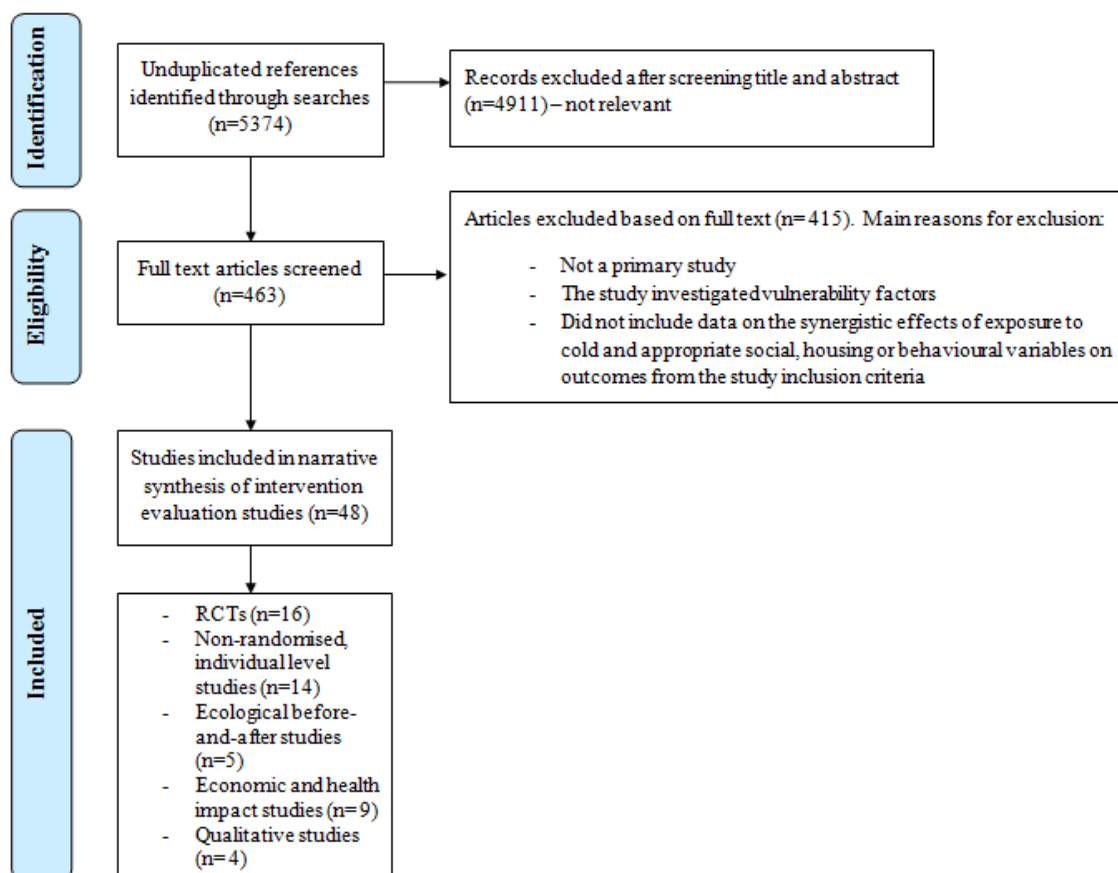
Figure 3.1: *Flow of included and excluded studies. Diagram source: (70).*

3.3 Results

3.3.1 Number and characteristics of studies

Forty-eight studies were included in the review. Twenty-seven studies were from the UK, eight were from New Zealand, four from the USA, two each from Finland, Sweden and Japan, and one each from Australia, Germany and Greece. Hence, the number of countries which the studies in this review derived from was fewer compared to the review of aetiology studies

presented in chapter two (see section 2.3.1). Studies were published between 1975 and 2013. Sixteen studies were randomised controlled trials (RCTs), fourteen were non-randomised studies conducted at individual level, five were ecological before-and-after studies, nine were economic impact studies and four used qualitative methods.

3.3.2 Study quality

Of the sixteen RCTs included in this review, five were rated as being of strong quality, seven were rated as moderate and four as weak. The five ecological before-and-after studies were rated as: moderate (n=2) and weak (n=3). The fourteen non-randomised individual level studies were rated as being of strong (n=3), moderate (n=4) and weak (n=7) quality. Scores for the four qualitative studies, based on CASP system, ranged from 6.5 to 8 out of 10. The nine economic studies received CASP scores ranging from 7 to 9.5 out of 12.

3.3.3 Study results

The main results from included intervention studies are described here, classified into groups by outcome, and sub-groups, based on the type of intervention investigated (i.e. related to behavioural, socioeconomic or housing factors). Each study is reported in a standardised way, with details of study design, country of origin, population studied, follow-up time periods, type of intervention, results and critical appraisal score given for each. Many of the included studies examined the impacts of an intervention on several outcomes and therefore appear multiple times in the narrative synthesis below.

i. *Studies evaluating the effectiveness of interventions on reducing all-cause mortality in relation to cold exposure or winter season*

An ecological before-and-after study from England, investigated the effectiveness of a fuel poverty reduction scheme on reducing EWM rates in the London Borough of Newham (166). The 'Warm Zone' scheme involved door-to-door assessments of eligibility for heating improvement grants to local residents. This study assessed whether EWM indices decreased for people aged ≥65 years in this area following implementation of the Warm Zone scheme compared to all of London, using data for a 12 year time period (1993-2005) from before and throughout the scheme. The results of the study indicated some small associations between the implementation of the scheme and reduced EWM rates amongst individuals aged ≥65 years in the London Borough of Newham. However, no conclusive trends were found in the data for the study period investigated. Lack of control for potentially confounding factors, including the possible implementation of alternative thermal efficiency schemes in other parts

of London during the study period, is a possible limitation acknowledged by the study authors.

ii.   Studies evaluating the effectiveness of interventions on reducing adverse circulatory health outcomes in relation to cold exposure or winter season
Impact of interventions to improve indoor environmental conditions

Four studies examined the effects of interventions aimed to increase household warmth on cardiovascular health (167-170). An ecological study from England investigated changes in EWM rate from cardiovascular disease for the whole population from 1964 to 1984, the period during which central heating installation in English homes increased from 13% to 69% and domestic fuel use increased. EWM rates from cardiovascular disease did not reduce significantly over this period. This was despite a decline in the number of influenza epidemics, and reduced cigarette consumption and saturated fat intake, which also occurred during the study period (167). However, the adverse effects of active smoking and saturated fat consumption on cardiovascular deaths tend to occur over decades (i.e. with a substantial lag). Consequently, the increase in smoking rates and saturated fat consumption that occurred in population of England during the decades before the time period considered in this study may have counteracted the protective health effects of central heating uptake and domestic fuel consumption. In addition, central heating ownership does not necessarily reflect its usage.

A non-randomised controlled study from Scotland examined the effects of improving the thermal quality of housing on blood pressure, amongst social housing residents in the Easthall community of Glasgow (168). The 'Heatfest' intervention involved the installation of insulation, draught proofing, gas central heating, solar panels, a dual-purpose heat recovery system and front and back verandas in 36 flats. Another 36 flats in the same community, which did not receive the intervention, were approached as a control group. Blood pressure readings were taken from participants in the intervention and control groups before the housing improvements were delivered and at least one year post-implementation of the intervention. In the intervention group, diastolic and systolic blood pressure readings fell significantly at the one year follow-up compared to baseline readings (P<0.001). A significant rise in diastolic blood pressure (p=0.011) and non-significant increase in systolic blood pressure readings (p=0.396) were found in the control group. There were no significant differences in baseline blood pressure readings between intervention and control group participants. In addition, none of the intervention or control group participants had made conscious changes in smoking habits, diet or exercise and there had been no changes in job

status between pre- and post-intervention readings. Participants and outcome assessors were not blinded to the exposure status of participants.

An RCT from Japan examined the influence of indoor temperature on blood pressure among 146 healthy participants aged 18-60 years (169). Ambulatory blood pressure was measured while the participants stayed in single experimental rooms from 9 pm until 8 am. Intervention group participants (n=70) were exposed to intensive room heating (mean temperature ± SD: 24.2±1.7°C), whilst control group participants (n=26) were exposed to weak room heating (mean temperature ± SD: 13.9±3.3°C). Participants who were exposed to intensive room heating had significantly lower systolic and diastolic morning and evening blood pressure readings compared to the control group (p≤0.01). However, the results also indicated that night-time blood pressure readings did not differ significantly between groups (p>0.05). The analyses were adjusted for differences in age, gender, BMI and current smoking status between intervention and control groups. However, it was unclear whether participants were representative of the healthy adult population of Japan.

A non-randomised controlled study from Scotland, compared health outcomes between 1281 households that had received a modern central heating system, energy advice and an optional check of state benefit entitlement as part of the Scottish Central Heating Programme and non-recipient households (n=1084) (170). Results were reported from participant interviews that occurred shortly before receipt of the intervention and two years later. Recipients of the programme were significantly less likely to report a first diagnosis of heart disease (OR 0.69, 95% CI 0.52-0.91, p=0.01) or high blood pressure (OR 0.77, 95% CI 0.61-0.97, p=0.02) compared to control group participants. The significance threshold used for these findings was p≤0.05. This is problematic, as noted by the authors, due to the large number of outcome measures under investigation (n=30) means that, statistically, 1.5 of these outcomes would be expected to yield a spuriously significant result by chance using a 5% probability threshold.

Summary of evidence – Studies evaluating the effectiveness of interventions on reducing adverse circulatory health outcomes in relation to winter season or cold exposure

Four studies examined the impacts of thermal efficiency interventions on circulatory health. These included one ecological study (national level) (167) and three individual level studies, one of which was an RCT (169) and two were non-randomised controlled studies (168) and (170). All of these studies received a Quality Assessment Tool for Quantitative Studies global rating of moderate. Consistent evidence was found that household warmth and thermal efficiency interventions were associated with significant reductions in blood pressure.

However, evidence in relation to the positive impacts of household warmth measures on circulatory diagnoses, was mixed.

iii.   Studies evaluating the effectiveness of interventions on reducing adverse respiratory health outcomes in relation to cold exposure or winter season

Impacts of interventions to improve housing conditions

An English ecological before-and-after study, described in the section on circulatory health (167), found that from 1964 to 1984, use of central heating increased from 13% to 69% of households and domestic fuel consumption increased. Also during this period, EWM from respiratory diseases for the whole population declined by 69%, even when adjusting for summer mortality and varying coldness of winters. However, this improvement was partly explained by a decline in influenza epidemics that occurred during the time period of the study.

An individual level before-and-after study from England investigated the effects of central heating installation on respiratory symptoms amongst 72 children who lived in damp homes and had previously been diagnosed with asthma (171). Assessments of housing conditions and respiratory symptoms were carried out before receipt of the intervention and at least 3 months after the intervention was received. The intervention was associated with energy efficiency improvement by a mean of 2.1 on the National Home Energy Rating scale (95% CI 1.68-2.47, P<0.001). All respiratory symptoms measured were significantly reduced after the intervention, with the greatest reduction being in nocturnal cough from a median score of 3 (most nights) to 1 (on one or several nights) (P<0.001) in the previous month. There was no control group in this study, which means that factors including seasonal effects on respiratory health were not controlled for.

A non-randomised, controlled before-and-after study from Scotland, already described in the section on circulatory health (170), compared health outcomes between 1281 recipients and 1084 non-recipients of the Scottish Central Heating Programme. This intervention involved installation of a modern central heating system and advice in relation to energy usage and, optionally, of state benefit entitlement. Self-reported health data were collected before the intervention and two years later. Recipients were significantly more likely to report having a first diagnosis of nasal allergy compared to non-recipients (OR 1.52, 95% CI 1.05-2.20, p = 0.03). Reduced nasal allergy may have been expected amongst heating recipients, assuming that the intervention resulted in increased household temperatures, reducing dampness, mould growth and spore release. There were no significant differences in other respiratory outcome

measures between intervention and control groups at the p<0.05 threshold. Intervention and control groups in this study were matched based on demographic, socioeconomic and housing factors. Smoking status at baseline and change in smoking status between pre- and post-intervention measurements were also well balanced between intervention and comparison group participants. However, as previously stated, the large number of statistical tests performed on various health outcomes in this study, increases the likelihood that a proportion of statistically significant results will have occurred by chance ("multiple comparisons problem"). The authors of this study did not adjust for this problem in the analyses, or by increasing the accepted significance threshold (170).

A single blinded RCT from New Zealand examined whether insulating existing houses increases indoor temperatures and improves occupants' health and wellbeing (172). The study groups were 1350 un-insulated households (intervention group n = 679; control group n = 671) containing 4407 participants from 7 low income communities in New Zealand. Each household had at least one person who reported having respiratory symptoms in the previous year. The intervention involved installation of ceiling insulation, draught-proofing windows and doors, and fitting sisalated paper beneath floor joists and a polythene moisture barrier on the ground beneath the house. Baseline data were collected in 2001, before the intervention was implemented, and follow-up data were collected in 2002. Receipt of the intervention in this study was associated with increased bedroom temperature during the winter (by 0.5 degrees centigrade on average), decreased relative humidity (-2.3%) and reduced odds of self-reported wheezing (OR 0.57, 95% CI 0.47-0.70), based on comparing change scores (follow-up scores minus baseline scores) for health outcome measurements between intervention and control group participants. Respiratory hospital admissions were also reduced for intervention compared to control participants, but not significantly (OR 0.4, 95% CI 0.22-1.29, p=0.16). Baseline characteristics were well balanced between groups in this study. A limitation of this study is that participating households were drawn from across New Zealand and the proportion of households in the intervention and control groups from different regions was not indicated. If intervention and control groups contained different proportions of households from different areas of New Zealand (e.g. from the North and South Islands), this could confound the results, due to geographical variations in factors including temperature and levels of circulating influenza, which influence respiratory health.

Another RCT investigated the effects of improved home heating on asthma in children (173). The study participants were 409 children aged 6-12 years with doctor diagnosed asthma from households in 5 communities of New Zealand. The intervention involved installation of a

non-polluting, more effective home heater before winter. Parents reported aspects of their children's health before the intervention at the end of winter 2005 (baseline). The heating systems were installed prior to winter 2006. Follow-up data were collected after winter 2006. Installation of the intervention in the homes of children with asthma was associated with significantly increased bedroom temperatures, reduced pollution and significantly fewer reports of poor health and asthma symptoms in the intervention group compared to the control group. However, lung function did not increase significantly in the intervention group compared to the control group. It is unclear the extent to which the improvement in asthma symptoms among intervention participants were attributable to increased indoor temperatures or improved indoor air quality.

Impacts of interventions to increase influenza vaccination coverage

An ecological before-and-after study from Japan examined the impact on COPD mortality of a change in the Preventative Vaccination Law, which made municipalities legally obliged to offer influenza vaccinations to adults aged ≥65 years (174). The amendment was enforced in November 2001. COPD mortality data between January 1995 and December 2009 were included in the analyses. After the amendment, a statistically significant risk reduction was observed in January (RR 0.84, 95% CI 0.81–0.88), February (RR 0.85, 95% CI 0.81–0.89), and March (RR 0.92, 95% CI 0.88–0.96), but not for non-winter months, among the population aged ≥65 years. No statistically significant changes were found in the risk of COPD death among the population aged <65 years in any month after the amendment. The analysis controlled for gender, age, trend and seasonal variations in influenza prevalence.

Another ecological before-and-after study from Connecticut, the USA, investigated the effects of an influenza vaccination campaign on hospital emergency department visits for respiratory diagnoses (175). The intervention was an influenza vaccination awareness campaign run by a local hospital in Stamford City in Fairfield County, Connecticut. Vaccination rates and emergency department visits for all respiratory diagnoses were compared between Stamford hospital and other hospitals in the same county over a 4-year period. Vaccination rates in Stamford hospital increased by 150% over three winter seasons and there was a reduced rate of hospital emergency department visits for respiratory diagnoses compared to other hospitals in the same county.

The main weakness of before-and-after studies is that they do not involve randomisation of participants to experimental or control groups, which means that there is greater likelihood of confounding by factors which are unequally distributed between groups, compared to RCTs.

The Met Office's Healthy Outlook® service ran between November 2012 and June 2013 in the UK. This programme was designed to help patients with Chronic Obstructive Pulmonary Disease (COPD) to manage their condition using automated telephone calls alerting individuals when weather extremes were forecast that were likely to exacerbate COPD. The phone calls received by participating patients explained the expected weather conditions and referred the individual to an information pack which provided advice on how to keep well. Participants were also asked a series of questions in relation to medication and symptoms, which were passed on to their general practitioner.

Mixed evidence was found in relation to the effectiveness of the Met Office Healthy Outlook® service. An RCT from England investigated the effectiveness of the service amongst 79 patients aged >40 years who had been clinically diagnosed with COPD and were recruited from 3 GP practices in Devon, South West England. Participants were randomised into two groups, one received alert calls (n=40) and the other acted as a control group (n=39) and did not receive alerts. Forty alert calls were received by intervention group participants over a four month period. Baseline data were taken on smoking status, medication use, condition management training, general health and presence of viruses. Participants completed the Exacerbations of Chronic Pulmonary Disease Tool Patient-Reported Outcome questionnaire during the study, which evaluates the frequency, severity, and duration of exacerbations of COPD. No significant differences were found in COPD exacerbation frequency between patients who received alert calls compared to controls who did not receive the calls (0.95±0.27 v 1.17±0.29, respectively). Exacerbations were shorter and less severe in the intervention compared to the control groups, but none of these differences were statistically significant at the p<0.05 level (176). Researchers were blinded to the intervention status of patients, but patients were not. Lack of double blinding (of researchers and participants) is a weakness of many of the intervention studies in this review, but the obvious nature of the interventions made it impractical to blind participants to this information.

An ecological before-and-after study from England compared COPD hospital admissions for patients aged ≥30 years from 87 general practices in the Bradford and Airedale Primary Care Trust (PCT) (West Yorkshire), between patients from practices in PCTs that used the service with those which did not (177). Comparisons were made over three periods: all winter (December to March), 7 days following an alert and 14 days following an alert over the winter period 2007-8. When accounting for the proportion of patients entered on the alerts system and the duration for which practices participated in the service, admission rate ratios for

practices fully using the service were 1.11 (CI 0.80–1.52), 1.22 (CI 0.73–2.04) and 1.21 (CI 0.82–1.78) for the three corresponding periods. Limitations of this study, which were identified by the study authors, included that a relatively small number of practices took up the service, few of those that did entered most of their patients on the system and there were relatively few alerts during the periods being compared.

An individual level before-and-after study from England examined the effectiveness of the Met Office alert service on healthcare utilisation amongst patients on the COPD Quality Outcome Framework registers from 3 primary care practices in Salford, North West England, UK, with mild-to-moderate airflow obstruction (178). One hundred and fifty seven (34% of target population) agreed to participate. These patients were aged around 71 years, (SD 9.7). Hospital admissions for acute exacerbations of COPD amongst these patients were compared between the intervention period (1 November 2008-31 March 2009) and the same period 12 months earlier. Five weather alerts generated (first alert reached 150 patients; second reached 146; third reached 138 patients; fourth reached 137 patients; and the fifth reached 125 patients) during the intervention period. There was a non-statistically-significant increase in hospital admissions per patient from 0.07 to 0.076 (p = 0.83). The number of general practice visits per patient dropped from 4.9 to 3.8 (p = 0.001) and there was a drop in average number of visits to patients by out-of-hours services from 0.52 to 0.14 (p = 0.013). The average number of home consultations provided by general practice increased from 0.05 to 0.92 (p = 0.001). Possible within participant changes between measurements, including condition improvement or deterioration in addition to climatic variation and influenza prevalence, could have impacted on the health outcomes for this study, but these were not controlled for in the design or analysis.

A qualitative semi-structured interview study from Bradford, England, explored patients and health care staff perceptions and experiences of the Met Office's cold weather alert service, their contribution to the management of COPD and implementation issues (179). Telephone interviews were undertaken with eighteen patients and six staff from five primary care centres in the Bradford area. Most patients were aged between 60 and 80 years, the youngest was 44. Some of the patients interviewed considered the telephone service to be an appropriate way to deliver information and to provide reassurance and useful medication reminders. However, several patients were indifferent or critical about the service and reported being sceptical about the reliability of the weather forecasts and felt that the service had little impact on the management of their condition. Primary care staff also interviewed in the study, considered

the service a success but some felt that it lacked participation by hard-to-reach groups, including non-English speaking patients and individuals with mild COPD.

A cross sectional survey from England, explored the acceptability and utility of the Met Office's Healthy Outlook® service to patients with COPD and its perceived impact on their behaviour and disease management (180). Participants who completed the survey were 3288 COPD patients who were drawn from 189 general practices in England, Scotland and Wales at the end of the winter of 2007/8 (34% response rate). The study found that older people and men were significantly less likely to take any form of action following an alert call (p = 0.0005 and 0.001, respectively). This study also found a strong, significant correlation between inactivity following an automated call and the degree of utility or reassurance reported (p<0.0005), which suggests that the forecasting service was most beneficial to those who were willing to change their behaviour in response to the warnings given. The results of these studies indicate that the service may increase health inequalities in COPD exacerbations, particularly between age groups and sexes. The authors identified that little is known about patients who opted out of the cold weather alert programme. The authors commented that, in order to provide a universal benefit to COPD patients, it is important to identify the reasons why some individuals decline to participate.

Impacts of dietary interventions

An RCT from Bethesda, the USA, investigated the association between ascorbic acid (vitamin C) supplementation and average number of colds during a winter (December – March) period amongst employees of the National Institute of Health, who volunteered to participate (181). Three hundred and eleven working-aged volunteers agreed to take 1gm of ascorbic acid (intervention group) or a lactose placebo (control group) in capsules three times per day for a period of 9 months. One hundred and ninety volunteers completed the study, which represented 44% of the treatment group and 34% of control participants. Average number of self-reported colds during the winter period (December to March) was 0.178 and 0.177 for treatment and control groups, respectively, in participants who completed the study. However, the results of this investigation may have been influenced by a break in the double blinding, as a post-trial questionnaire confirmed some participants had guessed their treatment status. There may also have been systematic differences between individuals who completed the study and those who did not, which may have biased the results. Data were not provided on the demographic profiles of intervention and control groups. However, the authors indicated that the distribution of these characteristics were not significantly different between groups. The lack of control for potential sources of bias, including differences in the baseline

incidence of colds between groups, may also have influenced the study outcome. Vitamin C has been hypothesized to reduce vulnerability to colds by enhancing immune function, but further research is needed to explore this potential association.

Summary of evidence – Studies evaluating the effectiveness of interventions on reducing adverse respiratory health outcomes in relation to winter season or cold exposure

Fourteen studies examined the impacts of interventions on respiratory health. These included five RCTs, eight non-randomised quantitative studies and one qualitative study. Study quality was mixed; two of the RCTs received a strong Quality Assessment Tool for Quantitative Studies global rating score, one was rated as moderate and two as weak. Of the eight non-randomised studies, three received a moderate rating and five were rated as weak. The qualitative study received a score of 8 out of 10 using the CASP system.

Mixed evidence was found in relation to the effects of household warmth interventions on respiratory symptoms. Influenza vaccination was generally associated with reduced diagnoses of respiratory conditions and there was evidence that this intervention was most effective amongst older person aged ≥65 years (174). However, this was based on ecological evidence and publication bias is likely to inflate the apparent positive effects of influenza vaccination.

The evidence in relation to the effects of the Met Office's Healthy Outlook® service on healthcare consultations amongst respiratory patients was mixed. A qualitative study identified scepticism from some patients about the reliability of Met Office weather alerts and lack of uptake by minority ethnic groups (179). This may partly explain the quantitative results of mixed effectiveness of the service on patient outcomes, as some patients may not use the service to manage their condition.

Evidence from an RCT suggested no effect of vitamin C consumption on improved respiratory health outcomes (181).

iv.   *Studies evaluating the effectiveness of interventions on improving general health outcomes in relation to cold exposure or winter season*
                    Impacts of interventions to increase household warmth

A qualitative semi-structured interview study from England investigated the impact of receipt of the Warm Front Intervention, which was a national scheme providing grants to enable individuals from vulnerable households to make thermal efficiency improvements to their home, and was available between 2001-2012 (182). Forty nine households from five urban areas (Birmingham, Liverpool, Manchester, Newcastle-upon-Tyne and Southampton) participated in the study. Each household had received the intervention, which comprised

installation, replacement or refurbishment of the heating system, insulation of the cavity wall or loft or both in some cases, and draught-proofing measures. The authors reported that most recipients who were interviewed reported improved and more controllable levels of warmth and hot water. Many of the interviewees also reported improved physical and mental health and several reported that chronic illnesses had been eased. The lack of consideration of the likely effects of the researcher on participant responses is a limitation of this and most other qualitative studies in this review.

A non-randomised controlled study from Scotland, described in the sections on circulatory and respiratory conditions, assessed the effect of a publicly funded domestic heating programme on self-reported health (170). Participants were 1977 households (no eligibility criteria other than receipt of the intervention) due to receive a modern central heating system under the programme. A control group not involved in the programme comprising 1872 households was matched to the intervention group by tenure, household composition, socioeconomic group and location (postcode sector). Intervention and control group participants were interviewed in their homes before the intervention was provided and at a one and two year follow-up. Results, derived from the initial and final interviews, found mixed evidence of the effects of central heating installation on various measures of health, including significantly higher scores on the 36-item Short Form Health Survey physical functioning scale and general health scales by the intervention group relative to the control group (estimated differences respectively = 2.51 units (95% CI 0.67 to 4.37 units) and 2.57 units (95% CI 0.90 to 4.34 units)). No significant effects were found for 25 other measures of health and wellbeing. However, as noted previously, the significance threshold used for these findings was $p \geq 0.05$, which is problematic due to the large number of outcomes measures under investigation (n = 30) which might be expected to produce 1.5 statistically significant results by chance.

An RCT from New Zealand (described in section *iii* (above) on respiratory conditions), investigated whether installation of a standard retrofit insulation package increased indoor temperatures and improved occupants' health and wellbeing (172). Participants (n=4407) were from 1350 households located in one of seven low income communities from across New Zealand. Baseline data were collected from intervention and control group participants prior to receipt of the intervention in 2001. Follow-up data were collected in 2002. The intervention was associated with increased bedroom temperature and decreased humidity and with reduced odds of poor self-rated health (OR 0.5, 95% CI 0.38-0.68). Lack of blinding of the participants in this study is a limitation as this may have influenced self-reported health

outcome responses, but the nature of the intervention made it unrealistic to perform double blinding.

Impacts of interventions to increase clothing protection

An RCT from Brisbane, Australia, investigated the effects of an intervention in which heart failure patients aged ≥50 years were randomised into an intervention group, which received two thermal hats and tops and a thermometer, or a control group who did not receive the intervention. Fifty five participants were randomised and data were analysed for 50 participants, who completed the study (26 in the intervention group and 24 in the control group). Over 100 winter days, the intervention group were found to have fewer mean days in hospital during the winter period compared to the control group (with a mean difference of 0.7, 95% CI -1.5 to 5.4), in addition to having 0.2 fewer mean number of GP visits (95% CI -0.8 to 0.3) and higher mean improvement in self-rated health (by -0.3 points, 95% CI -0.9 to 0.3, on a scale where 1 = excellent health and 5 = very poor health). Values for the 95% CIs indicated lack of evidence of a positive effect on these outcome variables in the study population. The authors reported that it was generally found that the thermal tops were well used by participants in the study, but the hats were only worn by 30% of participants, even in cold-temperatures (183). A limitation of the study is the use of self-reported health outcome data, which may have been influenced by receipt or lack of receipt of the intervention.

Summary of evidence – Studies evaluating the effectiveness of interventions on improving general health in relation to winter season or cold exposure

Four studies examined the effects of interventions on general health outcomes. These included two RCTs (Quality Assessment Tool for Quantitative Studies global rating score = strong (172) and Quality Assessment Tool for Quantitative Studies global rating score = moderate (183)); one non-randomised controlled study (Quality Assessment Tool for Quantitative Studies global rating score = moderate (170)) and a qualitative study (CASP global rating score = 6.5 out of 10) (182). Evidence from these studies indicated that interventions to improve household warmth were associated with improvements in some health outcome measures, but this was mainly from self-reports in studies where participants were not blinded to their intervention status.

Studies evaluating the effectiveness of interventions on reducing slips and falls in relation to cold exposure or winter season

Impacts of clothing-related interventions

Four studies examined the effects of footwear interventions on tendency to slip or fall (184-187). These included a non-randomised controlled study from Sweden, which examined independent and potential interaction effects of footwear and type of icy surface on the tenancy to slip, which was assessed using average scores from objective and subjective measures, in a sample of 25 participants, including 15 males and 10 females aged 22-62 years (186). Four types of footwear and five types of icy surface were tested. The results indicated that there were no significant interactions between types of footwear and icy surface on propensity to slip ($p>0.05$). However, there were significant independent effects of footwear design and type of icy surface on the potential of participants to slip. It was found that participants were least likely to slip when they wore farmer's boots, which contained lots of small ridges on their outsoles. Participants were most likely to slip whilst wearing boots that had smooth, flat outsoles and heels ($p <0.05$). The type of icy surface walked on by participants was also significantly associated with risk of slipping ($p<0.01$), with number of slips observed, from least to most, when participants walked on ice covered with: sand, gravel, salt, snow, and pure ice. All participants had over 5 months' experience of walking on icy roads and had lived in the Nordic region for at least seven months. Consequently, these results may not be applicable to other populations.

An RCT, also from Sweden, examined the effect of using anti-slip devices on prevention of slip and falls over one winter period (2007/8) (187). Participants were healthy, working aged adults aged 27-67 years old. These individuals were allocated to one of three groups. Participants in the intervention and control groups attended different information meetings in order to discuss problems and benefits from walking during the wintertime. Participants in the intervention group also received detailed information about the use of anti-slip footwear devices and were provided with one of three types of anti-slip devices: a heel device, a foot-blade device or a whole foot device. Participants in a comparison group did not attend an information session and were informed that they were participating in a travel survey. Based on self-reported questionnaire data, from 61 participants, including 22 from the intervention group, 23 from the control group and 16 from the comparison group, from diaries kept by participants over the winter season, the number of falls per kilometre walked was slightly reduced for intervention group participants (falls per km = 0.00069) compared to individuals

from the control and comparison groups (falls per km = 0.00107). However, these findings may not be generalisable to other populations, such as populations from other countries.

An RCT from Wisconsin, the USA, examined the effects of a non-medical gait stabilizing device, the Yaktrax Walker, on the rate of injurious falls in fall-prone older people (185). Participants were community dwelling, fall prone people aged ≥65 years. These individuals were allocated to an intervention group, who wore the Yaktrax Walker over the footwear during the winter period 2003/4, or a control group, who wore their ordinary footwear. Participants from both groups kept diaries documenting their daily number of indoor and outdoor slips, falls and injurious falls over the study period. Diaries were available for 109 participants (intervention group n = 55; control group participants n = 54) which provided data for 3,634 diary days for the intervention group and 4,274 for the control group. A comparison was made between the number of outdoor and indoor falls for each group. The relative risks of falling outdoors were generally significantly lower in the intervention group compared to the control group ($p<0.05$), even though the numbers of indoor falls were comparable between groups (185). There were no differences in baseline propensity to slip or fall (assessed based on indoor slip and fall rate) between groups. However, lack of blinding to the intervention may have influenced participant self-reported diary entries regarding their propensity to slip.

Another RCT, from Dunedin, New Zealand, investigated whether wearing socks over shoes improves traction on icy footpaths (184). Thirty pedestrians travelled in a downhill direction on one of two icy footpaths wearing either coloured socks over their normal footwear (the intervention group) or just their usual footwear (the control group). Wearing socks over footwear was associated with a statistically significant improvement in traction. The difference in mean self-reported slipperiness scores between the control (n=15) and intervention (n=14) group was 1.3 (95% CI 0.4-2.3). In addition, agreement between self-rated and observer-rated slipperiness was high (correlation coefficient =0.70). It was noted by the study authors that the improved traction in the intervention group compared to the control group may have been attributable to the fact that a higher proportion of the intervention group (71% versus 53%) appeared confident.

A problem with studies examining the effects of footwear interventions on the risk of falling on cold-surfaces was the small sample sizes that were used, which reduces the statistical power (i.e. the ability to detect a true significant difference between study groups) of these experiments. This is because larger samples are generally more representative of the study population.

Summary of evidence – Studies evaluating the effectiveness of interventions on reducing slips and falls in relation to winter season or cold exposure

Four studies examined the effects of interventions on the occurrence of slips and falls. Three were RCTs ((184, 185, 187), Quality Assessment Tool for Quantitative Studies global ratings = weak, moderate and weak, respectively) and one non-randomised controlled study ((186); Quality Assessment Tool for Quantitative Studies rating = weak). The most effective interventions appeared to be wearing shoes with ridged soles (187) and Yatrax Walker ice grips (185).

vi.   *Studies evaluating the effectiveness of interventions on reducing vitamin deficiencies in relation to cold exposure or winter season*

Impacts of dietary interventions

A non-randomised study from Finland investigated the effects of national policy on vitamin D fortification on vitamin D status among young Finnish men aged 18–28 years (188). Serum vitamin D concentrations were measured in 96 participants in January 2003 and in a different sample of young males in January 2004. The Ministry of Social Affairs and Health recommended that vitamin D be added to liquid milk products and margarines from February 2003. It was found that mean levels of serum vitamin D were higher in a sample of young males during the winter a year after the policy came into effect, compared to a different sample of males whose vitamin D levels were measured during the same month before the policy was implemented. The prevalence of vitamin D insufficiency in the sample who were measured a year after the policy was introduced, was reduced by 50% compared to levels observed in the pre-intervention group (188). However, baseline differences in serum vitamin D between groups were not adjusted for in analyses.

An RCT from Greece investigated seasonal variations in vitamin D status amongst Greek postmenopausal women receiving dairy products enriched with calcium and vitamin D for 30 months (189). Sixty-six postmenopausal women aged 55-65 years old were randomised into an intervention group (n= 30) or a control group (n=36). Intervention group participants attended nutrition and lifestyle counselling sessions and were advised to consume dairy products which provided a daily dose of 7.5 micrograms (µg) of vitamin D_3 for 12 months, increasing to 22.5µg for the remaining 18 months of intervention. Control group participants were simply advised to continue with their normal diet. Serum vitamin D levels were measured for both groups at baseline and at 6, 12 and 30 month follow-ups. After 30 months of intervention, during the winter period, serum vitamin D levels significantly decreased in the control group whilst remaining in the same high levels as in the summer period in the

intervention group. Also after 30 months of intervention, the prevalence of vitamin D insufficiency was significantly higher in the control group compared to the intervention group (60% versus 25.0%, P=0.006). There were no significant differences between groups at baseline regarding anthropometric (weight, height and BMI), physical activity, dietary intake and bone mass indices, which are related to vitamin D levels. In addition, mean serum vitamin D levels were higher in the control group compared to the intervention group at baseline. However, sunshine exposure and changes in lifestyle factors between groups during the study were not accounted for.

Summary of evidence – Studies evaluating the effectiveness of interventions on reducing vitamin deficiencies in relation to winter season or cold exposure

Two studies examined the effects of interventions on vitamin insufficiency in relation to winter months. One was an RCT (189) (Quality Assessment Tool for Quantitative Studies global rating score = moderate) and the other was a non-randomised study (Quality Assessment Tool for Quantitative Studies global rating score = weak) (188). There was some evidence that vitamin D fortification of food was associated with reduced vitamin D insufficiency. However, many other factors also influence serum vitamin D levels (e.g. active smoking, ethnicity, physical activity) and it was unclear how much of the effect from each study was attributable to the dietary interventions of interest.

vii.   *Studies evaluating the effectiveness of interventions on improving emotional health and wellbeing in relation to cold exposure or winter season*

Impacts of dietary interventions

An RCT from England assessed the effect of vitamin D supplementation on the mental health of older women (190). Women aged ≥70 years were randomised to receive daily supplementation of 1000mg calcium and 800 International Units of vitamin D during the winter period, or no intervention. Baseline data, including mental component scores of the 12-item Short Form questionnaire were collected from 2117 women (1205 and 912 in the control and intervention groups, respectively) during May-October and from 1621 women (941 and 680 respectively, in the control and intervention groups) at a six month follow-up (i.e. during the months November-April, which incorporates the four 'winter' months). Comparison of the six month mean mental component scores between intervention and control group participants, adjusting for baseline mental component scores and age, showed there was no significant difference between the two scores (p = 0.262). Data on the proportion of eligible women who agreed to participate in the study were unavailable. Also, it is possible that

factors other than supplementation may have differentially affected the mental health of intervention and control groups between baseline and post-intervention measurements (e.g. causes of life stress; propensity of individuals to experience seasonal affective disorder). In addition, a clearer indication of the effect of vitamin D supplementation on mental health in relation to winter season could have been ascertained by delivering the intervention before the winter period and taking follow-up measurements at the beginning of the following spring.

Impacts of interventions to increase physical activity and light exposure

Another RCT, from Finland, examined the effects of an exercise and bright light intervention on mood and quality of life during the winter (191). Participants were 80 working-age adults who were randomised into one of three groups, respectively receiving an exercise intervention under bright light conditions (n=35), exercise intervention under normal light conditions (n=35) or relaxation training (n=28). The intervention lasted for 8 weeks and questionnaire data on mood and health-related quality of life were collected at study entry and at weeks 4 and 8 and at a 4 month follow-up. Physical exercise combined with bright or normal light conditions was associated with a significant reductions in scores for atypical depressive symptoms (p=0.005) and typical depressive symptoms (p<0.001) at 8 weeks compared to the control intervention (relaxation training). The intervention group who received physical exercise under bright light conditions also had significantly reduced scores for atypical depressive symptoms (p = 0.001) (191). The increased effectiveness of the physical activity intervention on under bright light conditions may be caused by neurological mechanisms that reduce the symptomology of seasonal affective disorder (sometimes referred to as "winter depression"), in response to increased light exposure amongst this treatment group. Limitations of this study, identified by the authors, include different levels of attrition of participants between groups and also possible selection bias, as participants were required to take some interest in fitness training, which may have appealed more to individuals with certain characteristics (e.g. persons in better health at baseline).

Impact of household thermal efficiency interventions

Eight studies evaluated the mental health impacts of household thermal efficiency interventions, six of which came from the UK and one each from Germany and New Zealand.

Three studies were from England. One investigation (Allen, 2005, cited in (192)) comprised two uncontrolled before-and-after studies, both of which evaluated the UK's Housing for Healthier Hearts project in Bradford. The intervention involved heating installation/repair, reroofing and replacement windows in households containing person(s) with serious coronary

disease. The first study in this evaluation found significant improvements in mental health, measured using the mental health component of the SF-36, following the intervention, based on outcome data from 32 households. In addition, scores on the Hospital Anxiety and Depression Scale indicated a significant reduction in depression following the intervention. However, anxiety scores on the Hospital Anxiety and Depression Scale did not improve significantly. In the second study, a significant reduction in mental disorder, measured using the GHQ-12 tool, was found following the intervention, based on outcome data from 16 households.

A different study from England (193) was an RCT which evaluated the Watcombe Housing Project, whereby 119 council owned houses (comprising 480 residents) in south Devon, UK, received household upgrades including central heating, ventilation, rewiring, insulation, and re-roofing. The intervention was delivered in two phases, between 1999 and 2000. Health impacts of the intervention were assessed using annual postal questionnaires, which were sent to intervention recipients and a control group in 1999 and 2000. The questionnaire included two measures of mental wellbeing, namely mental disorder, assessed using the GHQ-12 tool, and mental health, which was assessed using the SF-36. The results showed no statistically significant differences between changes in SF-36 or GHQ-12 scores in intervention group (n=49 households) compared to a control group (n=61) following the intervention. However, the authors of this study noted that health improvements may not have been evident due to the short time scale between receipt of the intervention and evaluation of its potential health impacts.

A qualitative study from England (182), described in the section on general morbidities, investigated the effects of thermal efficiency grants provided to low income households under the Warm Front intervention scheme, on various health outcomes. A purposive sample of 49 out of 3000 households which received home energy improvements under the scheme from five urban areas of England, stratified by area, household type and period since intervention (recent installation or installation in the preceding winter) was randomly selected for inclusion in the study. Data from semi-structured interviews indicated that many participants reported improved mental health and emotional well-being in relation to the intervention. This qualitative study comprised a relatively small number of individuals and it is not therefore possible to make generalisations at the population level from this work, although it is indicative of a positive effect, which would be a logical impact of such an intervention, but does not equate with a measureable and statistically quantifiable impact.

Two studies evaluated the health impacts of thermal efficiency interventions in Scotland. One study (194) used a controlled before-and-after design to evaluate the Scottish Central Heating Programme. This programme involved installation of central heating and thermal efficiency measures to households in the private rented sector which lacked central heating, and to privately owned households containing person(s) above pensionable age which lacked a functional central heating system. Data were collected from an intervention group and a comparison group, the latter of which comprised households that did were not part of the intervention programme, prior to receipt of the intervention and at one and two year follow-ups, after the intervention was delivered. Data from the two year follow-up indicated that the intervention group (n=1,281 households) showed a statistically significant improvement in health-related quality of life, assessed using the SF-36 tool, compared to the comparison group (n=1,084 households). However, as noted by the study's authors, the size of the difference between groups was small.

Another study from Scotland (195) used a cross-sectional design to assess the effects of a housing regeneration project, which included insulation measures, on mental wellbeing amongst 3,911 residents from 15 deprived neighbourhoods of Glasgow. The results showed that mental wellbeing, measured using the Warwick-Edinburgh tool, was significantly positively associated with internal insulation (p = <0.001).

A controlled before-and-after study from Northern Ireland (196) evaluated a fuel poverty reduction programme, which aimed to tackle fuel poverty in a rural context through improving household energy efficiency levels and increasing household income through encouraging increased uptake of social security benefits. Energy efficiency measures, including some central heating systems, were installed in 54 homes. Data were collected from households in the intervention group and from a control group before the intervention was delivered and at one-year post-intervention. Data from the post-intervention survey were collected from 54 intervention group households and from 46 control group households. The study found a non-significant reduction in the prevalence of stress/ mental illness at one year post-intervention in the intervention group, whereas the control group showed a significant increase in this outcome following the intervention.

Another before-and-after study, from Germany, evaluated the health effects of the World Health Organization's Frankfurt housing intervention project (197). The programme involved the provision of thermal insulation and the replacement of windows and heating systems in homes in which these features were inadequate. Initial data were collected in spring 2006 before the intervention was delivered and follow-up data were collected following the

intervention, in spring 2007. Follow-up data were available from 235 households (n = 131 and n = 104 for the intervention and control groups, respectively). The prevalence of depression (measured from self-reported sleep disturbance, loss of appetite, lack of motivation/interest and lack of self-esteem) decreased in the intervention and control groups following the intervention, whereas the prevalence of strong depression increased in both groups. The authors concluded these results are difficult to attribute to the renovation work and that further analysis of these data should control for factors including the age of the residents.

A single blinded RCT from New Zealand (described in section *iii* in relation to respiratory health outcomes), examined whether insulating existing houses increases indoor temperatures and improves occupants' health and wellbeing (172). The study groups comprised 1350 un-insulated households (intervention group n = 679; control group n = 671) containing 4407 participants from seven low income communities in New Zealand. Mental health was assessed using subscales from the SF-36 (namely role functioning physical, role functioning emotional, and social functioning). Participants in the intervention group had a significantly increased improvement on the role emotional scale (P<0.0001) and on the role physical scale (P<0.0001), relative to the control group.

A limitation of the studies in this section is the short time period between implementation of thermal efficiency interventions and collection of data on health outcomes. In addition, the self-reported nature of the health data collected is a potential limitation, although mental health outcomes were assessed using validated tools in each study.

Summary of evidence – Studies evaluating the effectiveness of interventions on improving emotional health and wellbeing in relation to winter season or cold exposure

Ten studies examined the effects of interventions on emotional health and wellbeing during the winter period. One RCT (190) (Quality Assessment Tool for Quantitative Studies global rating = strong) found no significant effects of vitamin D supplementation on scores from a mental health questionnaire. Another RCT found some evidence that an exercise intervention under bright light conditions improved mental health ((191), Quality Assessment Tool for Quantitative Studies global rating = moderate)). A qualitative study found that recipients of a thermal efficiency intervention reported improved mental health and emotional well-being (182). Evidence in relation to the mental health impacts of household thermal efficiency interventions using data from quantitative studies showed mixed but generally positive results (Quality Assessment Tool for Quantitative Studies global rating = strong ((193), (195), (194), (197), (172)); Quality Assessment Tool for Quantitative Studies global rating = moderate

(196); Quality Assessment Tool for Quantitative Studies global rating = weak (Allen, 2005, cited in (192)).

viii.   *Studies evaluating the effectiveness of interventions on reducing adverse wider social impacts of cold exposure or winter season*

Impacts of interventions to increase clothing protection

An RCT from Queensland, Australia (183), already cited in the section on general morbidities, assessed the effects of providing coronary patients with two thermal hats and tops and a digital thermometer (intervention group) on healthcare utilisation. This can be considered a social outcome due to the economic costs to society of medical consultations. Fifty five participants aged ≥50 years were randomised into an intervention group, who received two thermal hats and tops and a thermometer, or a control group who did not receive the intervention. Fifty participants completed the study (26 in the intervention group and 24 in the control group). The mean number of days in hospital per 100 winter days was higher (2.5) in the intervention group compared to 1.8 in the usual care (control) group, with a mean difference of 0.7 (95% CI −1.5 to 5.4), although the intervention group had 0.2 fewer GP visits on average (95% CI −0.8 to 0.3) compared to the control group. The study reported greater usage of the thermal tops compared to hats by intervention group participants. The self-reported nature of outcome data is a limitation of this study.

Impacts of housing-related interventions

A qualitative study from Auckland, New Zealand, evaluated the impacts of the Healthy Housing Programme, which aimed to improve the housing circumstances of low income families who lived in social housing (198). Thematic analyses of semi-structured interview data from members of 30 recipient households indicated that the programme had strengthened social cohesion (198). Interviewers were ethnically matched to participants, to help build positive relationships during the interview process. The authors of the study acknowledged that participant responses to questions may have been influenced by the knowledge that the research was funded by the same organisation that provided the intervention.

A single blinded RCT that was conducted in the following five communities in New Zealand: Porirua, the Hutt Valley, Christchurch, Dunedin and Bluff, investigated the effects of installing a more effective, less polluting home heater on outcomes including school absenteeism (199). All households contained a child aged 6-12 years with diagnosed asthma. Households were randomised into an intervention group (n =200) whose homes were installed with a more effective heater before the winter of 2006. The homes of children in the control

group (n=174) were not provided with an intervention until the study follow-up data had been collected. Demographic and health information were collected before the intervention. Data on school absenteeism for study participants were obtained for the summer before the intervention was delivered or was likely to be in use and for the winter when the intervention was likely to be used. Outcome data, in terms of school attendance records, were collected for 135 intervention group participants and 134 control group participants. Results showed that installation of a more effective and less polluting home heating system in the homes of asthmatic children was associated with a 21% reduction in the number of days absent from school compared to children in the control group (p<0.02). Limitations identified by the authors of the study included that the study had more low-income households and more Maori and Pacific Islander households compared to the whole population of New Zealand, which reduces the generalisability of the study's findings.

Another RCT from New Zealand (172) (described in section *iii* on respiratory health), investigated the impacts of a household thermal efficiency intervention provided to low income households, using data from seven communities from across New Zealand. The study participants were from 1350 un-insulated households (intervention group n = 679; control group n = 671) containing 4407 participants from seven low income communities in New Zealand. Each household had at least one person who had reported respiratory symptoms in the last year. Baseline data were collected in 2001, before the intervention was implemented, follow-up data were collected in 2002. Insulation-related increased bedroom temperature and decreased humidity were associated with significantly reduced odds of self-reports of children taking a day off school (0.49, 95% CI 0.31–0.80, p=0.004), self-reports of adults taking a day off work (0.62, 95% CI 0.46–0.83, p = 0.0017) and self-reported general practitioner (GP) visits (0.73, 95% CI 0.62–0.87, p=0.0002) and non-significantly with GP visits according to medical records. Participant knowledge of their interventions status could have influenced their self-reported outcome data; however, it was not possible to blind participants to this information.

A qualitative study from England (182), also described in the sections on general morbidities and mental health and wellbeing, evaluated the impact of the Warm Front thermal efficiency intervention scheme. Qualitative interviews were undertaken with a purposive sample of 49 recipient households from 5 English cities. Intervention recipients reported an expansion of domestic space associated with the intervention, including an increased usage of kitchen areas, during the cold-months. Additional reported benefits included improved nutrition, presumably because of the increased ability for individuals to pay for better quality food due

to their reduced fuel costs attributable to improved household thermal efficiency. Qualitative studies are descriptive rather than analytical in nature and do not include samples that are representative of the study population. Consequently, they do not provide strong evidence of cause-effect relationships between exposures or interventions and outcomes and the results of qualitative studies cannot be generalised to the population level. However, evidence from these studies can be used to formulate hypotheses about disease mechanisms which can be tested quantitatively.

A non-randomised controlled study from England, analysed existing survey data to assess the nature of the benefits of a thermal efficiency intervention performed in flats in 4 apartment blocks in a poor inner-city area of Sheffield, Northern England (200). The comparison group were residents of 3 unimproved apartment blocks, from the same inner-city area as the intervention group participants and who had similar socioeconomic circumstances. The study found that recipients of the intervention used financial savings from reduced fuel bills associated with the improved thermal efficiency of their housing to pay for additional home heating, thus increasing their level of household warmth. Reduced heating costs associated with the intervention also enabled recipients to purchase other 'basic essentials of life'. This indicates that thermal efficiency improvements may help to reduce social inequalities, by enabling a better standard of living for recipients.

An RCT from North East England evaluated the health and social impacts of a fuel poverty intervention (201). Two hundred and thirty seven households in full or marginal fuel poverty were randomised to an intervention group (n=129), who received an energy efficiency intervention package in year three of the study, or a control group (n=108) who received the intervention in year four of the study. Receipt of a thermal efficiency improvement package was associated with improved household temperature and increased satisfaction with household warmth in the intervention group compared to a control group (p=0.02). Heating costs were not found to be reduced following the intervention (201). This suggests recipients used the financial savings from reduced fuel bills associated with the thermal efficiency interventions to pay for extra heating, thus financing their improved thermal comfort. Limitations of the study design include that it was not possible to blind participants to their intervention status.

A non-randomised controlled study from England evaluated the impact of the Warm Front intervention on winter thermal comfort in low-income dwellings (202). Data were collected pre- or post-intervention from 2500 dwellings selected from five major urban areas in England over the winters of 2001/02 and 2002/03. The intervention included (i) insulation

only, (ii) gas central heating only or (iii) insulation and gas central heating. Data from households in the intervention group were compared with those collected from a baseline (control) group, before they received the intervention. Results indicated that the scheme led to an increase in the mean indoor temperature from 17.1^0C to 19^0C. In addition, each of the three intervention packages was associated with significant improvements in the level or thermal comfort and reduced clothing level compared to the group who were assessed at baseline ($p \leq 0.05$) (202). Comparison of different intervention and control groups during the periods controls for climatic factors (e.g. mean environmental temperature across the study areas during specific winter seasons). It was not clear whether factors that may influence thermal comfort and clothing requirements (e.g. age, sex and clinical factors), were balanced between groups, although only fuel poor households containing a vulnerable person, defined in terms of age and medical vulnerabilities, were eligible for the intervention.

An economic study from Ireland evaluated the projected costs and benefits of a national thermal efficiency programme (203). The intervention involved retrofitting existing dwellings with various thermal efficiency technologies and heating improvements. The study valued the economic benefits of the programme, measured as improved levels of thermal comfort and reduced energy costs, at €461 discounted at 5% (i.e. what that value of money would be currently worth), over 20 years. Improved thermal comfort and reduced energy costs accounted for 21% and 79% of the total benefits of the programme, respectively. This was a computer simulation rather than an evaluation of an actual intervention and health outcomes were not assessed.

A different economic study evaluated the costs and benefits of a thermal efficiency intervention in Greater Manchester, Northern England (204). The cost-benefit analysis considered Affordable Warmth Access Referral Mechanism interventions in 52 households, whose residents were 82 adults and 12 children. The interventions were mainly insulation (wall and loft) and heating improvements (boiler repair or new central heating). Scenarios were considered whereby benefits, in terms of change to anxiety and depression state measured using the EuroQol instrument, and quality-adjusted life year (QALY) gains over one and five year periods. A QALY is equal to one year of life in perfect health (205). In this study, QALY gains ranged from 1.67 to 31.16 depending on the scenario modelled. Life years gained from living longer were estimated to be 2.55 years, assumed to equal to 1.53 QALYs. The study authors cited that using the NHS threshold of £20,000 as the value of one QALY. The intervention in this project cost £88,800 and therefore must generate at least 4.44 QALYs to be cost effective. In the scenarios modelled, the value of the QALYs gained ranged from

£64,000 to £653,800. The authors acknowledged that the models are unsuited to use in specific populations, such as cancer patients who may gain more benefit from increased household warmth.

A study from New Zealand evaluated the costs and benefits of retrofitting, in which the homes of asthmatic children from the lower North Island and the South Island were installed with a cleaner, more efficient heating system (206). Participants were randomised to either receive a new heater prior to winter 2006 or to receive the intervention after the outcome data had been collected (control condition). Of the 209 and 200 control and intervention group households, respectively, 174 and 175 were still part of the study at the end. During and after the winter of 2006, health and energy use data were collected. The ratio of health benefits, reduced energy usage and carbon savings against the costs of installing and running the new heater were 1.09:1 in a scenario which assumed that children from the intervention group experienced high rates of asthma over the duration of the expected lifespan of the new heater. In a second scenario, which assumed typical rates of asthma for children in the intervention group over the expected lifespan of the heater, the ratio of benefits to costs was 0.31:1. However, the authors indicated that the sample size used in this study was not large enough to provide sufficient statistical power.

Another study, from regions across the North and South islands of New Zealand, evaluated the impact of an insulation retrofitting programme on healthcare utilisation (207). The data were based on 51,663 insulation retrofits installed in 2009-10 and 49,096 in 2010-11. Benefits were analysed over 30 years for the impact of insulation and ten years for the impact of clean heat. Annual health-related benefits (savings) per household treated (New Zealand dollars ($)/house, for all homes) were estimated as follows: hospitalisation and pharmaceutical use related benefits: $75.48, value of reduced mortality: $439.95, total health benefits: $563.18. A limitation of the study is that only metered data were used to estimate changes in energy use; the study did not include data on the impacts on other fuels, such as coal or wood.

An economic study investigated the health co-benefits of four proposed greenhouse gas emission reduction strategies in the UK (208). The strategies related to food and agriculture, household energy efficiency strategy and two were in relation to urban transport. The household energy strategy involved improving insulation and ventilation of the housing stock to improve health and reduce greenhouse gas emissions. The time period used to assess costs and benefits in this study was 20 years (2011–2030). The study found that health benefits (disease burdens in terms of Years Lost due to Disability and Years of Life Lost) enhanced the cost effectiveness of the thermal efficiency strategy only over the very long term (beyond

the 20 year time horizon of the study). This was a policy simulation rather than being based on an actual intervention.

A study from Northern England evaluated the economic impact of a fuel poverty intervention (the 'Kirklees Warm Zone Project') on mental health and wellbeing (209). The intervention ran from 2007-2010 and provided energy efficiency improvements and other services, including home safety measures and benefit checks, to residents of the Metropolitan Borough (a local authority area) of Kirklees, in West Yorkshire. The intervention was provided to a range of households, specifically targeting privately owned homes due to their low thermal efficiency relative to social housing in the area. However, all residents of Kirklees received some form of intervention. The costs of the project were measured against health benefits, primarily in term of mental wellbeing, including a range of outcomes such as common mental disorder, anxiety and depression; physical health impacts were also included in the model. Estimates of the likely impact of the intervention on health outcomes were derived from the epidemiological literature and these were converted to monetary values using NICE's QALY values. Using this method, it was estimated that a capital investment of £13.3 million to the scheme, would produce benefits to mental well-being and physical health that would recoup 36p per pound of investment over a lifespan of likely impacts. Alternatively, a capital investment of £24 million in the project was estimated to produce a health benefit return of 20p per pound of investment. Limitations of the evidence used to derive odds ratios for this study were identified by the study authors, including that data used to assess mental health impacts of interventions were predominantly self-reported.

Another study assessed the health benefits versus costs of a thermal efficiency intervention from Northern Ireland (210). Northern Ireland's Warm Zone Scheme ran from 2000-2008. The intervention involved retrofitting houses to improve thermal efficiency ratings. Estimates of cost-effectiveness were made over a 15 year time period, the estimated lifespan of the intervention. Health impacts were estimated in relation to the expected occupants of treated dwellings (including senior citizens, young adults and children). The total number of treated homes was 60,223; this figure was disaggregated by age of recipients for the purposes of analysis. The study estimated that with an investment of £109 million in the scheme, between 23% and 42% of this cost could be offset against QALY gains from reduced household health hazards. Also, between 1% and 2% of this investment could be offset against NHS savings from treating fewer cold-related accidents and illnesses. The authors of the study identified a limitation in the method used to calculate cold-related health hazards, which focused on physical health impacts, presumably as mental health outcomes are more difficult to quantify.

A study from Wales calculated the health and social costs and benefits of interventions to reduce health and safety hazards related to cold housing (211). The authors of the study used the results of a national housing survey which estimates the prevalence of health hazards related to cold housing, based on the Housing, Health and Safety Rating System methodology. These health impacts were monetised using NHS data on the costs of treating the health conditions that are related to cold housing. The costs of reducing serious health hazards of cold housing were calculated using the estimated costs of remedial work. The results indicated that the installation of an efficient heating system, and upgrading of loft insulation in a home with serious cold-related health hazards, would raise the thermal efficiency rating of the property well above average. In addition, the potential costs to the NHS of treating cold-housing-related health hazards in the home would be recouped in approximately five years. Additionally, when annual fuel savings are added to the model, it was estimated that the cost of the improvement could be paid back in half of this time. The authors estimated that more advanced thermal efficiency improvements would produce fuel and carbon savings but not much impact on health. As acknowledged in a different study (209), the Housing, Health and Safety Rating System focuses on physical health impacts.

A study estimated the public health and societal cost benefits of insulation retrofits in existing housing across the USA (212). The study was based on modelled emission reductions from insulation retrofits in single-family homes (n=46 million) in the United States. Concentration-response functions for morbidity and mortality from $PM_{2.5}$ were derived from the epidemiological literature, and economic values were assigned to health outcomes based on willingness to pay studies. It was estimated that the insulation retrofits would result in 3,100 fewer tons of $PM_{2.5}$, 100,000 fewer tons of nitrous oxides, and 190,000 fewer tons of sulphur dioxide per year. These emission reductions equated to 240 fewer deaths, 6,500 fewer asthma attacks, and 110,000 fewer restricted activity days per year. The authors of the study acknowledged uncertainties related to the interpretation of $PM^{2.5}$ health effects and other dimensions in their model.

A qualitative focus group study from England investigated the value to recipients of two cold-weather-related fuel subsidies (213). The Winter Fuel Payment is a tax-free payment provided to recipients of the state pension or certain other social security benefits in the UK. The Cold Weather Payment is a benefit provided during periods of cold weather to individuals in receipt of certain benefits. Three categories of focus groups were used to collect qualitative data from different types of participants, they were: pensioners (n=18 participants); individuals living with household members with a disability (n=8 participants); or individuals

from a household containing a child who was under the age of 5 years (n=5 participants). Findings of the research indicated that the Winter Fuel Payment is considered to provide a significant and valuable contribution to older households and to lessen worry and stress associated with high energy bills and increased heating usage. Also, winter fuel payments received by older households and Cold Weather Payments received by younger vulnerable households may act as a prompt for households to think about budgeting for fuel. The Cold Weather Payment was valued by those who received it, but only during the occasions when a payment has been triggered. Finally, for those eligible for the Cold Weather Payment, a need was identified among some households for additional financial assistance during the winter period. This was particularly pronounced in the cases of mothers with young children and in low income households, a number of whom testified to missing out on meals in order to top-up their prepayment meter, which is often a more expensive way of paying for fuel compared to monthly payments, and in the case of households where there is an existing disability or illness. Qualitative studies can provide useful insights regarding the utility of interventions for improving health.

Summary of evidence – Studies evaluating the effectiveness of interventions on reducing adverse wider social impacts in relation to winter season or cold exposure

Seventeen studies considered the effectiveness of interventions aimed at reducing the wider social impacts of cold weather. Four of the studies were RCTs (172, 183, 199, 201). Quality Assessment Tool for Quantitative Studies global rating scores = strong, moderate, strong and moderate, respectively). The results of one study provided evidence that an intervention to increase clothing protection over the winter period was associated with reduced healthcare utilisation, but this was based on self-reported data. Results from the other RCTs indicated that household thermal efficiency interventions were associated with reduced school and work absenteeism, in addition to fewer GP visits. There was also evidence that the benefits of such interventions are used to improve thermal comfort in the home, rather than to reduce fuel usage and costs.

In addition, there were two non-randomised controlled studies (202) and (200) (Quality Assessment Tool for Quantitative Studies global rating scores = weak and moderate, respectively). The findings from these studies provided evidence that thermal efficiency interventions were associated with reduced heating costs and improved thermal comfort.

Three studies used qualitative methods (182, 198, 213), CASP scores = 7, 7, and 6.5 out of 10, respectively. The results from these studies indicated that thermal efficiency interventions could have positive impacts on social cohesion and improve the dietary quality of recipients.

Cold-weather-related fuel subsidies were found to be valuable to recipients, but a need for additional financial assistance was highlighted amongst those ineligible for the Winter Fuel Payment.

Nine studies were economic impacts assessments (196-197, 199-205), CASP scores ranged from 7 to 9.5 out of 12. These studies provided mixed evidence in relation to the economic benefits of thermal efficiency improvements, depending on the populations used in each study and parameters included in the models, particularly in relation to outcomes.

3.4 Summary

In this systematic review, I used a narrative approach to synthesise evidence from a heterogeneous range of studies which evaluated the effects of interventions on reducing winter- and cold- related excess adverse health and social impacts. Forty-one studies were included in the review, which came from the UK, New Zealand, the USA, Australia, Sweden, Japan and Finland. Only fifteen studies were RCTs, which are generally considered to provide the strongest evidence of cause-effect relationships between interventions and outcomes. A general limitation of the RCTs in this review was the lack of double blinding, which meant that participants were often aware of their intervention status. However, most of the studies used objective outcome measures, which may reduce potential bias in which intervention group participants are more likely to report that their health has improved after receipt of an intervention.

Qualitative studies provided information regarding the processes underlying the effectiveness or ineffectiveness of interventions. Economic studies enabled societal costs of cold weather to be quantified. The cost-effectiveness estimates varied between populations and based on parameters included in the analyses.

Most of the included studies evaluated the effects of interventions which aimed to increase household warmth using central heating installation or upgrades and improved household thermal efficiency standards. Several studies identified that individuals tend to take the benefits of thermal efficiency interventions to improve their level of thermal comfort, as opposed to reducing their fuel bills. In relation to outcomes, proportionally most studies investigated the effects of interventions on reducing respiratory conditions. This is valuable, given that most cold-weather-related deaths and caused by respiratory illnesses. However, the effects of interventions on reducing cold-weather-related adverse health impacts in relation to other condition groups that contribute a large proportion of excess winter deaths and illnesses, was lacking.

The results in relation to the effectiveness of interventions on reducing cold-weather-related adverse health and social outcomes are summarised as follows. Household warmth interventions appeared to be effective at reducing blood pressure, which is a risk factor for cardiac disease, but evidence in relation to their effects on hard outcomes (i.e. cardiovascular diagnoses), which affect patients' lives, were inconsistent. Influenza vaccination was generally associated with reduced diagnoses of respiratory conditions and there was some evidence that this intervention was most effective amongst older persons aged ≥65 years (174). However, publication bias, whereby research with statistically significant results is more likely to be submitted and published than work with null or non-significant results, is acknowledged to inflate the perceived positive effects of clinical interventions based on the literature (214). Healthy user effect, where uptake of an intervention, such as influenza vaccination, is more common amongst healthier individuals, may also bias the findings, by reducing the apparent effectiveness of interventions (215).

Interventions to improve household warmth and personal clothing protection were generally associated with improved general health, but this evidence was mainly based on self-reported data. The most effective footwear interventions for reducing slips and falls of those investigated were wearing shoes with ridged soles (187) and Yatrax Walker ice grips (185). There was some evidence that vitamin D fortification of food can reduce vitamin D insufficiency in winter months, but the evidence was from studies which generally failed to control for a comprehensive range of factors that influence serum vitamin D levels. There was evidence that a thermal efficiency intervention and an exercise intervention that was delivered under bright light conditions in winter months had positive impacts on mental health and wellbeing (191).

This review illustrates the range of interventions which have been used to reduce excess adverse health and social outcomes in relation to cold exposure and winter season. Unlike previous studies, this review integrated evidence in relation to the effects of interventions on different outcomes. The lack of a second reviewer is a likely source of bias in this review and the review presented in chapter two.

Strengths of the available evidence include the evaluation of interventions which focus on a broad range of socioeconomic, housing and behavioural factors. However, there is less evidence on the effects of interventions in reducing cold-weather-related adverse health impacts caused by non-respiratory conditions.

Most studies evaluated the relatively short-term health and social impacts of interventions in this review. Also, there was a lack of data collection in relation the potential adverse impacts

of interventions, particularly in relation to household thermal efficiency measures. There are stronger building regulations around household ventilation in Scandinavian countries. In Sweden, many new homes are equipped with heat recovery ventilation systems, which clean warm air generated within the house and feed it back into the property (216). Potential adverse health impacts of insulation measures include over-heating during summer where internal sources (e.g. cooking appliances) generate heat which is retained inside the property; and also the potentially increased incidence of respiratory conditions during colder months where ventilation levels are inadequate.

It has been noted that the potential adverse impacts of households with high levels of thermal efficiency but inadequate ventilation are likely to have the most profound impacts on the health of individuals with existing respiratory conditions, even though their cardiovascular health outcomes are likely to be improved by increased household warmth (18).

The results of this review indicate that interventions to increase household warmth may be effective at reducing a range of adverse health and social outcomes. In chapter four, I consider the mechanisms by which the factors identified in chapters two-three could moderate associations between cold exposure and illnesses and deaths from specific condition groups in England.

Chapter Four.

How do winter season and cold exposure lead to circulatory and respiratory morbidities and mortality? Developing evidence-based pathway models

4.1 Introduction

In chapters two and three, I systematically reviewed and synthesised evidence investigating associations between socioeconomic, housing and lifestyle-related factors and health and social outcomes, in relation to winter season and measures of cold exposure. Most studies investigated the effects of individual social factors which act directly upon biological disease pathways (downstream 'proximal' factors), on the risk of winter- or cold-related circulatory and respiratory health outcomes. In this chapter, I consider the mechanisms by which these factors could moderate associations between cold exposure and circulatory and respiratory illnesses and deaths in England. I also consider some upstream ('distal') factors, including geo-climatic factors and the social determinants of health, which could indirectly impact on circulatory and respiratory health outcomes during the winter period and in relation to cold exposure, through their impacts on the proximal factors of interest.

Improved understanding regarding the nature of associations between different factors and winter- and cold-related adverse health and social outcomes could help identify targets for intervention. It could also provide information to enable a coordinated response between government departments and stakeholder organisations, to reduce the adverse health and social impacts of cold weather.

The conceptual work presented in this chapter provides information about the potential mechanisms through which various factors, identified in the systematic reviews in chapters two and three, could impact on circulatory and respiratory health, and may therefore influence morbidity and mortality rates, in relation to winter season and cold weather. This information is used to inform the analyses in chapter eight, concerning the relationships between explanatory factors and spatial and temporal variations in morbidity and mortality rates across England and between winter seasons.

The outline of this chapter is as follows. In section 4.2, I explain how I have assessed the strength of epidemiological evidence, in terms of whether an association is likely to be causal (i.e. cause-effect relationship between exposure x and outcome y) or due to chance, bias,

confounding or reverse causality (effect-cause relationship between exposure x and outcome y). This information is used to indicate the strength of evidence in the pathways in figures 4.1 to 4.6, based on the appraisals of studies presented in chapters two and three.

In section 4.3, I discuss the purpose of conceptual models in public health and the scope and structure of the evidence-based pathway models, presented in figures 4.1 to 4.6.

Subsequently, in section 4.4, I describe hypothesized mechanisms by which exposures from chapters two and three could impact on circulatory and respiratory health outcomes. In figures 4.1 to 4.6, I present diagrams illustrating relationships between exposures, interventions and outcome variables based on evidence form chapter two and three.

A chapter summary is presented in section 4.5.

4.2 Epidemiology, 'causality' and the hierarchy of evidence

Epidemiology refers to '*the study of the distributions and determinants of health-related states or events in specified populations*' (217, p.S1015). Epidemiologists investigate the frequency of health and disease in populations in relation to potentially relevant factors (218). Epidemiological evidence can demonstrate that particular factors are associated with increased or decreased occurrence of a health outcome in a population that is exposed to those factors (219). It can, therefore, be used to identify 'risk' and 'protective' factors. Risk factors are attributes, characteristics or exposures associated with an increased risk of an adverse health or social outcome (220). Protective factors are associated with a reduced risk of negative health or social outcomes or an increased likelihood of positive outcomes (220). Epidemiological methods are used to monitor disease trends, by providing information about when, where and among whom particular health outcomes are likely to occur (218). However, epidemiological evidence alone cannot prove that a specific exposure causes a health or social outcome (221).

Causation is a concept for which there is no single accepted definition within the epidemiological literature (222). According to deterministic criteria, a cause is a condition that is necessary or sufficient for an effect (e.g. a change in health or social outcome) to occur (222). A necessary cause is a condition without which the effect *cannot* occur, whilst a sufficient cause is a condition with which the effect *must* occur (222). These criteria are most applicable to the investigation of associations between variables in the physical sciences, particularly in situations where there this a pattern of one-to-one correspondence between causes and their effects (222). However, deterministic definitions of causality are less useful in the context of health and social sciences, in which most outcomes have complex

aetiologies. To exemplify this, there is strong, consistent scientific evidence, from epidemiological, clinical and laboratory studies, that tobacco smoking is strongly associated with lung cancer (223). However, tobacco smoking cannot be considered a cause of lung cancer using the necessity or sufficiency criteria, as lung cancer occurs amongst non-smokers and not all smokers develop lung cancer (222). Hence, there is no single cause of all lung cancers (223) and we can only conclude that smoking is associated with a substantially increased risk of lung cancer (221) using the necessity and sufficiency criteria.

Factors can be associated with health and social outcomes in different ways. Predisposing factors are variables that do not cause the outcome but affect vulnerability to it (221). For example, heart attack occurs when the blood supply to the heart is interrupted (224). The risk of heart attack increases with age. However, increased age does not cause heart attack, other conditions must be present for this outcome to occur (221), such as thickening of the arterial wall due to atherosclerosis, which is more prevalent amongst older persons (225). Enabling factors facilitate manifestation of a health outcome (221). An example of this is the spread of influenza between persons due to indoor crowding which may promote an outbreak of the virus in a community. Precipitating factors are conditions that are associated with the definitive onset of a health outcome (221). An example of this would be cases of individuals, generally with cardiac risk factors, who suffer a heart attack during or shortly after strenuous exercise. Reinforcing factors aggravate a health state (221). For example, COPD patients are likely to experience exacerbation of their condition after repeated, daily exposure to cold, damp housing conditions.

Although epidemiological studies cannot prove that relationships between exposure and outcome variables are causal, aspects of epidemiologic study design and analysis can be used to reduce the likelihood of observing an association between exposure and outcome variables that is attributable to factors other than causality (221). Causal associations between exposure and outcome variables can be indicated where there is sufficient, unbiased epidemiological evidence (226). Sometimes epidemiological evidence is the best available and is considered to provide sufficient evidence to act on a problem (e.g. in relation to the associations between folic acid deficiency in pregnant women and foetal neural tube defects; or between thalidomide consumption in expectant mothers and limb malformations in their offspring).

Invalid (spurious) associations between exposure and outcome variables occur due to random or systematic error. The term 'error' refers to *the difference between the observed value of a measurement and the true value'* (227, p.228). Random error (chance) differs between samples. An example of random error is provided here, based on a text book example (228).

The scenario is a hypothetical investigation of the association between occupying a household with central heating and being obese, where there is no real association between the exposure and outcome variables of interest in the study population (e.g. adults from England). If a random sample of 200 (100 obese and 100 non obese) adults were randomly drawn from the study population in which 60% of adults occupy centrally heated households, we might expect approximately the same proportions of our obese and non-obese participants to live in a home with central heating. However, each sample that is randomly drawn from the study population will contain different numbers of individuals from centrally heated households. If, by chance, a greater proportion of obese individuals from our sample live in a household with central heating compared to the non-obese adults, we would observe a false positive association between central heating and obesity (i.e. a type 1 error) and we would reject the null hypothesis of a lack of association between living in a centrally heated household and obesity.

Statistical significance tests are used to quantify the probability that an observed association between an exposure and an outcome variable occurs by chance. A probability ('p') value of ≤ 0.05 from a significance test indicates that the probability of obtaining the observed or a more extreme association between variables (e.g. between occupying a centrally heated household and being obese) in the dataset by chance, is less than or equal to 5%. This is based on the proportion of samples with the same or more extreme association between exposure and outcome variables of interest, from a hypothetical infinite number of random samples drawn from the study population, when there is no real association between the variables (229).

Spurious associations between exposure and outcome variables can also be caused by systematic error (bias), which refers to '*deviation in one direction of the observed value from the true value of the construct being measured*' (230, p. 601). With random errors, the proportions of experimental and control groups with certain attributes (e.g. living in centrally heated housing) can be higher or lower than in the population from which samples are drawn. However, as these errors produce associations that are either above or below the true value in individual samples, they tend to cancel out over a sufficiently large number of observations, so that the mean for the error becomes zero. Systematic errors on the other hand, are always in one or the other direction of the population value and do not cancel out over repeated samples (231, p.217).

There are various different types of bias. Selection bias occurs when individuals with certain characteristics are more likely to be included in a study. Hence, there are *systematic*

differences between the characteristics of study participants and non-participants (66). An example of selection bias is in a hypothetical study comparing the incidence of medical consultations over a given time period between children from households who received a thermal efficiency intervention compared to children from the general population. If participants in the study were non-randomly selected as, for example, they had an existing illness and it was considered that they would benefit more from the intervention compared to healthy individuals, then this could artificially reduce the perceived effectiveness of the intervention. This is because children who received the intervention may still require more medical care compared to healthy children due to their medical status, despite the effect of the intervention.

Chance and bias occur when samples in a study are non-representative of the population from which they were drawn (232). Confounding refers to a situation whereby '*an extraneous factor (a factor other than the variables under study) which is not controlled for, distorts the results'* (230, p.602). The extraneous factor must be independently associated with the exposure and outcomes of interest – it must not lie on the causal pathway between the exposure and outcome variables under investigation (e.g. cholesterol mediates, rather than confounds the association between saturated fat consumption and coronary heart disease (CHD)) (232). Chance and bias produce an association between exposure and outcome variables from data in study samples that is invalid (232) (i.e. it is different from the true association in the study population). However, confounding produces a real association but misattribution about which exposure is causing the effect (232). An example of confounding is a hypothetical association between social renting and the prevalence of coronary heart disease (CHD). Renting a home from a social housing provider does not cause heart disease, but individuals from socially-rented households are more likely have other CHD risk factors, including being active smokers, less physically active and to have a high saturated fat intake, compared to home owners. This is because social renting and lifestyle-related CHD risk factors may all be commonly associated with income deprivation. Hence, CHD risk factors are independently associated with social renting and CHD (i.e. they are confounding rather than mediating factors).

Various criteria have been proposed to assess the likelihood that an association between an exposure and health outcome is causal, based on epidemiological evidence. However, most of these methods have been criticised for lacking applicability to modern health problems with complex aetiologies (221). The Bradford-Hill criteria, established in 1965, are still widely used to assess whether associations are causal, but are now generally considered as

guidelines, as most of the criteria are neither necessary nor sufficient for proving causality (233).

Causality guidelines have largely been replaced in recent years by the concept of 'evidence-based medicine' (EBM), which refers to the integration of science into the practice of medicine (234). EBM involves identifying the 'best available evidence' to inform clinical decision making. The evidence presented in chapters two and three of this thesis came from a range of study designs. Advocates of the EBM approach classify study designs according to their internal validity, which refers the extent to which we can infer that the observed effect (i.e. health or social outcome) is caused by the exposure or intervention being evaluated (66) rather than being due to bias or confounding.

Using the EBM approach, a hierarchy ('pyramid') of evidence is used to depict the strength of evidence, in terms of the level of internal validity for different study designs. According to this approach, RCTs are considered to be the 'gold standard' of research design for their ability to infer causality and estimate the effects of interventions on health and social outcomes. This is because they generally have high internal validity, promoted by the practices of randomisation and blinding. Randomisation refers to the process of allocating participants to intervention or control groups using an unbiased method (235), such as a random number generator. Blinding refers to the concealment of participants' allocation to intervention and control groups from participants (single blinding) or participants and researchers (double blinding). Where there is a sufficiently large sample size, randomisation reduces the likelihood of obtaining spurious results caused by chance and bias due to the disproportionate distribution of participants with certain characteristics between study groups. Blinding promotes internal validity in RCTs by reducing the likelihood of a 'placebo effect' whereby knowledge about participants' intervention status may affect their outcomes (e.g. self-rated health) or the outcome assessor's judgement (236). When all factors other than the intervention are considered equal between groups, stronger information about causal relationships between an intervention and health or social outcomes can be deduced (237).

The RCTs from the systematic review in chapter three varied in quality. Some of the studies had small sample sizes (e.g. 183). This reduces the likelihood that the proportions of participants with characteristics that could influence the outcome are (i) balanced between intervention and control groups and (ii) reflect the proportions of individuals with those attributes in the study population. In addition, various studies did not (or were unable to) conceal allocation status from participants and, or assessors (168). In one study, it was revealed that some participants had guessed their intervention status (181). This is likely to

have compromised the validity of the results of the investigation, which assessed the association between ascorbic acid (vitamin C) intake and self-reported incidence of cold symptoms.

The systematic literature review in chapter three also included intervention evaluation studies (e.g. 168), in which participants are allocated to intervention and control group via non-randomised methods (66). Lack of randomisation increases the likelihood that observed results (associations between intervention and outcome variables) are caused by bias. This is because participants could be selected for inclusion in the treatment and control groups based on their characteristics, which could influence their health and social outcomes independently from the intervention. Lack of randomisation therefore reduces the ability to infer that a causal association exists between the exposure and outcome variables of interest. However, controlled non-randomised studies are generally considered to have higher internal validity compared to observational studies.

Observational studies involve investigation of associations between interventions or exposures varying naturally between participants on health or social outcomes (66). These studies are generally considered to have low internal validity relative to experimental studies. This is because there is a lack of control over factors other than the intervention that could affect the outcome measures, which reduces the ability to make causal inferences from the research findings. However, observational studies are generally regarded as having higher external validity (i.e. generalisability of the finding to persons or situations beyond the specific research context) compared to experimental studies. External validity is important in relation to the conceptual work presented in this chapter. This is because the hypothesised mechanisms described in section 4.4, by which explanatory factors could impact on circulatory and respiratory health, and may therefore influence morbidity and mortality rates across England, in relation to winter season and cold weather, are developed based on evidence from studies presented in chapters two-three, which were conducted on various different populations.

Cohort (follow-up) studies are observational studies in which individuals with different levels of exposure to a particular factor are followed in time to compare the incidence of health or social outcomes between groups (226). For example, a hypothetical study that explores the association between child poverty and health and social outcomes across the lifespan, by recruiting individuals in childhood, measuring their household income and collecting follow-up data on indicators such as adult employment grade and the incidence of heart disease. Cohort studies enable the researcher to determine that the assumed direction of association

between variables exists, whereby the exposure (e.g. child poverty) occurred prior to the outcome (e.g. occurrence of heart disease in adulthood) (238), rather than vice versa (reverse causality).

Case-control studies involve comparing the characteristics of groups of individuals with (cases) and without (controls) a specific health outcome (e.g. food poisoning). This enables calculation of the magnitude of association between exposures and the outcome of interest (66). These studies can be conducted more rapidly and economically than cohort studies and are regularly used by health protection scientists to assess the occurrence of disease outbreaks in relation to infectious agents and environmental hazards.

When conducting a non-randomised study, the effects of characteristics other than exposures under investigation that could influence the health outcome of interest could be controlled for in the design phase, by creating equal distributions of potentially relevant additional factors between groups ('matching'), or in the analyses (e.g. using multivariable regression) (232). A case-control study from the systematic review in chapter two (109), which investigated milk intake as a predictor of hypertension amongst occupational workers from Taiwan, controlled for the effects of other explanatory variables, as follows. Cases (individuals with hypertension) and controls (individuals without hypertension) were all i) males and ii) cold-exposed in their job (i.e. the groups were matched based on these characteristics, which could influence their risk of hypertension). The groups were not matched in relation to other factors that could influence their risk of hypertension. However, demographic, lifestyle-related, anthropometric and heredity factors that were significant predictors of hypertension in simple (univariable) analyses, were included in a multivariable model, along with milk intake, thereby controlling for their effects on the outcome variable (hypertension).

Cross-sectional studies are a type of observational study involving measuring exposures and outcomes at a single point in time (238). These studies can be descriptive, used to assess the prevalence of disease and potential explanatory factors in defined populations (239), and / or analytical, whereby the relationships between exposure and outcome variables are quantified, based on comparison of the exposure status between individuals with and without a particular health outcome (239). Advantages of cross-sectional studies include that they can be relatively economical and can generate a large amount of data within a short time duration compared to other study designs. Unlike cohort and case-control studies, cross-sectional investigations are generally unable to demonstrate that the correct temporal association exists between exposure and outcome variables (238). However, cross-sectional surveys can include retrospective questions concerning health effects experienced after or in conjunction

with a particularly exposure, or receipt of an intervention. For example, one cross-sectional study presented in chapter two asked if participants had experienced shortness of breath during cold exposure (116).

Case-series involve description of a small number of individuals with an outcome who have all experienced the same exposure (238). For example, several studies from the systematic review in chapter two described an association between snow shovelling and cardiac risk factors amongst heart attack patients (e.g. 112). Unlike cohort and case-control studies, case-series do not involve control groups (240). Consequently, these are descriptive rather than analytical studies and are typically used when the number of cases of an outcome is rare.

Ecological studies examine rates of health or social outcomes in relation to exposures in populations rather than individuals (241) using aggregate data (e.g. comparing EWM rates of across English regions in relation to mean winter temperature and fuel poverty prevalence). Like other observational methods, ecological studies are prone to confounding. Also, as ecological studies use aggregate data, they generate average values for each area in the analysis. Associations that are found between exposure and outcome variables at a particular area (ecological) level (e.g. English regions) cannot be assumed to exist at other geographical levels (e.g. Local Authority Districts) or to provide information about the characteristics of individuals within a population (e.g. LAD x may have the highest smoking rates in England, but it cannot be assumed that an individual is an active smoker because they live in LAD x). Several studies from the systematic review in chapter two assigned area-level deprivation scores to individuals based on where they lived, in order to analyse the association with winter or cold-related adverse health outcomes (e.g. (73)). The assumption that individuals within these studies conformed to the average level of deprivation for their area of residence is termed the '*ecological fallacy*'. However, ecological studies are economical and are useful for developing hypotheses concerning relationships between a wide range of exposures and outcomes, which can then be tested using methods with the capability to provide stronger evidence of causality.

Qualitative studies are descriptive studies that involve interviewing or observing participants to gain insights about particular issues. These studies do not involve the collection and statistical analysis of numerical data and therefore do not provide strong evidence of cause-effect relationships between exposures or interventions and outcomes. However, evidence from these studies can be used in public health research to formulate hypotheses about disease mechanisms, which can be tested quantitatively.

Economic evaluation studies are used in public health to evaluate the cost-effectiveness of interventions aimed at improving population health. These studies do not provide strong evidence of disease causality, as they do not directly measure associations between interventions and health outcomes and are susceptible to bias, in relation to the parameters included in the economic models.

4.3 Conceptual models in public health

4.3.1 Conceptual models – definition, purpose and limitations

Conceptual models are commonly used in public health to illustrate hypothesized relationships between exposure and outcome variables (242). They can be defined as: ''*a ...[system] of proposed causal linkages among a set of [variables] believed to be related to a particular public health problem*'' (243). Conceptual models provide a useful heuristic tool to guide policy decisions in relation to the development and implementation of public health interventions (243). They also enable the identification of knowledge gaps in the literature in relation to particular public health problems (244) and the generation of testable hypotheses about disease pathways. However, conceptual models simplify reality by reducing complex processes down to a small number of variables and variable interactions, thereby failing to adequately reflect the dynamic interplay of factors driving real world phenomena (e.g. EWM). Specific criticisms of published conceptual epidemiological models include the lack of clarity regarding hypothesized cause-effect relationships between included variables, the lack of specificity in relation to the outcome(s) whose aetiology the model aims to define and inadequate provision of accompanying text to explain pathways in the model (243, 244). The pathways from the models presented in figures 4.1 to 4.6 in section 4.4, indicate associations between exposures or interventions and outcomes based on evidence from quantitative epidemiological studies from chapters two-three. An accompanying narrative is provided to describe potential mechanisms by which different factors could impact on cold-related circulatory and respiratory illnesses and deaths.

4.3.2 Epidemiological paradigms of disease aetiology

A paradigm can be defined as a collection of assumptions that orientate thinking and research within scientific disciplines (245-247). Several paradigm shifts have occurred in the field of epidemiology over past centuries, driven mainly by changes in population disease profiles. In the current era, in which chronic diseases are generally the main causes of ill health in developed countries, a 'black box' paradigm is said to be dominant, in which epidemiologists study associations between exposures ('risk factors') and health outcomes, generally using

statistical methods, to generate evidence from which 'laws' of disease causation (248) can be inferred. This approach has been criticised for its simplicity and lack of attention to disease processes and interactions between different risk factors. In relation to the evidence base around the aetiology of cold-weather-related illnesses, there is a lack of knowledge regarding the mechanisms by which different factors interact to influence disease susceptibility through their effects upon mediatory biological pathways.

During the 1990s, it was argued that we were entering a new era of 'eco-epidemiology', whereby consideration is given to interactions between different types risk factor, including biological and social influences, in relation to human health outcomes (246-248). The conceptual origins of this approach can be traced back in history. For example, John Snow identified that the 1854 Broad Street cholera outbreak was attributable to biological and environmental factors, in terms of the disease being caused by a water-borne agent (now known as the *Vibrio cholera* bacterium), and that the source of this outbreak was an infected water supply from a street pump in Soho (249, 250).

The notion of multi-level disease causation was expanded throughout the 1900s, with increased consideration of the dynamic relationships between macro and micro level disease determinants (e.g. social policies and genetic mutations, respectively) (249, 250). Since the 1990s, consideration of the interactive effects of biological and social influences on disease processes has increased. This is due to various factors, including developments in human genetic biology (e.g. the mapping of the human genome in 2003), which have improved our knowledge of molecular disease causing processes. There has also been increased recognition that many prominent health problems, including the 2014 Ebola outbreak in West Africa and the global obesity epidemic, are caused by biological and social factors. In addition, the development and application of novel approaches to public health research are providing new insights regarding disease aetiology (249, 250).

Although the conceptual diagrams in figures 4.1-4.6 contain only proximal factors that were identified from the systematic reviews in chapters two-three, I relate these factors to geo-climatic and societal (distal) factors, which are likely to influence the daily environmental and living conditions to which population groups are exposed (proximal factors). In turn, these proximal factors are hypothesized to act on biological pathways to influence susceptibility to illnesses and deaths from specific conditions during and following periods of cold weather. Consequently, the conceptual work presented in this chapter is more sophisticated than

alternative models on the topic of cold-related morbidities and mortality, which have focused on a small number of proximal factors (155).

4.3.3 Scope of the evidence-based pathway models and hypothesized pathways described in section 4.4

The discussion presented in section 4.4 aims to conceptualise the hypothesized aetiology of illnesses and deaths from circulatory and respiratory diseases in relation to cold exposure, moderated by other factors. Circulatory and respiratory diseases were studied as most excess winter deaths in England and Wales are caused by these condition groups (7, 251). Deaths from dementia and Alzheimer's disease show more seasonality than circulatory diseases and mortality from injuries and poisoning are also greater during the winter compared to non-winter months. However, there is a lack of evidence regarding the potential causes of seasonal variations in mortality from these condition groups (252).

The nature of cold-weather-related morbidity and mortality is likely to vary between countries due to differences in climatic, cultural, political, environmental, socioeconomic, housing, energy, healthcare, demographic and biological factors, which influence illness and death rates. England has a stronger political interest in modifiable causes of cold-weather-related adverse health and social outcomes compared to other countries (253). I therefore consider it to be most useful to focus on the situation in one country, and for the country of interest to be England. However, some of the evidence used to develop the evidence-based pathway models in figures 4.1 to 4.6 come from studies conducted outside of England, which means that some of the hypothesized pathways are likely to be relevant (i.e. externally generalisable) to other parts of the UK and internationally.

4.3.4 Structure of the evidence-based pathway models in section 4.4

The evidence-based pathway models presented in figures 4.1 to 4.6 were developed based on quantitative epidemiological evidence from the systematic literature reviews in chapters two-three. The left hand columns contain social factors that were identified as being associated with a significantly increased or decreased risk of circulatory or respiratory outcomes. The middle column includes 'soft' outcomes, in terms of biological symptoms of, and risk factors for, disease. The right hand column contains 'hard' disease outcomes, in terms of condition-group-specific diagnosable illnesses, hospital admissions and deaths. The numbers in text boxes refer to publications informing the pathway.

Associations between variables in the evidence-based pathway models in chapters 4.1 to 4.6 are based on evidence from studies that found significant relationships (at p≤0.05 level) between the exposure and outcome variables shown. Exposure-outcome variable associations that were not shown to be significant are not included in the model as these associations could have occurred by chance. The level of evidence in support of the association between each exposure and outcome in the evidence-based pathway models in figures 4.1 to 4.6 is indicated and is based on the quality appraisal scores from the systematic reviews in chapters two-three. Associations between exposures and outcomes in the models are rated 'strong' if they are supported by at least one study with this rating from the system used to appraise the studies in chapters two-three. Associations are rated 'moderate' if they are supported by at least one study with this quality appraisal rating from chapters two-three, but where none of the studies that assessed the association between the exposure and outcome of interest were rated as 'strong'. Finally, associations are considered to provide 'weak' evidence of potential causality if they are supported only by studies classified as providing weak evidence, from the quality appraisals in chapters two and three. A key for figures 4.1 to 4.6 is shown below.

Key for figures 4.1 to 4.6

- Evidence from ecological studies is indicated by blue text and lines ⟶
- Evidence from individual level studies is indicated by **black text and lines** ⟶
- Solid line indicates the association between exposure and outcome variables is supported by strong evidence ⟶
- Hashed line indicates the association between exposure and outcome variables is supported by moderate evidence – – ▶
- Dotted line indicates the association between exposure and outcome variables is supported by weak evidence ⟶
- Upward facing arrow indicates the exposure or intervention is associated with significantly increased risk of the outcome

  ↑ ↑

- Downward facing arrow indicates the exposure or intervention is associated with significantly decreased risk of the outcome

  ↓ ↓

The reason for not using the hierarchy of study designs described in section 4.2 to assess the strength of evidence in relation to associations between exposure and outcome variables is that the studies from chapters two-three that were conducted using the same designs varied in quality. For example, a well conducted cohort study is likely to provide stronger evidence of

potential causality compared with a poorly conducted RCT (254) whereas some classifications would rate these two studies as being of similar weight.

The evidence-based pathway models in figures 4.1 to 4.6 contain only factors from the systematic literature reviews in chapters two-three that were associated with significantly increased risk of circulatory and respiratory illnesses and deaths at proximal level of effect. However, in the narrative section (4.4), I expand on the potential disease pathways and relate the proximal factors from the evidence-based pathway models in figures 4.1 to 4.6 to wider environmental and social influences. This narrative incorporates evidence from qualitative studies presented in chapters two-three.

4.4 Hypothesized pathways between winter season, exposure to cold and other factors and the occurrence of circulatory and respiratory illnesses and deaths.

4.4.1 Impact of meteorological factors on UK weather

In order to conceptualise the causes of cold-weather-related adverse health outcomes in England, it is necessary to consider the climatic factors which create English weather patterns.

The UK has a temperate climate that is characterised by generally cool but mild weather conditions, which vary throughout the year. England is a long country of approximately 686 km in length (as the crow flies) from extreme southwest (Land's End in Cornwall) to extreme northeast (Berwick-upon-Tweed) (255). Variations in climatic conditions across England are due to various factors, including regional differences in prevailing wind direction. The North-East receives its prevailing winds from the arctic, which generally makes it the coldest part of England; the climate of the North-West is predominantly influenced by maritime winds which blow off the Atlantic Ocean, bringing relatively warm and wet conditions to this area; the South-East receives continental winds, which are cold in the winter, and the South-West receives relatively warm, tropical winds from the south (256). Topographical features, including mountain ranges, also create climatic variations between relatively close areas in England. For example, north-westerly winds bring damp weather to the North-West of England. However, via a process termed 'orographic lift', this moist air cools as it lifts over the Pennines (a mountain range in Northern England) and forms rain clouds. It subsequently rains, mainly on the upward side of the mountain range, leaving the north-eastern side (in County Durham), dryer (257). Factors such as these give rise to considerable regional and sub-regional variations in weather conditions across England.

In relation to the country as a whole, the North Atlantic Jet Stream is understood to influence English weather patterns through its influence on prevailing wind direction across the country. The effect of the North Atlantic Jet Stream on English weather patterns will be considered briefly here.

Mortality rates in England are higher during the winter period compared to other seasons (258). The winter period is generally the coldest time of the year, although non-winter months can sometimes be colder than the months December-March (251). Most excess winter deaths are caused by four main condition groups, including circulatory and respiratory conditions, which are exacerbated in cold weather conditions. English weather is influenced by prevailing wind direction, which is affected by variations in the position of the North Atlantic Jet Stream. The North Atlantic Jet Stream is a narrow band of strong wind located in the high atmosphere over the Atlantic Ocean, at the boundary between low pressure cold air from the polar north and high pressure warm air from the south (259). These air pressure differences cause the North Atlantic Jet Stream, which flows across the Atlantic Ocean, from West to East, towards the UK, due to the Earth's rotation on its axis (260).

The position of the North Atlantic Jet Stream shifts northwards and southwards, seasonally (261). These positional shifts are measured by variations in the North Atlantic Oscillation (NAO) (262), which refers to air pressure differences over the ocean between Iceland and the Azores (263). The position of the North Atlantic Jet Stream over the UK affects its weather conditions. When north-south air pressure differences are strongest, the NAO is said to be in a 'positive phase' and the North Atlantic Jet Stream flows along its usual trajectory, steering warm, wet weather from the south-west, off the Atlantic Ocean, towards the UK. Alternatively, when the North Atlantic Jet Stream's position deviates south of the UK and the NAO is said to be in a 'negative phase', cold, dry air from the north-east prevails, sometimes bringing arctic conditions to the UK (264-266).

The North Atlantic Jet Stream is just one of a number of interacting climatic factors that influence English (and UK) weather conditions. Along with other factors, the North Atlantic Jet Stream contributes to the mild but variable weather conditions that are experienced in countries of the UK throughout the year. The position of the North Atlantic Jet Stream, and NAO indices, are used by meteorologists to predict UK weather.

There is evidence that NAO values are associated with weather conditions in England on an annual and on a monthly time scale (267).

4.4.2 Environmental and biological mediators of the association between cold weather and circulatory and respiratory illnesses and deaths

In order for the risk factors described in this chapter to influence health outcomes, these associations need to be mediated by biological disease-causing mechanisms. Biological mediators of cold-weather-related illnesses and deaths are not well defined for many of the medical conditions that show increased prevalence in relation to cold exposure (7). It is necessary to consider the clinical disease pathways between exposure and outcomes, as this could provide useful information including targets for clinical intervention. Also, for statistical purposes, it is necessary to consider lag effects in order to accurately test associations between exposures and outcomes. The 'flexion point' refers to the point at which a change in an exposure variable is associated with a change in a biological disease causing mechanism (268). Many studies identified in the systematic review in chapters two-three used risk factors for, and symptoms of, circulatory and respiratory illnesses as outcome measures, rather than clinically defined health conditions (269). This is useful in the context of the research presented in this thesis as it provides information about the likely biological pathways that mediate associations between cold exposure, other explanatory factors and adverse health outcomes. The information in this section of the thesis (4.4.2) describes the known clinical pathways and hypothesized mechanisms based on evidence from the literature, by which circulatory and respiratory illnesses and deaths may show increased prevalence in relation to cold exposure.

Evidence from a recent analysis indicates that most excess cold-weather-related deaths in England occur at modestly cold temperatures of around $4\text{-}8^0$C (270). Death rates are markedly elevated in response to small (e.g.1^0C) reductions in temperatures below region-specific thresholds (270). Deaths from respiratory causes are most sensitive to reductions in temperatures below these thresholds (270). It is known that exposure to cold, dry air can induce contraction of the small to medium sized respiratory passages, a state called bronchospasm, which is characteristic of exacerbations of asthma and COPD (271). Another cause of cold-weather-related respiratory deaths are seasonal viral infections, which are responsible for annual epidemics that peak during the winter periods in temperate countries (272). Seasonal influenza affects all age groups but has the greatest health impacts on high risk groups (272), including young children, the elderly and individuals with disabilities or long term health problems. The causes of seasonality for influenza and other communicable respiratory diseases are not well understood. Some evidence suggests that it may be due to factors including the enhanced survival of pathogens and reduced immune function of human

hosts during the winter period or seasonal behaviour changes, including increased indoor crowding, which increases person-to-person contact rate and the ability for influenza to spread. More research is needed to improve understanding about the nature of the seasonality of infectious respiratory conditions (273). Deaths from respiratory causes can be delayed by 3-3.5 weeks after a cold day.

Circulatory deaths are also sensitive to temperature decreases below specific cold weather thresholds, which differ between English regions (270). Cold exposure is associated with increases in blood cholesterol, blood pressure and the risk of blood clots, which increases the risk of heart attack and the risk of stroke. Data indicate that there is a delay between the occurrence of cold days and increased mortality rate from all-causes. However, a recent analysis found that mortality rates start to increase the day after a cold day and that this early peak in deaths was attributable to circulatory conditions (270).

It is possible that biological acclimatisation may increase resilience against cold-weather-related adverse health outcomes amongst populations who live in colder areas of England. The policy relevance of biological acclimatisation effects would be to deliver interventions such as cold weather payments at milder cold temperature thresholds in warmer parts of England. Heat wave plans are triggered at different temperature thresholds by region in England to allow for acclimatisation.

Studies that have investigated the nature of excess winter and cold-weather-related morbidities and mortality have focused on the effects of low temperatures. However, various weather conditions that are associated with low temperatures and occur most commonly and intensely during the winter period in England, may also contribute to increased morbidity and mortality rates. Associations between different meteorological factors and the occurrence of circulatory and respiratory medical conditions are not well understood and are likely to be confounded by other environmental factors. Increased knowledge regarding the relationships between different aspects of 'cold weather' and health outcomes could help to inform the development of early warning systems, and of health and social care interventions, to support individuals with clinical vulnerabilities in relation to anticipated and prevailing weather conditions. A short discussion of the potential impact of individual climatic factors on respiratory and circulatory health is presented below.

Humidity could exacerbate respiratory conditions by making the air heavier and more difficult to breathe. Alternatively, as previously noted, low humidity caused by cold, dry air can induce bronchospasm (271). A study from the review in chapter three found that a thermal efficiency intervention was associated with reduced indoor humidity, which was associated with

significantly reduced odds of self-reported wheezing, amongst recipients of a thermal efficiency intervention from New Zealand (172) (evidence rating = strong). However, the association between reduced humidity and reduced self-reported respiratory symptoms in this study could have been attributable to increased temperatures in the households of intervention recipients.

There is evidence of both positive and negative associations between humidity and heart attack risk. For example, a study from the wider literature (i.e. not presented in chapters two or three), found a positive relationship between humidity and the occurrence of heart attacks (274). However, this association, from a study that used data from Athens in Greece, could have been confounded by increased air pollution levels, which are independently associated with humidity and heart attack rates, but were not controlled for in the design or analysis of this study. Another study (275), from America, found that humidity was associated with reduced cardiac hospital admissions. However, humidity and temperatures were highly correlated in this study, which suggests the negative association between humidity and heart attack rates could have been confounded by increased temperatures in more humid areas.

Wind speed could hypothetically exacerbate asthma, by making the air more difficult to breathe during exposure to strong winds. Alternatively, it has been suggested respiratory and cardiac events may be less prevalent in wet and windy weather conditions, as individuals may be more inclined to stay indoors and have less exposure to prevailing weather conditions (275). Vitamin D has been associated with increased cardiac risk (275). It is therefore possible, that reduced availability of, and exposure to, sunshine during the winter period may be associated with increased cardiac death rates (275).

There is a lack of strong evidence concerning associations between climatic factors other than temperatures and circulatory and respiratory health outcomes, or of knowledge about the disease mechanisms which could mediate relationships between climatic factors and health. This undermines the development of informed, directional hypotheses regarding the statistical relationships between these variables.

Air pollution, defined by the World Health Organisation (WHO) as '*contamination of the indoor and outdoor environment by any physical, biological or chemical agent that modifies the natural characteristics of the atmosphere*' (276), is another factor which can mediate the effects of cold weather on health. Air pollution profile changes seasonally (277), due to changes in the sources of air pollution between seasons, which include seasonal changes in indoor energy usage, traffic flow, and meteorological factors that react with air pollutants.

Epidemiological evidence indicates that air pollution can exert negative health impacts, resulting in hospitalisations and deaths, in small concentrations and in relation to both short-term and long-term exposure (278). Air pollution is a major public health issue, due to its association with many human diseases, including respiratory and circulatory illnesses (279). Particulate matter (PM) and ozone are two common UK air pollutants, which are thought to have greatest health impacts in relation to circulatory and respiratory diseases (280). PM is a mixture of solid particles and liquid droplets in the air and is composed of naturally occurring substances (e.g. dust and sea spray) and waste products from human fuel combustion (e.g. soot) (281).

Recent evidence has also increased concern about the adverse impacts of oxides of nitrogen and sulphur dioxide on the circulatory and respiratory systems (282).

Hypothesized mechanisms by which air pollutants exert their adverse circulatory and respiratory health impacts include that: (i) inhalation of small particles causes lung inflammation triggering changes in blood clotting, (ii) air pollutants affects the stability of fatty deposits (atheromatous plaques) found inside the arterial walls which supply blood to the heart and (iii) air pollutants trigger reflexes which initiate coughing and changes in the rhythm of the heart (278). However, more research is needed on these potential mechanisms.

4.4.3 Impact of vulnerability factors

The prevalence of different cold-weather-related adverse health and social outcomes differs between population sub-groups. Most cold-weather-related deaths occur amongst older people and individuals with pre-existing medical conditions. Although the reasons for this are not well defined, some possible mechanisms are discussed below, supported by qualitative evidence from the systematic reviews presented in chapters two-three.

Older people are at increased risk of cardiovascular events, due to factors including age-related build-up of atheroma inside arterial walls (283). There is also evidence that biochemical changes in the blood, which occur in response to cold exposure and increase the risk of cardiac events, take longer to return to normal levels in older people (269). Older age is also associated with the reduced function of thermoregulatory mechanisms (284) and generally with reduced mobility, both of which make it more difficult to keep warm. There is evidence that, as a population, older people tend to wear more clothing compared to younger adults (285) which may reduce personal cold exposure. However, there is also evidence of reduced thermal perception with older age, meaning that older people (in particular the very old – e.g. ≥85 years) may not perceive temperature changes effectively and adapt their level

of clothing protection, activity levels and household warmth, appropriately (269). Various factors are likely to increase vulnerability to cold weather and winter deaths amongst older people, including social isolation, although the nature of this vulnerability has not been investigated in relation to cold weather.

Individuals with pre-existing circulatory and respiratory conditions are at increased risk of morbidity and death during periods of cold weather, as these medical conditions are exacerbated by personal cold exposure, via the mechanisms outlined in section 4.4.2. Elderly persons and individuals with disabilities and long term health problems may also be at increased risk of fuel poverty. This is due to factors including that these population groups are likely to have low household incomes compared to the population average and may also have increased energy requirements, due to spending longer periods of time at home, and in some cases, the need to use energy to operate medical equipment (45). Elderly female participants who were interviewed in a qualitative study from the review in chapter two identified low state pension as a cause of fuel poverty (161). In a different qualitative study, from the review in chapter three, the Winter Fuel Payment was identified as making a valuable contribution to the budget of older households (213). However, the qualifying minimum age for receipt of this benefit is 62 years. In addition, changes to welfare state benefits have occurred since the 2010 election of the Conservative-Liberal Democrat Coalition Government, make working-aged individuals with disabilities and long-term health problems ineligible for many fuel subsidies (45).

There is also qualitative evidence that behavioural factors including window opening and frugality contribute to the occupancy of cold homes amongst some elderly persons (162, 213), even in situations where householders could afford additional fuel costs to increase internal household temperatures to thermally comfortable levels (286). Consequently, is it possible that cold-weather-related financial subsidies, which are provided as unconditional cash transfers with no obligation to spend any of it on household fuel (287), may not be used to increase household warmth amongst some pensioner households. However, there is evidence that recipients are more likely to spend a greater proportion of the Winter Fuel Payment on fuel, compared to if this was provided as an unnamed subsidy (287).

The evidence in relation to vulnerability to cardiovascular and respiratory conditions associated with gender is mixed and likely to be confounded by age, given that most cold-related deaths occur in older age groups and women generally live longer than men (59). Factors that could influence gender-related health disparities in relation to cold exposure

include that males are generally more physically active, and are therefore potentially more able to generate body heat through thermogenesis, compared to women.

There is little evidence on vulnerability to cold-weather-related deaths in relation to ethnicity. A study from the systematic review in chapter three found that the African American population was more susceptible to cold-weather-related deaths compared to white people (86). However, this study was from the USA and the association between African-American ethnicity and cold-weather-related deaths is likely to be confounded by recognized higher levels of deprivation, and possibly deprivation-related-factors for poorer health, amongst Black-African compared to White Americans.

4.4.4 Impact of lifestyle-related factors

Models containing evidence-based pathways between lifestyle-related exposures and circulatory and respiratory outcomes in relation to cold weather or winter season, based on evidence from the systematic literature review from chapters two-three, are presented in figures 4.1 to 4.6.

Evidence in support of the adverse health impacts of behavioural factors is substantial. Heart disease and respiratory illnesses are leading causes of illness and deaths amongst UK adults (288). Aspects of behaviour have been identified as key risk factors for these adverse health outcomes. It is therefore possible that behavioural factors exacerbate the adverse circulatory and respiratory health impacts of cold exposure. In this section (4.4.4) I discuss possible cold-related circulatory and respiratory disease pathways in relation to the behavioural exposures from the evidence-based pathway models which are shown in figures 4.1 to 4.6, in relation to the wider determinants of health.

There is evidence of a socioeconomic gradient in the prevalence of many adverse health behaviours in England, such as smoking prevalence, in addition to lifestyle-related risk factors for obesity, including reduced physical activity levels and increased intake of energy dense foods (289). The causes of socioeconomic gradients in the prevalence of health-related behaviours are not well understood. However, factors including increased access to unhealthy food (i.e. higher density of fast food retailers in deprived areas), lack of access to exercise facilities including green spaces (e.g. parks) and the relatively high cost of embracing a healthy lifestyle, may contribute.

There is also a body of evidence about intermediate variables such as future orientation, in which socioeconomic deprivation is associated with increased hedonism and reduced engagement in health-promoting behaviours (290). However, in relation to season, evidence

from one study presented in the systematic review in chapter three found a reduced cardiac health advantage amongst less socioeconomically deprived groups in the winter compared to the summer (96). This was attributed to reduced engagement in health-promoting behaviours amongst more affluent groups during the winter period. Christmas and New Year are associated with increased circulatory and respiratory mortality rates (291), which could be attributable to excess food and alcohol consumption, which are likely to occur across all socioeconomic strata. In addition, it is possible that winter weight gain is related to evolved mechanisms which promote energy storage during the winter period, in which food was likely to have been less abundant and energy needs greater in order to support thermogenesis to keep the body warm. Consequently, the socioeconomic gradient in health in relation to obesity-related lifestyle factors may be more important during the summer period.

Active smoking is associated with narrowing of the arteries, which increases the risk of cardiovascular disease, and with an increased risk of COPD (292). To a large extent, these are long-term effects that occur after decades of exposure, but there is also evidence of an association between smoking and cardiac events via short-term pathways. Experimental evidence has shown a pronounced effect of smoking on platelet aggregation, which is involved in the blood clotting mechanism and can increase the risk of heart attack and stroke (293). Short-term smoking cessation can reduce platelet number and aggregation in long-term smokers (294). This has been cited as the reason for reduced myocardial infarction (heart attack) rate after the implementation of smoke free legislation (295).

Evidence from the systematic review in chapter two, concerning the effects of smoking on health in relation to winter season or cold exposure, are as follows. Active smoking prevalence was significantly associated with increased winter IHD hospital admissions across health regions of Quebec (94) (evidence rating = moderate). Passive smoking was associated with significantly increased sympathetic nerve activity, which could increase the risk of cardiac events, in response to the cold pressure test amongst pre-menopausal women from the USA (106) (evidence rating = moderate). In relation to the respiratory system, active smoking was associated with significantly increased prevalence of respiratory symptoms over the winter period amongst Finnish adults (130, 131) (evidence rating = moderate for both studies). Another study found increased number of winter hospital admissions for respiratory illnesses amongst patients from central England, who consulted medical services with lower respiratory tract infection or exacerbation of chronic respiratory disease (117) (evidence rating = weak). In a study from Scotland, poorer respiratory health status was found amongst COPD patients who smoked, in relation to exposure to cold housing (126) (evidence rating = weak).

Alcohol consumption was associated with significantly increased diastolic blood pressure response to the cold pressure test amongst adults from the rural north of China (99) (evidence rating = weak). Increased blood pressure is a cardiac risk factor.

Obesity and related factors, including reduced physical activity, high saturated fat intake and high LDL cholesterol profiles are associated with adverse circulatory health outcomes. It is, therefore, possible that individuals with these risk factors are at higher risk of experiencing adverse circulatory health events during the winter season or in relation to cold exposure. Studies from the systematic review in chapter two found that winter increase in saturated fat intake was associated with significantly increased serum total and LDL cholesterol amongst male industrial employees from Israel (113) (evidence rating = moderate). Another study found that BMI was significantly, positively associated with winter total cholesterol concentrations, amongst a sample of community dwelling elderly men and women from England who were aged 65-74 years (100) (evidence rating = moderate). In a different study, physical activity was associated with significantly reduced blood pressure in response to the cold pressure test amongst adults from rural northern China (99) (evidence rating = weak). This effect could be attributable to reduced atherosclerosis in the arteries of individuals who are more physically active.

Obesity is also associated with increased visceral adiposity, which can mechanically impair lung function (296). This reduced lung capacity is a possible mechanism for the association between obesity and severe influenza amongst infected individuals (135). However, obese individuals are also likely to have other medical complications which increase their risk of death. Obesity was significantly associated with increased risk of fatality from severe acute respiratory infection among patients from a hospital surveillance scheme in Romania (134) (evidence rating = weak).

Low milk intake was associated with a significantly increased risk of hypertension in males from Korea who were exposed to cold working conditions, compared to sex, age and work-matched participants (109) (evidence rating = strong). This could be due to the high calcium content of milk, which may increase smoothness of muscle inside arteries (297), thereby decreasing the resistance of blood flow, which reduces blood pressure and cardiac risk.

Vitamin C intake may be reduced during the winter period, if, hypothetically, individuals are less likely to consume fruit and vegetables (sources of vitamin C) during this period. The association between vitamin C intake and the incidence of symptoms of the common cold was assessed by one study from the systematic review in chapter three but was found to be non-significant (181).

Outdoor exposure could increase cold exposure and potentially therefore, adverse circulatory and respiratory health impacts. A cross-sectional study found a significant increase in chest pain was found by 7% per every ten hours spent outdoors amongst Finnish adults (116) (evidence rating = moderate).

Compulsory provision of influenza vaccinations for individuals aged ≥65 years in Japan was associated with significantly reduced COPD mortality rates (174) (evidence = moderate). The overall benefits of this intervention are unclear, due to factors including publication bias and potentially the superior health of individuals who receive the influenza vaccination (215).

Medical condition management may modify the risk of ill-health in cold weather. Lack of medical treatment for hypertension was associated with significantly increased risk of hospital admission for ICH during the cold period amongst patients from Finland (107) (evidence rating = moderate).

Figure 4.1: *Evidence-based pathway model which illustrates the strength of evidence for relationships between lifestyle-related exposures and circulatory outcomes in relation to cold exposure or winter season, based on evidence from the systematic literature review from chapters two-three.*
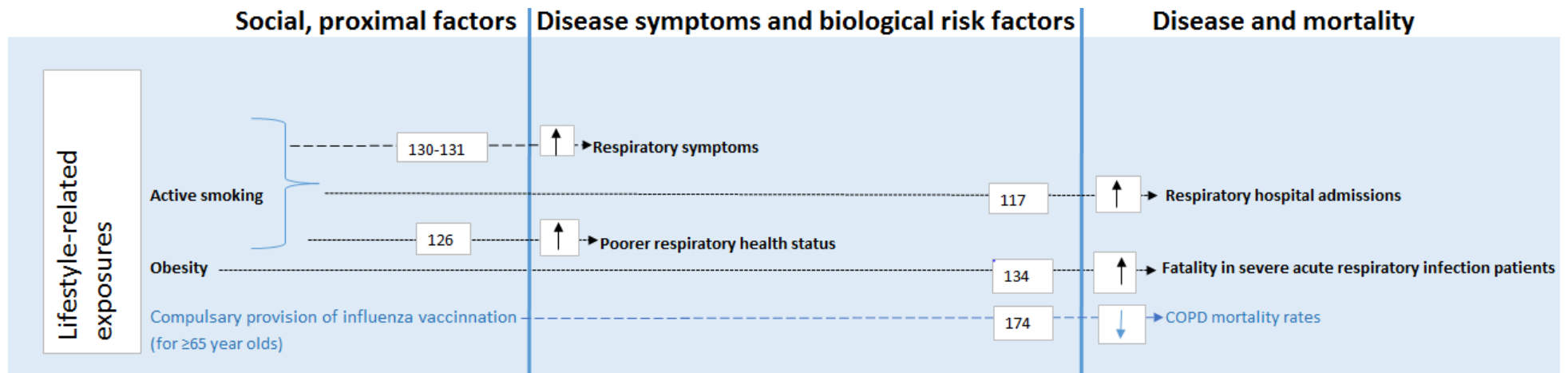
Figure 4.2: *Evidence-based pathway model which illustrates the strength of evidence for relationships between lifestyle-related exposures and respiratory outcomes in relation to cold exposure or winter season, based on evidence from the systematic literature review from chapters two-three.*

4.4.5 Impact of socioeconomic factors

The current literature indicates inconsistent associations between composite measures of socioeconomic deprivation and cold-weather-related cardiovascular and respiratory risk. There was evidence from the review in chapter two that composite deprivation indices were associated with significantly increased winter IHD hospital admission rates across health regions of Quebec (94) (evidence rating = moderate), and with increased cold-weather-related cardiovascular mortality rates across Taiwanese townships (95) (evidence rating = moderate). It is possible that associations between socioeconomic deprivation and cardiovascular health outcomes are mediated by lifestyle factors.

Low household income and over-crowding, which are individual measures of socioeconomic deprivation, have been found to be associated with adverse respiratory health outcomes in children during the winter period. An ecological study found neighbourhood poverty level and crowding were associated with significantly increased incidence of paediatric influenza-associated hospitalisations in the USA (120) (evidence rating = moderate). Low household income was associated with significantly increased occurrence of otitis media during the winter amongst children in a different study, from Brazil (121) (evidence rating = moderate). This is possibly due to the fact that children from low income, over-crowded households have greater exposure to infectious agents, including viruses, from other household occupants.

Figure 4.3: *Evidence-based pathway model which illustrates the strength of evidence for relationships between socioeconomic exposures and circulatory outcomes in relation to cold exposure or winter season, based on evidence from the systematic literature review from chapters two-three.*
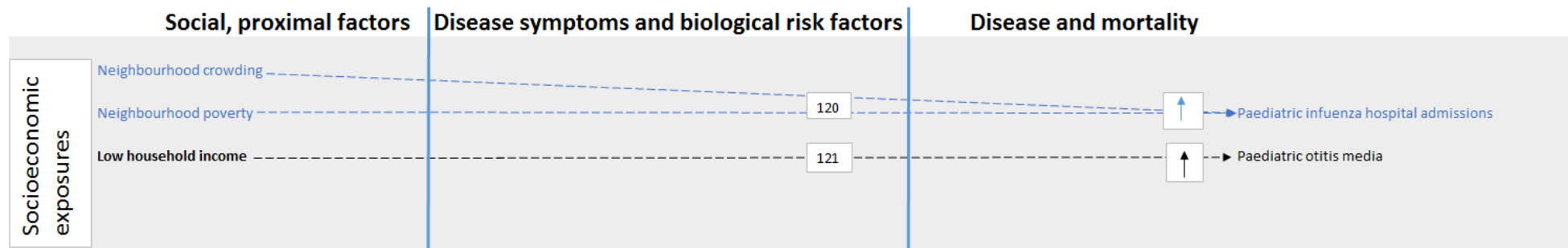
Figure 4.4: Evidence-based pathway model which illustrates the strength of evidence for relationships between socioeconomic exposures and respiratory outcomes in relation to cold exposure or winter season, based on evidence from the systematic literature review from chapters two-three.

4.4.6 Impact of housing-related factors

Indoor temperatures are influenced by outdoor environmental temperatures and internal housing conditions, including the standard of thermal insulation and the presence and usage of a functional central heating system. Indoor and outdoor temperatures could influence the level of personal cold exposure and circulatory and respiratory health outcomes via the mechanisms described in section 4.4.2, above. Exposure to weak room heating was associated with significantly increased systolic blood pressure amongst healthy adults from Japan (169) (evidence rating = moderate). Low living room temperature was associated with total cholesterol in elderly persons from England (100) (evidence rating = moderate). Low predicted indoor temperature (colder hall temperature) was associated with EWM from cardiovascular disease in England in another study (83) (evidence rating = moderate). In relation to respiratory health, having fewer days with at least nine hours of warmth at 21^0C was associated with significantly worse health amongst COPD patients from Scotland (126) (evidence rating = weak). Cold housing was associated with significantly increased incidence of asthma amongst postnatal women from New Zealand (127) (evidence rating = weak) and with worse self-reported respiratory health amongst elderly persons from across Europe (104) (evidence rating = weak). Increased bedroom temperatures were associated with significantly reduced self-reported wheezing amongst occupants of low income households from New Zealand (172) (evidence rating = strong).

Increased household thermal efficiency was associated with significantly reduced incidence of self-reported wheezing amongst individuals from low income households from New Zealand (evidence rating = strong) (172). Low thermal efficiency was associated with significantly increased EWM from CVD in England (83) (evidence rating = moderate). This is possibly because thermally inefficient housing is colder if residents do not, or are not able to, counteract heat loss with heat generation through central heating usage.

Evidence from the systematic review in chapters two-three identified that receipt of a new central heating system was associated with significantly reduced blood pressure and occurrence of heart disease in Scottish householders (170) (evidence rating = moderate). Presence of central heating was associated with reduced EWM rates from CVD in the English population (83) (evidence rating = moderate). Dissatisfaction with the central heating system was associated with significantly increased self-reported respiratory problems in children from regions of eight European countries (104) (evidence rating = weak). Evidence in relation to beneficial effects of central heating from studies in the reviews presented in chapters two-three was mixed (102, 104, 128, 167). This could be due to the fact that individuals with

functioning central heating systems are reluctant to use them for financial reasons (i.e. living in fuel poverty), for practical reasons (e.g. the central heating system is non-functional), attitudinal reasons (e.g. valuing prudence and / or misunderstanding the adverse health impacts of cold-exposure) or cognitive reasons (e.g. decline in thermal perception mechanisms) (286).

There is limited evidence concerning the effects of ventilation and dampness on circulatory and respiratory health outcomes in relation to cold weather or during the winter season (59, 104, 129). Unventilated housing could support the spread of communicable respiratory diseases, particularly in highly insulated properties and in over-crowded housing in which individuals have high contact rate with fellow inhabitants. Dampness supports mould growth, which can release spores that may cause or aggravate respiratory health conditions, by triggering an immune response that creates respiratory symptoms. The causes of damp housing include leaking pipes, penetration of housing by rainwater and rising damp caused by the lack of an effective damp proof course (298). Respiration and indoor activities including bathing and clothe laundering also generate moisture in cold houses. Cavity wall insulation could increase dampness, by providing material which can be used by rainwater to track from the outer wall to the inner wall of housing (299) and preventing drying airflow to enable evaporation of water within the cavity before it reaches the internal wall. Reductions in cold, damp housing conditions were associated with significantly decreased diastolic blood pressure amongst residents of flats from Scotland (168) (evidence rating = moderate). Damp housing conditions were also associated with significantly increased EWM from CVD in England (83) (evidence rating = moderate). However, it is likely that the association between damp housing and circulatory risk is confounded by the fact that damp housing is indicative of low indoor temperatures.

An intervention study from the review in chapter three found that a thermal efficiency intervention that aimed to increase household thermal efficiency in households from New Zealand was associated with reduced humidity, which was associated with significantly reduced odds of self-reported wheezing amongst recipients (172) (evidence rating = strong). This is likely to have been related to increase warmth in intervention households.

Older property age was associated with significantly increased diastolic blood pressure (101) (evidence = weak) and EWM from CVD in England (83) (evidence = moderate). This is likely to reflect the adverse cardiovascular health impacts of various aspects of housing condition associated with property age, potentially including reduced thermal efficiency.

Significant associations were found between living in privately rented and owner-occupied accommodation and EWM from CVD in England (83) (evidence rating = moderate). The nature of this association could be explained in terms of reduced thermal efficiency levels in privately rented and owner occupied housing, and increased fuel poverty amongst individuals from these housing tenures.

Living in a rural area was associated with significantly reduced risk of being hospitalised for lower respiratory tract infection or exacerbation of chronic respiratory disease, in a study of English adults from central England who sought healthcare consultations for respiratory conditions (117) (evidence rating = weak).

It is possible that urban dwellers were more likely to seek healthcare consultations due to their relative ease of access to medical facilities, compared to rural dwellers; this is supported by evidence from the wider literature (300). Increased exposure to air pollution could also explain part of the increased risk of hospitalisation from respiratory diagnoses in urban compared to rural areas. Rural dwelling was associated with significantly increased risk of post-cold-surge cardiovascular mortality across Taiwanese townships (95) (evidence rating = moderate). This may be attributable to lower environmental temperatures in rural areas and also reduced medical access, meaning that individuals are more likely to die following cardiac events.

4.4.7 Impact of Fuel Poverty

Fuel Poverty is associated with cold housing, which can increase personal cold exposure, and, therefore, the risk of respiratory and cardiovascular illnesses through the biological mechanisms described in section 4.4.2. In support of this, three studies found that a 'Fuel Poverty Risk Index', which comprised several fuel poverty risk factors, namely energy inefficient housing, low income, householder (older) age and under-occupied housing, was associated with significantly increased risk of being a respiratory hospital admission amongst older people (4, 119, 128) (evidence ratings = weak, moderate and weak, respectively). A different study found that individuals from fuel poor households were more likely to have more lifestyle-related risk factors for cardiovascular and respiratory diseases, which indicates an additional pathway between fuel poverty and adverse health outcomes (301).

Fuel poverty is caused by a broader combination of factors than originally identified by Boardman (30), including the general availability of fossil fuels, low household incomes, thermally inefficient housing, household under-occupancy, access to energy networks and

energy tariffs. These factors are issues which can be addressed, or interventions targeted towards a broader range of 'at-risk' groups, based on action at the political level.
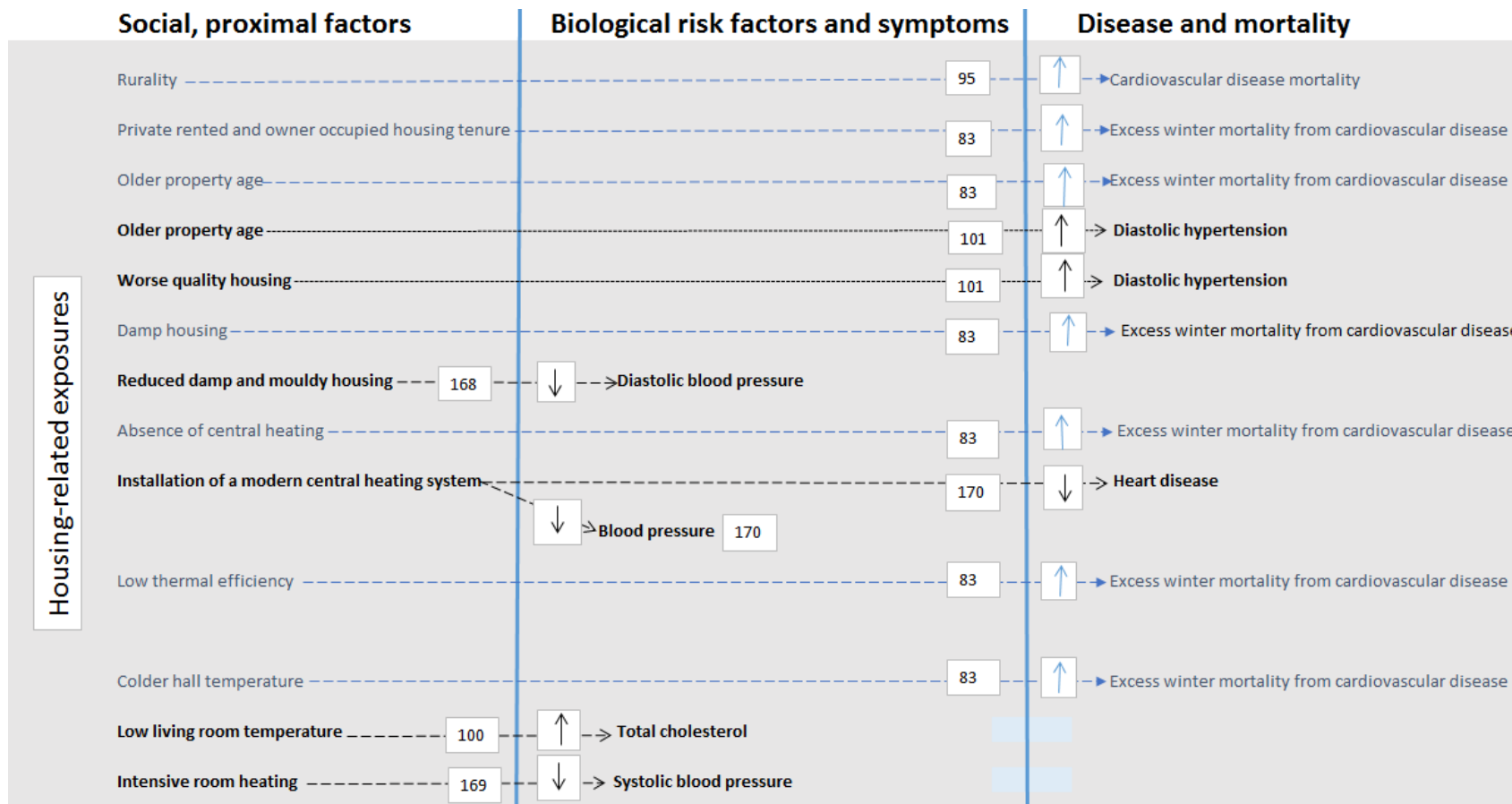
Figure 4.5: *Evidence-based pathway model which illustrates the strength of evidence for relationships between housing-related exposures and circulatory outcomes in relation to cold exposure or winter season, based on evidence from the systematic literature review from chapters two-three.*
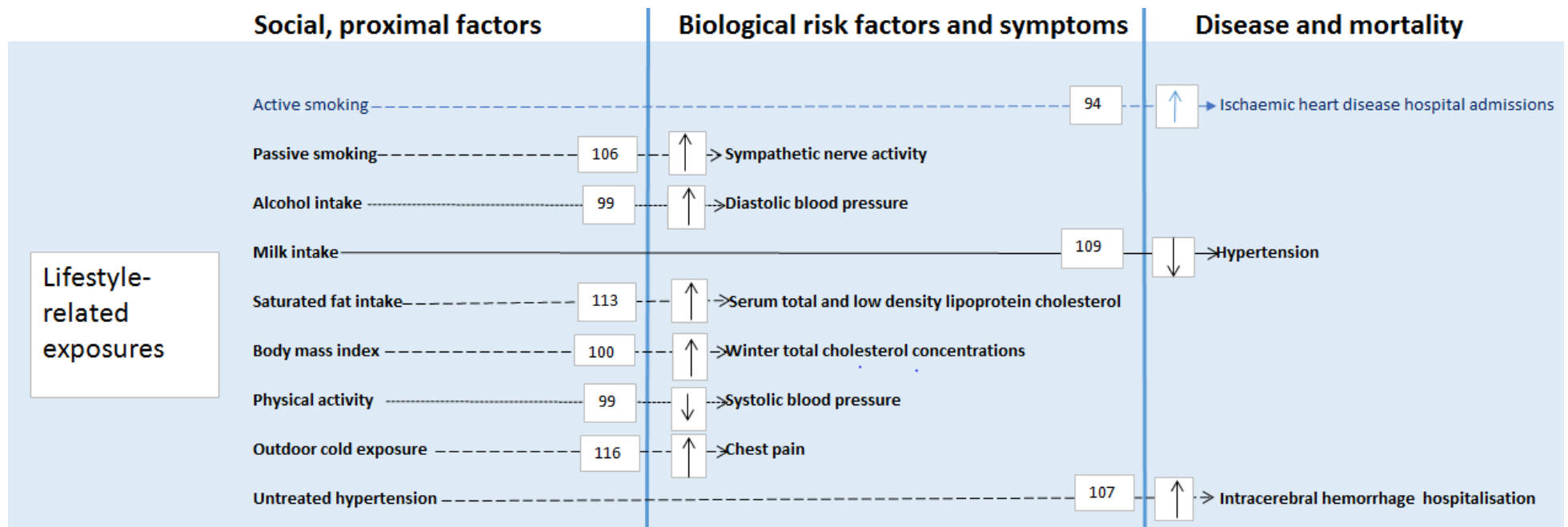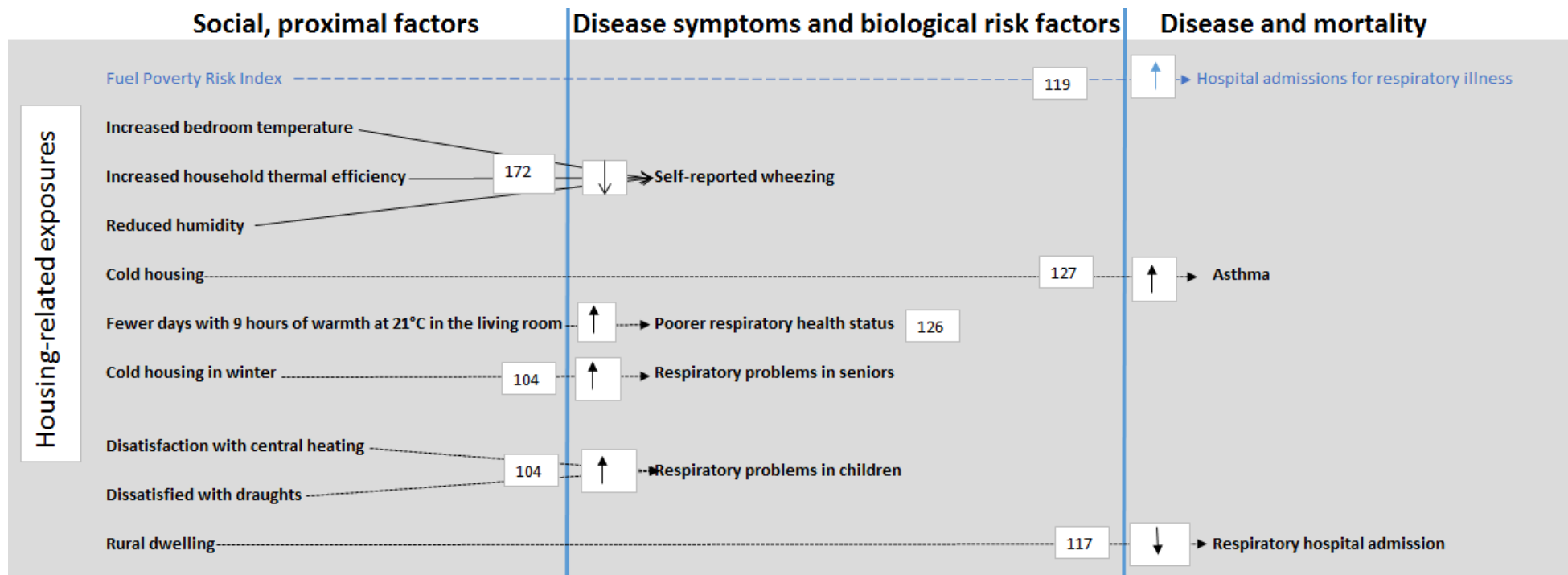
Figure 4.6: *Evidence-based pathway model which illustrates the strength of evidence for relationships between housing-related exposures and respiratory outcomes in relation to cold exposure or winter season, based on evidence from the systematic literature review from chapters two-three.*

4.5 Summary

In this chapter, I developed evidence-based pathway models of associations between exposures and interventions, and circulatory and respiratory health outcomes in relation cold exposure and winter season, using evidence from the systematic literature review in chapters two-three. I also considered possible mechanisms by which different exposures and interventions could modify the risk of circulatory and respiratory health outcomes in relation to cold exposure.

The information in figures 4.1 to 4.6 illustrate that existing evidence has focused on the effects of individual factors. Very few studies identified in the systematic literature review from chapters two-three considered the mechanisms by which different factors interact to influence health. Consequently, I am unable to produce an evidence-based model of pathways between cold exposure and adverse health outcomes moderated and mediated by various environmental, social and biological factors that shows interactive effects of different explanatory variables on health.

Figures 4.1 to 4.6 illustrate the evidence concerning associations between exposures or interventions and outcomes in relation to cold exposure and winter season. However, the evidence is drawn from a large number of heterogeneous studies differing in terms of populations of interest, whether the data were collected at individual or ecological level and the exposure and outcome measures used. It is therefore, inappropriate to assume that the same pathways exist in different populations and ecologic levels. More insightful information regarding the effects of different factors on cold-related health outcomes could be gleaned from conceptual models based on evidence derived from specific population groups.

The conceptual work presented in this chapter provides information about the potential mechanisms through which various factors could impact on circulatory and respiratory health, and may therefore influence morbidity and mortality rates, in relation to winter season and cold weather. This information is used to inform the analyses in chapter eight, concerning the relationships between explanatory factors and spatial and temporal variations in morbidity and mortality rates across England and between winter seasons.

 In chapter five, I identify and examine data sources which can be used to represent variables from this chapter in the analyses.

Chapter Five.

Methods (i): Identification and selection of suitable data for the analyses

5.1 Chapter outline

In chapter four, I developed evidence-based pathway models of associations between social factors and circulatory and respiratory symptoms, disease risk factors and health outcomes, in relation to cold exposure and winter season. I also considered the mechanisms through which various environmental and social factors could impact on circulatory and respiratory health, and may therefore influence spatial and temporal variations in health across England in relation to cold weather and between winter seasons. This information is used to inform the analyses in chapter eight, to identify factors associated with spatial and temporal variations in cold-related-and excess winter morbidities and mortality.

In this first of three methods chapters, I explain how data were identified to represent variables from the evidence-based pathway models, which were then used in the statistical analyses presented in chapter eight. In chapter six, I describe the methods that were used to format each data source and build a linked dataset containing explanatory and outcome variables for the analyses. In my final methods chapter (chapter seven), I introduce the statistical methods used to explore associations between individual and combinations of explanatory factors and spatial and temporal variations in excess adverse circulatory and respiratory health outcomes, in relation to periods of cold weather and winter season. The results from these analyses address research questions three (i.e. which factors are associated with spatial and temporal variations in winter- and cold-weather-related morbidity and mortality rates) and four (i.e. does the same combination of variables drive spatial and temporal variations in cold-weather-related morbidity and mortality rates) from the introduction (section 1.2).

5.2 Criteria for locating and selecting suitable data for the analyses

I identified data to represent variables from chapter four using internet searches and communications with individuals from academic, public and third sector organisations. Data on a range of health, social and environmental factors are routinely collected by organisations within the UK. Most of these data are publicly available via the internet. The wealth of secondary data available are mostly collected for specific purposes, and, consequently, it is

not always possible to access appropriate data to address a specific research or policy question (302).

Each data source that I identified to represent variables from chapter four in the analyses had limitations, and in situations where multiple data sources were available to represent a particular variable, a decision had to be made to select the most suitable data. In order to ensure that the process of data selection was as systematic as possible, I developed the following criteria, based on my consideration of what constituted a '*model*' data source in relation to the aims of this project. Firstly, the data should be available at, or convertible to, the spatial units of interest in this study, which are local authority districts, 2011 boundaries (LAD11). Secondly, the data should be available at, or convertible to the temporal units of interest, which are months. Thirdly, the data should be available for the whole study area, which is England. Fourthly, the data should be available for the whole study duration of 2001-12. Finally, the data should be representative of the populations of the spatial areas of interest (Local Authority Districts (LADs) for the whole of England). My rationale for identifying these criteria, are as follows:

1. Availability at the spatial units of interest (LADs)
The spatial areas of interest in this study are LADs. Local authorities are government administrations that operate at two levels in many parts of England. The two levels are county councils (upper tier) and district councils (lower tier). County and district councils have responsibility for the provision of different services to their populations (303). Some parts of the UK have a one tier system, which are referred to as 'unitary authorities'. English LADs include (metropolitan and non-metropolitan) districts, unitary authorities and London boroughs. The upper tier of English local government (i.e. counties) are not included in LAD boundaries (304, 305). In 2011 there were 326 LADs in England.

Limitations of using LADs as the spatial units of interest in the analyses in chapter eight are that LAD boundaries change regularly, as a result of attempts to improve efficiency of local government for different areas (306). This is problematic for targeting interventions towards areas with high hospital admission and mortality rates, as LADs often only exist for short periods of time. Also, LADs also have relatively large (compared to other small spatial units, e.g. Census output areas) and variable population sizes, ranging from 2,200 – 1.072 million (307), with a national average population size of 5,500 (308) for 2011 boundary codes, and incorporate socially heterogeneous populations, which differ in relation to their demographic and socioeconomic attributes. The use of LADs as the spatial units of interest in this study prevents the identification of health inequalities and associated risk factors within these areas.

I originally intended to use middle layer super output areas as the spatial units of interest in this study. There are two tiers of super output area in England, namely lower layer super output areas (LSOAs) and middle layer super output areas (MSOAs). These are aggregations of census output areas, which are the smallest geographic units in which UK Census data are reported. English output areas were created in 2004 (following the 2001 Census), in order to improve the reporting of small area level statistics, by creating areas of approximately equal population sizes, containing adjacent and socially homogenous (in relation to tenure and accommodation type) postcodes (309). The boundaries of individual output areas are relatively static compared to other small area geographies (e.g. LADs), as they are only changed (merged or divided) between censuses in situations whereby (i) their population sizes deviate from maximum or minimum population thresholds (ii) in order to improve an output area or super output area's social homogeneity or (iii) to align with changed local authority boundaries (309). Just 0.11% of MSOAs were changed between the 2004 and 2011 systems, and the ONS provides a geographical conversion tool which allows data to be mapped between these classifications. There are currently 171,371 output areas, 32,844 LSOAs and 6,791 MSOAs in England. Each MSOA has a population size of between 5 and 15,000 people (309).

The temporal stability of Census output and super output areas makes them appropriate for exploring changes in disease prevalence through time, in relation to explanatory factors. In addition, their small and socially homogeneous nature enables identification of health inequalities within local authority areas and associated risk factors, and also potentially reduces the ecological fallacy. For example, in situations whereby individual households are assumed to be in fuel poverty, due to being located in areas containing a high proportion of thermally inefficient housing; this may lead to the delivery of costly interventions (e.g. financial support during periods of cold weather) to the whole population, including non-fuel poor households.

Despite the advantages of using MSOAs as the spatial scale of interest for the analyses in this thesis, there is greater availability of data at LAD compared to smaller area levels, for most of the variables identified in chapters two-four. LAD level data are also generally of better quality, due to being directly measured. Data for many of the variables at MSOA level are estimated from data collected at a larger ecological scale (e.g. LADs or regions), applied to MSOAs using modelling techniques. For example, if smoking prevalence data are collected at LAD level, but not MSOA level, whereas income deprivation data are available at both ecological levels, information regarding the association between smoking and income

deprivation at LAD level can be used to estimate smoking prevalence at MSOA level. However, the estimates are unlikely to be accurate.

I initially obtained some datasets for the analyses at MSOA level; however, I made the decision to aggregate up or re-locate these data at LAD level, due to the lack of robust data on a comprehensive range of factors of interest at smaller area levels. Responsibility for public health was conferred on local authorities by the Health and Social Care Act 2012 (310). It is, therefore, useful to describe data at LAD levels to inform improvement and protection of health. However, health disparities are often pronounced within LADs and the reduction of these health inequalities is a measure on which different LADs are compared (311). It may, therefore, be more informative to use smaller ecologic units in further research to investigate health disparities in specific LADs.

As discussed, LADs are subject to boundary changes through time. However, the names and numbers of LADs were the same between 2011 and 2014. At the time when analyses for this thesis were undertaken, 2014 boundaries were the system currently used, therefore results from this thesis are relevant to existing LADs.

2.   Availability at the temporal units of interest (months)

I chose months as the temporal units of interest in this study. This enabled me to assess associations between explanatory factors and outcome variables for specific months in the analyses. The acquisition of data for smaller temporal units (e.g. days and weeks), would be likely to produce missing data for areas with small populations during non-winter months, when mortality counts are generally lower. In addition, mortality counts of very small numbers may jeopardise confidentiality as individuals could be identified from these data.

3.   Availability for the study duration (2001-12)

I chose to analyse data for the time period 2001-12 in this study, for the following reasons. First, as from 2001 onwards, specific policies, legislations and guidelines were developed to reduce the adverse health and social impacts of cold weather (see chapter one for a discussion) (312-314). Also, in the winters of 2009/10 and 2010/11, the UK experienced unusually cold weather conditions. The political and climatic events which occurred from 2001 onwards make this an interesting period to assess temporal variations in cold-weather-related population health outcomes across England. Also, the period 2001-12 is the most recent period for which complete data are available. The analysis of data within a twelve year period in this study does not enable modelling of associations between exposures and outcomes that occur over longer time durations, which are particularly useful when modelling

the effects of lifestyle-related factors on chronic health outcomes and mortality, as these associations generally occur over decades (i.e. there is a lag effect).

4. *Availability for the study area (England)*

I chose to use England as the area of study in this study as it has a relatively strong political interest in reducing the excess adverse health and social impacts of cold weather. Also, England has population data available on a wide range of health, social and environmental indicators, including those which are of interest in this research. There is a lack of comparable data on many of the variables of interest in this research in Northern Ireland, Scotland and Wales, which is a main reason for not including other parts of the UK in the analyses.

5. *Representativeness of the populations of English LADs*

Another factor which influenced the selection of data for use in this project was their representativeness in relation to the social characteristics of each area. Data sources collected from samples that were representative of the populations of English LADs were preferred, in order to ensure that inferences regarding exposure-outcome associations are valid at this ecological level.

In sections 5.3, I describe data sources that were identified to represent the required variables and the process of selecting data sources based on the five criteria outlined above.

5.3 Data to represent identified variables for analyses

5.3.1. *Morbidity and mortality data*

The health outcomes of interest in this research, based on the discussion in chapter four, are morbidity and mortality from circulatory and respiratory conditions. The Office for National Statistics (ONS) is the UK's national repository for social statistics. The ONS holds electronic details of all deaths registered in England and Wales from 1959 onwards and information about the post code of usual residence of deceased individuals became available from 1981 (315). The ONS publish mortality statistics on their website as standard outputs, and are able to produce bespoke tabulations containing specific variables.

Hospital Episode Statistics (HES data) are commonly used in epidemiological research to measure the occurrence of medical conditions within the English population. English HES data are available from the Health and Social Care Information Centre from 1989-90 onwards (316). The Health and Social Care Information Centre is a public body which delivers information to improve patient services, care and outcomes across England. As with the ONS, the Health and Social Care Information Centre provides a service from which applicants can obtain datasets containing variables of interest for specific research projects. The Health and

Social Care Information Centre also has access to ONS data and offer to provide linked HES and ONS mortality statistics in bespoke tabulations.

Initially, I consulted the websites of the ONS and the Health and Social Care Information Centre, to investigate whether any suitable data were available for my analyses. I was unable to locate morbidity and mortality data that were broken down by small areas and months for the time period of interest (2001-12). I therefore, applied for bespoke data tabulations of HES and mortality data. Initially, I contacted the Health and Social Care Information Centre to discuss my requirements in October 2013 and, after a delay in being provided with the relevant information to complete my application, I submitted my data request on 13 January 2014. I requested the data for MSOAs as I originally intended to perform analyses at this ecological level. The data which I applied for were monthly mortality and hospital inpatient counts for English MSOAs from 2001-12, broken down by condition group (circulatory conditions and respiratory conditions, ICD-10 codes I000-I999 and J000-J999, respectively), five year age groups and sex. I was informed by the organisation that this bespoke data request should be completed within six weeks from application. However, during my PhD, restructuring of health and social care functions in England took place, following the 2010 election. These changes impacted on the management and release of patient data. A brief overview of the changes is provided in the following paragraphs.

The Health and Social Care Act 2012, specified major changes to health and social care functions in England, including the introduction of several new health bodies. One of the new bodies, NHS England, which aims to improve health outcomes for people living in England, identified the need to provide better, more joined up information regarding the care that individuals receive within different parts of the English NHS (317). This increased use of patient information raised public concerns about the use of health data, including possible abuse by insurance companies, who could potentially use patients' data to calculate personal insurance premiums. However, the Care Act (2014) restricted the flow of potentially identifiable health data solely for purposes of benefit to the health and social care systems (318).

On 5 March 2014, a review was commissioned to investigate the release of data by the Health and Social Care Information Centre's predecessor organisation, the NHS Information Centre (318). The results of this investigation were released on 17 June 2014 and concluded that the handling of medical data by the NHS Information Centre was unacceptable (319). In order to restore public confidence regarding the use of personal health data, the Health and Social Care Information Centre undertook a review of processes for handling and releasing information.

On 17 June 2014, the Health and Social Care Information Centre set out a procedure that would involve stricter regulation of data release and usage.

In order to practice my analyses whilst waiting for outcome data from the Health and Social Care Information Centre, I contacted the ONS in May 2014 to enquire whether I could obtain a reduced dataset, containing mortality data. ONS was able to provide monthly mortality data for English MSOAs from 2001-12, by condition group, however they were unable to provide the mortality data broken down by sex or age group, unless in the first instance, I applied to become an approved researcher, a process which could take six months. As these data were only intended to be used for preliminary research, so that analyses could be undertaken quickly when the data from the Health and Social Care Information Centre arrived, I accepted the reduced dataset, without age group and sex breakdown. The ONS are unable to provide HES data.

The Health and Social Care Information Centre did not fulfil my data application during my PhD. I cancelled my application in May 2015 as at this time I was still awaiting information about when the data might become available. Consequently, I was required to use the mortality data that I obtained from the ONS in my final analyses.

The characteristics of data which the Health and Social Care Information Centre and the ONS hold and those which I was able to obtain from the ONS are presented in table 5.1 in relation to my suitability criteria from section 5.2.

Table 5.1: *Sources of data to represent morbidity and mortality variables in statistical analyses assessed against five suitability criteria*[†]

Data	Variable	Sources	Time period available	Temporal units available	Geographic area available	Spatial units available	Representativeness
Data held by the organisations	Mortality counts	Office for National Statistics, (ONS); Health and Social Care Information Centre	1981 onwards	Various, including English Middle Super Output Areas (MSOAs) and Local Authority Districts (LADs)	England and Wales	Various, including months	Representative of the populations of England and Wales and their constituent areas (e.g. MSOAs / LADs)
	Morbidity (hospital inpatient) counts	Health and Social Care Information Centre	1989-90 onwards	Various, including English MSOAs and LADs	England and Wales	Various, including months	Representative of the populations of England and Wales and their constituent areas (e.g. MSOAs / LADs)
Data obtained	Mortality counts	ONS	2001-12	MSOAs	England	Months	Representative of the populations of English MSOAs, and LADs once aggregated
	Morbidity (hospital inpatient) counts	Health and Social Care Information Centre	None	None	None	None	None

[†] Cells shaded green indicate that the variable of interest (e.g. mortality count data) fulfils the requirement in the column in relation to the criteria specified in section 5.2 (e.g. the data are available for the study period, 2001-12). This coding is used in all tables in this chapter.

5.3.2. *Influenza data*

Influenza is considered to contribute to spatial and temporal variations in cold-weather-related mortality in England (5). It is therefore, important to include a measure of influenza activity in the analyses for this project. Influenza is not a notifiable disease, meaning there is no legal requirement for cases to be reported to health authorities. In addition, most cases of influenza do not result in healthcare consultations, therefore only a small proportion of cases are recorded and even fewer cases are confirmed from lab samples. As most cases of ILI go undetected, measures of influenza activity are proxy measures rather than true incidence data (320).

Influenza surveillance in the UK is coordinated by Health Protection Agency (HPA) Influenza Surveillance Section, Respiratory Disease Department, HPA Colindale (321). The HPA website lists sources of UK influenza data under the following categories: i) clinical surveillance through primary care, ii) microbial surveillance and iii) disease severity and mortality data. Some influenza data sources were developed following the 2009 Swine Flu Pandemic (322).

I contacted organisations including Public Health England, to enquire about accessing influenza data for this project. I intended to decide which data were most suitable for my analyses, in relation to my inclusion criteria as specified in section 5.2, once I had determined which data were available. In the following paragraphs, I discuss the suitability of the influenza data sources and my attempts to access them.

Influenza surveillance data are collected from GP practices around the country which provide data on infectious diseases that are used in syndromic schemes. However, these data are based on GP consultations in a small number of practices. The Royal College of General Practitioners (RCGP) spotter practice scheme provides the only community-based influenza incidence data which are available throughout the year and for the whole study period of interest in this research (2001-12) (320, 323). The data are collected from over 100 GP practices in England and Wales and act as an early warning to changes in the incidence of common illnesses, including influenza activity. Weekly communicable disease reports are published by the HPA, which present influenza data from various sources including the RCGPs spotter practice scheme, at national and supra-regional (north, central and south of England) levels (324), but not for smaller areas of England. The RCGP spotter scheme also does not have good coverage of the whole country - for example, it includes very few North East practices. It is also not based on laboratory-confirmed influenza cases. The data are from an aggregate practice population of >900,000 people, which represents about 1.5% of the

population of England and Wales (320, 323). I applied to the RCGP in January 2014 to obtain influenza data from the GP spotter practice scheme for my study. The organisation refused to release the data until a policy review scheduled in spring 2014, had been completed. I submitted a second application to the organisation, including a full protocol for my study, in autumn 2014, but I received no data or further communication from the organisation, despite my efforts to contact the team who were dealing with my request.

An alternative GP surveillance scheme is Q Surveillance, which is the world's largest real-time infectious disease surveillance system and produces weekly reports on the prevalence of infectious diseases like influenza and pneumococcal infection (325). These data are obtained through monitoring GP consultations and deaths from infectious diseases on a daily basis for an aggregate population of 23 million patients at Primary Care Trust (PCT) level (325). PCTs were established across England between 2000 and 2002 as commissioners and providers of health services amongst local populations, but were abolished in March 2013 and replaced by clinical commissioning groups following the publication of the 2012 Health and Social Care Act (219). However, as PCTs existed for the duration of my study, they are potentially an appropriate administrative boundary to use in this project. Q Surveillance data are derived from a larger number (3,400) of UK GP practices than the RCGP scheme, but do not cover the whole time period of this study (the data are available from 2008). There are additional limitations of this data source. Firstly, researchers wishing to obtain these data are required to be employed by a UK research institution, which I am not. Secondly, the number of observations it is permitted to access in a dataset is limited to 1,000. This would mean I would only able to access data from 2008 onwards at national level. Nevertheless, I attempted to contact the custodian of these data to enquire about obtaining Q Surveillance data to include in my project, but I received no response to my e-mail. I was unable to locate alternative contact details (e.g. a telephone number), to follow-up my e-mail.

NHS Direct provided a 24 hour telephone helpline service for the general public to access health-related advice, from its establishment in 1998 to its dissolution in March 2014. In partnership with the HPA, the NHS Direct Syndromic Surveillance System, which covered the whole of England and Wales, recorded data on certain symptoms with a winter focus on cold/flu and fever calls (321). In relation to the aims of the project in this thesis, data from the NHS Direct Syndromic Surveillance System has the advantage of running since 1998 and therefore it covers the whole period of my study. However, it is based only on people who contacted the NHS Direct service with ILI symptoms. I contacted the NHS information

governance team to enquire about the availability of NHS Direct influenza syndromic surveillance data, but I was informed that the data were unavailable at area levels.

The National Pandemic Flu Service was a telephone and internet service that ran in England between 23 July 2009 and 11 February 2010, which the general public could contact if they had symptoms of influenza, following which, individuals were taken through a series of questions to determine if they should receive antiviral drugs (321). Like the NHS Direct syndromic surveillance scheme data, the National Pandemic Flu Service only holds information about people who used the service. Also, these data were only collected for a seven month period.

Flu Survey is an internet-based influenza surveillance project which is run by the London School of Hygiene and Tropical Medicine (326). The aim of the system is to provide an up-to-date robust system which captures influenza activity amongst individuals who would not have consulted health services. The system is based on participants from the general population, who are asked to report any flu-like symptoms each week during the influenza season. The scheme was established in 2009 and was in its fifth year of reporting at the time when I acquired data for this project. This data source has the limitations of being based on voluntary reporting and being unavailable for my study duration, from 2001-12. I contacted the Flu Survey team twice by e-mail to ask if they could provide data for my project, but received no response.

The Medical Officers of Schools Association / HPA scheme is based on the collection of weekly data on various illnesses including ILI from boarding schools which are enrolled in the scheme, each week during the school terms (321). The scheme includes up to 42 schools and the report covers a population of approximately 12,000 pupils. Most of the children are located in the southern half of England, with pupils aged between 5 and 18 years, although the majority are boys aged from 13 to 18 years (321).These data are unrepresentative of the study populations of interest in my research and therefore I considered this an inappropriate source of influenza data.

Outbreaks of acute respiratory illnesses in institutional setting (e.g. schools, care homes and hospitals) are reported to the Respiratory Diseases Department at Public Health England-Colindale (321). However, as with the Medical Officers of Schools Association system, data from institutional settings are unrepresentative of the whole population of England.

Public Health England has also started to conduct a community influenza telephone survey to monitor influenza circulation in England, based on a sample of approximately 800

households. However, this survey only began during the 2013/14 influenza season (321), which is outside of my study period. The HPA also monitors influenza using microbial samples obtained from patients in healthcare settings, but these data are unavailable at aggregate level.

Hospitalisation and mortality data are used to monitor cases of severe influenza in the English population. As discussed in chapter one of this thesis, influenza is often incorrectly diagnosed and it can aggravate other medical conditions, whereby influenza hospitalisations and deaths are likely to be under-recorded (327, 328).

The UK Severe Influenza Surveillance System involves the mandatory reporting of lab confirmed hospitalised cases of influenza within NHS hospitals and Trusts in England. This scheme was piloted in 2010/11 and ran in 2011/12 (321). The data are collected on a weekly basis, broken down by age group and influenza type, and are disseminated by the HPA through weekly influenza reports (321). I contacted the custodian of these data to request access to the full dataset and was told that I could not be allowed access to the data as they were currently being used in analyses.

The weekly influenza report, which contains data from the RCGP GP spotter practice scheme and UK Severe Influenza Surveillance System, is only available online from the publication released on 13 October 2011, which is less than two months before the end of my study duration. I requested back-issues of this report from the custodian of the UK Severe Influenza Surveillance System data and from the RCGP, but these were not provided. However, the weekly influenza reports would be unsuitable to use in my analyses due to the fact that, as already explained, they only provide data at national and supra-regional levels. These data are unlikely to provide accurate information about influenza activity for individual LADs.

An alternative option for obtaining proxy influenza data was to apply to the Health and Social Care Information Centre or ONS for monthly hospitalisation and or mortality counts, respectively, broken down by LAD of residence and specific influenza disease codes. This would provide influenza data for the entire duration and geographical area of interest in my study and at the spatial and temporal units of interest. However, there are various problems with using these data, as follows. Firstly, inaccurate diagnosis and the presence of co-morbidities means that influenza is often under-recorded as the cause of hospital admission and death. Secondly, the Health and Social Care Information Centre were not releasing data, as discussed in section 5.3.1. Thirdly, the ONS would be unlikely to release data specifically

for influenza disease codes at monthly and LAD level, as the number of deaths would be extremely small and individuals could potentially be identified from information regarding their cause and month of death and their area of residence. The small numbers would also undermine the reliability of the data, although this is dealt with in my analyses by using Bayesian approaches (see chapter seven for details). Influenza mortality data are also highly unrepresentative of community level influenza activity. Fourthly, mortality data for the influenza disease codes are included in the outcome data for respiratory deaths. Including the same influenza data in statistical analyses twice could introduce the problem of mathematical coupling, which refers to the situation whereby part of an association between two variables is due to a common component which is included in both variables (329). This can lead to invalid results and conclusions.

I contacted various other individuals and organisations throughout 2014 for advice about obtaining influenza data from the sources listed on the HPA website, but no data were provided and I received feedback from a member of staff from Public Health England that organisations were not releasing any influenza data at this time.

Influenza activity has complex aetiology that is not well understood (330), therefore I was unable to identify any other appropriate indicators which could be used as substitute measures of influenza activity.

A summary of the influenza data sources that I consulted for this project are presented in table 5.2, below.

Table 5.2: *Sources of data to represent influenza circulation in statistical analyses assessed against five suitability criteria†*

Data	Source	Time period	Temporal units	Geographic area	Spatial units	Representativeness
GP consultation rates for influenza-like-illnesses (ILI)	Royal College of General Practitioners (RCGP)	1966 onwards	Weekly	England	National and supra-regional	These data are based on GP consultations and are therefore not a true measure incidence of ILI. The data are also unavailable at Local Authority District (LAD) level and are geographically and socioeconomically unrepresentative (324) of the study area (England)
Q Surveillance infectious disease data	University of Nottingham	2008 onwards	Daily	UK	Primary Care Trust	These data are not a true measure of influenza incidence as they are based on GP consultations. However, they are collected from 3,400 UK practices and are therefore a more representative proxy for circulating influenza compared to the RCGP spotter practice scheme data

Table 5.2 *(continued i)*†

Data	Source	Time period	Temporal units	Geographic area	Spatial units	Representativeness
NHS Direct Syndromic Surveillance Scheme consultation data	NHS Data Protection Service	1998-2014	Not specified	England and Wales	Not specified	These data are based only on calls from the general public with symptoms of cold and flu to the NHS Direct Service. These data are therefore unlikely to be representative of influenza activity in the population
National Pandemic Flu Service consultation data	Listed on Health Protection Agency (HPA) website, no contact details available	Jul 2009-Feb 10	Not specified	England	Not specified	These data are only from people who contacted the service
Flu Survey data	Contact form available on Flu Survey website	Flu seasons from 2009/10 onwards	Weekly	England	Not specified	These data are based on people who participate in weekly online symptom reporting

Table 5.2 *(continued ii)*†

Data	Source	Time period	Temporal units	Geographic area	Spatial units	Representativeness
Medical Officers of Schools Association / HPA scheme	Listed on HPA website, contact details unavailable	Not specified	Weekly	England	Not specified	These data are based on reporting of ILI from 42 boarding schools, located mainly in Southern England
Institutional outbreak data	Respiratory Disease Department, HPA Colindale	Not specified	Not specified	The UK	Not specified	These data are based on ad-hoc reporting of acute respiratory illness outbreaks from institutional settings
Public Health England (PHE) Community Telephone Survey	PHE Contact email address provided on HPA website	2013/14 influenza season onwards	Not specified	England	Not specified	These data are based on individuals aged ≥18 years from 800 households per season who agree to participate
HPA microbial surveillance	HPA Colindale / RCGP	Not specified	Not specified	England	Not specified	These data are based on samples collected from participating GP Practices
UK Severe Surveillance System	HPA / Department of Health	2011/12 onwards	Weekly	England	NHS hospitals / Trusts	These data are based on lab confirmed samples from hospitalised patients
Influenza hospitalisation data	Health and Social Care Information Centre	1981 onwards	Various, including months	England and Wales	Various, including English Local Authority Districts (LADs)	These data are based on patients hospitalised and diagnosed with influenza
Influenza mortality data	Office for National Statistics (ONS)	1989-90 onwards	Various, including months	England and Wales	Various, including English LADs	These data are based on patients who died and were diagnosed with influenza

5.3.3 Environmental factors

i. meteorological variables

The position of the North Atlantic Jet Stream is operationalised in this thesis using North Atlantic Oscillation (NAO) Indices, which are available as monthly measurements from the National Climatic Data Centre (331) on a daily and monthly basis, from 1950 onwards.

The Met Office is the UK's National Weather Service and provides monthly data for a grid covering the UK at 5 by 5 km resolution for various meteorological variables, most of which are available for the whole of my study period, from 2001-11(332). I obtained the 2012 data via personal communication with the Met Office, as these data were unavailable on the internet. All of the meteorological data are freely available for use in non-commercial research. Gridded data were obtained for three measures of monthly mean air temperature, namely: 1) mean daily maximum temperature, 2) mean daily minimum temperature and 3) mean air temperature. A recent analysis, conducted using data for English Government Office Regions, found that most excess cold-weather-related deaths in England occurred at modestly cold temperatures, of around 4-8^{0}C (270). I therefore decided to obtain data for three climatic measures to compare the strength of association between each of these factors and the outcome measures at LAD level.

Most investigations on cold-weather-related deaths have relied on measures of temperature. In order to explore associations between different climatic factors and circulatory and respiratory mortality rates, I obtained data for the following meteorological variables: number of days of air frost (count of days across the month when the minimum air temperature is below 0°C); sunshine duration (duration of bright sunshine during the month (hours per day)); mean wind speed (hourly mean wind speed (knots) at a height of 10 meters above ground level averaged over the month) and mean relative humidity (hourly (or 3-hourly) relative humidity (%) averaged over the month).

All of the meteorological data were averaged across English LADs (2011 boundaries), using the R statistical software programme (333). The main limitation was the presence of large proportions of missing data within each of the datasets, which could affect the accuracy of monthly values for meteorological variables assigned to LADs.

ii. measures of air pollution

Various sources of air pollution data are available, each with their own limitations. The 2004-10 Indices of Multiple Deprivation (IMD) provide data on individual as well as composite aspects of deprivation, for English LSOAs and regions (334). The IMD contains an 'outdoor

living environment' domain, which includes air quality data, based on estimates of the concentration of four pollutants, modelled across LSOAs. However, the outdoor living environment domain also incorporates data on the number of road traffic accidents in LSOAs. IMD data are also only available for the years 2004, 2007 and 2010 and each dataset includes data that were collected during previous years, which makes it difficult to link these data to other data used in this project on a temporal basis. Also, different data sources were used to calculate IMD domains between years, although the IMD scores from 2004-10 are comparable (334). However, IMD scores for individual domains are also unsuitable for regression analyses, particularly temporal analyses of changes in indicators within areas through time as the IMD data are provided as ranks or scores, neither of which are interval level data. For example, the IMD rank scores are calculated relative to other areas, meaning that changes in IMD rank scores overall and on individual domains within a particular area (e.g. area X) through time may be caused by changes on that domain within other areas (e.g. areas Y and Z). This would change the rank position of area X, even when its actual performance on an indicator of deprivation has not changed between years.

An alternative potential indicator of exposure to air pollution, which is increasingly used in epidemiological studies, are road types (335). UK roads are classified using a letter and numbering system (336). 'A' roads are generally the busier than 'B' roads and are therefore generally associated with the generation of more air pollution (335). Information about A and B density could therefore, provide an indicator of variation in mobile sources of air pollution between areas and through time (335). Road network data are available from the EDINA National Data Centre database (335). However, A and B road density does not necessarily provide an accurate indicator of area level traffic flow and air pollution levels as there is likely to be a high level of variation in traffic flow on the same road types between areas (e.g. B roads in the London area may have greater traffic flow compared to A roads in Northern England).

Road traffic data, which are available from the website of the Department for Transport (337), could be used as an alternative proxy measure of mobile air pollution. These data are available from the year 2000 to present and consist of quarterly and annual reports of road traffic levels for English Local Authorities and Regions. However, these data do not provide information regarding estimated levels of individual air pollutants, which is problematic, due to the differential effects on various health outcomes of individual air pollutants.

Daily historical air pollution data are publicly available for key UK air pollutants at national, regional and local authority levels, dating back to 1961 from the Department for Environment,

Food and Rural Affairs' (DEFRA) UK-AIR Archive data selector tool (338). However, the monitoring stations are sporadically distributed between and within areas. Consequently, the data are not provided for every English local authority.

DEFRA also provide modelled annual mean estimates for several air pollutants across 1 by 1km grid squares of the UK, from the Air Information Resource (338). These data can be modelled over small areas of England (e.g. MSOAs and LADs). $PM_{2.5}$ (particulate matter (PM) with fractions $\leq 2.5\mu m$) data are available for the years 2002-12 and PM_{10} (PM with fractions $\leq 10\mu m$) data are available from 2001-12. Disadvantages of these data include that they are incomplete due to inconsistent monitoring between stations, over time and in relation to different air pollutants.

The sporadic distribution of monitoring stations (e.g. some are situated near roadsides, others in rural locations) of data from DEFRA's Air Information Resource also undermines the representativeness of these data for assessing the level of exposure of populations from each LAD to air pollution. These data are also not provided for the temporal units of interest in this study (months), which means that the seasonal effects of air pollution on cold-weather-related deaths cannot be assessed in the analyses. Finally, the methods used to measure the PM data were changed from 2004, from tapered element oscillating microbalance (TEOM) to gravimetric analysis. Differences have been found between air pollution measurements from the results of co-located TEOM and gravimetric devices. The change in measurement devices used to collect air pollution data during my study period is problematic for comparing the effects of air pollution on cold weather related adverse health outcomes through time. Previously, a factor of 1.3 was applied to all TEOM-measured concentrations to estimate the gravimetric equivalent. However, this was considered un-robust as the factor would vary geographically and throughout time (339). I was advised by researchers from the London School of Hygiene and Tropical Medicine (personal communication), that the 1 by 1 km modelled annual air pollution data were the most suitable for use in this project (340). Although earlier maps (pre-2005) may show lower concentrations of PM than more recent ones (2005 onwards), there is no agreed method to scale them to be comparable. There is an increasing trend for researchers to measure the impacts of air pollution on human health based on smaller particles of air pollution, which are more able to penetrate deeper into the lung tissues. I therefore used the $PM_{2.5}$ data in my analyses.

Also from DEFRA's Air Information Resource, I obtained data for nitrogen dioxide (NO_2), which were available as annual mean values modelled over 1 by 1 km grid squares of the UK from 2001-12. I obtained these data as it is possible that these emissions, which can adversely

impact on the cardiovascular and respiratory systems, have increased since 2001, due to increased reliance on diesel cars.

The characteristics of data that were considered to represent environmental variables from chapter four in statistical analyses are shown in table 5.3, below.

Table 5.3: *Sources of data to represent environmental variables in statistical analyses assessed against five suitability criteria*[†]

Data	Source	Time period	Temporal units	Geographic area	Spatial units	Representativeness
Position of the North Atlantic Jet Stream, North Atlantic Oscillation (NAO) indices	National Climatic Data Centre	1950 -	Daily and monthly	North Atlantic Ocean	N/A	N/A
Meteorological variables	UK Met Office	1910-2012	Daily and monthly values	UK	5x5km gridded datasets which can be modelled to Middle Super Output Area (MSOA) and Local Authority District (LAD) levels	Missing data and sporadically distributed monitors undermines the representativeness of these data to LADs for the study period
Air Pollution	Department for Environment, Food and Rural Affairs	2001-12(for PM_{10} and NO_2) and 2002-12 (for $PM_{2.5}$)	Annual mean values	UK	1x1km gridded datasets which can be modelled to MSOA and LAD levels	Missing data and sporadically distributed monitors undermines the representativeness of these data to LADs for the study period

5.3.4 Biological factors

In chapter four, I suggested biological pathways through which proximate exposures are hypothesized to exert their adverse impacts on the health outcomes of interest.

The Health Survey for England is an annual cross-sectional survey commissioned in the early 1990s by the Department of Health, to monitor the health of the English population (341). The Health Survey for England is now commissioned by the Health and Social Care Information Centre. The Health Survey for England collects data on a range of variables in relation to mental and physical health, objective health and biological measures, demographics, housing and lifestyle factors and socioeconomic circumstances (341). The Health Survey for England has a nationally representative annual sample size of approximately 8,000 individuals from private English households. These data are readily accessible to academics registered with the UK Data Archive (342). The emphasis of the Health Survey for England changes each year, meaning that some of the variables included in the survey change between years.

Biological variables that were included in surveys for some of the years between 2001 and 2012, which could be used to represent some of the biological mediator variables from chapter four, include: fibrinogen (a measure of blood clotting potential), high density lipoprotein and total cholesterol, angina (as a measure of atherosclerosis), systolic and diastolic blood pressure measurements, presence of a cardiovascular disease, presence of diabetes and presence of respiratory problems including lung function and wheezing (the latter as a measure of bronchospasm). Immunoglobulin (an antibody) levels were measured in some Health Survey for England surveys. I considered whether this could be used in my analyses to measure the association between cold weather and immune function (low immune function could increase susceptibility to respiratory infections). However, immunoglobulin is generally used as an indicator of allergies (343), rather than immune function.

The Health Survey for England data are only representative of the English population of private households. Also, the data are collected at individual household level and can be aggregated to regional level, but details about LAD of residence are not included in the survey data. Consequently, the publicly available data cannot be aggregated to LAD level. I excluded Health Survey for England data from my analyses due to the lack of availability or convertibility of these data to LAD level.

I could not find any suitable alternative sources of data for the biological variables that are listed in the previous paragraphs of section 5.3.4, at LAD level. I therefore decided to exclude these variables from the analyses.

Obesity is a biological risk factor for various health problems, including conditions of the cardiovascular and respiratory systems. The most widely used indicator to classify individuals as being underweight, normal weight, overweight or obese is BMI. Obesity is defined as the situation where a person's BMI score is ≥30. BMI provides an indicator of total adiposity (i.e. the amount of fat around the body) (344). However, some evidence suggests that the accumulation of body fat around the waist (central, or abdominal adiposity) presents a greater risk to circulatory health than fat deposition on other parts of the body (344). Guidance from the National Obesity Observatory, Public Health England, specifies that the best evidence to date suggests that measures of general and central adiposity should be used together, in order to best identify individuals at increased risk of obesity-related ill health (344). Waist to hip ratio is a measure of central adiposity. However, most data sources use BMI as the official obesity indicator (344).

Several sources of aggregate data on overweight and obesity are available. The main sources are listed on the website of the National Obesity Observatory (345), which is Public Health England's resource for providing data and information about obesity and its determinants in England. The Health Survey for England measured waist circumference for adults in 1993-4, 1997-8 and 2001-7, and has collected data on participants' height and weight from 1997 onwards (346). These data are available at individual level and can be aggregated to GOR level. In addition, Health Survey for England data from 2006-8 are available at LAD level as a modelled dataset. Limitations of these data include that only one dataset is available, which prevents them from being included in temporal analyses. Also, these data are estimates, modelled from individual level data to MSOA level and aggregated to LAD level (347, 348). Consequently, these data may not be entirely robust.

The Active People Survey is a large annual telephone survey of sport and active recreation, commissioned by Sport England. The survey provides data of how participation in sport and recreation varies geographically and between demographic and socioeconomic groups in England (349). The first wave of the Active People Survey took part in 2005/6. It is representative at LAD level. It also has a large sample size, with 363,724 adults (aged ≥16 years) participating in the Active People Survey in 2005/6 and 157,100 in the 2011/12 survey (350). However, the response rate is around 28%, which is substantially lower than for other large scale surveys (351). The Active People Survey began collecting data on adult weight

and height, from which BMI is calculated, in January 2012 (349). All data from the Active People Survey are self-reported, which could introduce a bias into the results. Self-report data can be inaccurate due to factors including memory lapses, misinterpretation of questions asked, simplification of question responses and modification of answers to make them more socially desirable (352). Self-report bias occurs when certain population groups are more likely to provide inaccurate answers in a given direction. For example, if there is geographical variation in the tendency to overestimate height and underestimate weight, this could undermine the validity of results and subsequent inferences about the association between BMI and mortality rates across LADs. However, BMI data from the Active People Survey are corrected for self-report bias using individual level data for 2006-10 from the Health Survey for England (349), in which the height and weight of participants were measured by interviewers. A disadvantage of the Active People Survey in relation to this study is that their BMI data are only available for one year of my study (2012) and therefore cannot be used to assess changes in obesity prevalence through time in relation to cold-weather-related mortality. However, only one dataset containing adult obesity data are available at LAD level from the Health Survey for England data, which also precludes temporal analysis of these data. I therefore included LAD level BMI data from the Active People Survey in my analysis, which, unlike the Health Survey for England data, are measured at, rather than modelled to, LAD level.

The Active People Survey does not include data on children who are under 16 years of age. I included a measure of child obesity in my analyses, to determine whether this was associated with adverse cold-weather-related adverse health outcomes, especially in relation to respiratory deaths. The National Child Measurement Programme began in 2005/6 and involves the measurement of height and weight in children in reception class (aged 4-5 years) and year 6 (aged 10-11 years) in order to determine obesity prevalence (353). Participation rates for the National Child Measurement Programme are high (1,076,824 children and 93% participation in 2012/13) (354). These data are currently available at LAD level from 2006/7 to 2012/13.

The characteristics of data considered to represent biological variables that were identified in chapter four are shown in table 5.4, below.

Table 5.4: *Sources of data to represent biological variables in statistical analyses†*

Variable	Source	Time period	Temporal units	Geographic area	Spatial units	Representativeness
Fibrinogen levels (a measure of blood viscosity and blood clot formation)	Health Survey for England dataset, Available from the UK data service	2003–04, 2006 and 2009.	Annual	England	Individual level, can be aggregated to regional and national levels	Not representative below Government Office Region (GOR) level
Blood pressure	Health Survey for England dataset, Available from the UK data service	2001-12	Annual	England	Individual level, can be aggregated to regional and national levels	Not representative below GOR level
Wheezing (measure of bronchospasm)	Health Survey for England dataset, Available from the UK data service	2001-2; 2010	Annual	England	Individual level, can be aggregated to regional and national levels	Not representative below GOR level
Lung function	Health Survey for England dataset	2001-2, 2004 and 2010	Annual	England	Individual level, can be aggregated to regional and national levels	Not representative below GOR level

Table 5.4 *(continued)*†

Variable	Source	Time period	Temporal units	Geographic area	Spatial units	Representativeness
Angina (measure of atherosclerosis)	Available from the UK data service	2003-6; 2011	Annual	England	Individual level, can be aggregated to regional and national levels	Not representative below GOR level
Serum LDL and total cholesterol	Health Survey for England dataset	2003–04, 2006, 2008-12	Annual	England	Individual level, can be aggregated to regional and national levels	Not representative below GOR level
Adult obesity prevalence (BMI) (%)	PHE Local Health webs	Active People Survey 2012	Annual	England	MSOA and LAD	The data are weighted to be representative of the population of individuals aged 16+ in each LAD
Waist circumference	Health Survey for England , accessed through the UK data archive	2001-7	Annual	England	GOR level	
Child (reception and year 6) obesity prevalence (%)	Public Health England's Local Health website, source: the National Child Measurement Programme	One dataset, Oct 2010 - 13	Annual	England	MSOA and LAD	These data are representative of children in reception class (aged 4-5 years) and year 6 (aged 10-11 years) only

5.3.5 Vulnerability factors

There is no strong evidence to suggest that gender and ethnicity are associated with an increased risk of cold-weather-related deaths (59). However, most EWM occurs amongst elderly people (355). Ideally, causal pathways for cold-weather-related deaths would be tested in specific age groups, as this could provide information to enable interventions to be developed and targeted most effectively to reduce these deaths. The availability of age-specific mortality data would also allow me to control for differences in age profile between LADs and within LADs through time in the analyses, which are likely to influence spatial and temporal variations in mortality rates, using standardisation techniques. However, as indicated in section 5.2., I was unable to obtain mortality data broken down by age group.

In order to identify associations between population age profile and spatial and temporal variations in cold-related mortality, I therefore included a variable measuring the proportion of older persons (individuals aged ≥65 years, considered as the most vulnerable age group for cold-weather-related mortality, the outcome of interest in the analyses, compared to younger persons) in each LAD for each year from 2001-12. I created this variable using population data from the 2001 and 2011 censuses and 2002-10 and 2012 mid-year population estimates (356). The data from 2001 and 2011 I derived from the censuses, based on questions about the ages of the inhabitants of members of each household. On consecutive years, in between censuses, the number of individuals in one year age bands are calculated by adding one year to the age of each individual from the previous year (each year runs from 1 July to 30 June the next year), therefore three year olds become four year olds etc., adding births and removing deaths occurring during the year and allowing for migration to and from each area using proxy data (357).

UK censuses are social surveys of the entire population of the UK which have been carried out every ten years since 1801, except for 1941 due to World War II (358). They provide information regarding demographic and socioeconomic characteristics of the population, which are used for a variety of purposes, including academic research. Data from UK censuses are released at different levels of aggregation (359). As it is a legal requirement to complete the UK Census every ten years, participation rate is high at individual level (person response rate was 94% for England and Wales in 2001 and 2011) and within local authorities (range of response rate by local authority was 64-99% from the 2001 census and 82-98% from the 2011 census) (360).

The characteristics of data that were used to represent variation in age (n ≥65 years) between LADs and years in the analyses are shown in table 5.5, below.

Table 5.5: *Sources of data to represent variation in age (proportion of the population aged ≥65 years) in statistical analyses†*

Variable	Source	Time period	Temporal units	Geographic area	Spatial units	Representativeness
Proportion of the population of each Local Authority District (LAD) aged ≥65 years	Office for National Statistics Census and mid-year population age structure estimates	2001-12	Years	England	Middle Super Output Areas aggregated to LADs	Range of response rates by local authority was 64-99% from the 2001 census and 82-98% from the 2011 census

5.3.6. *Socioeconomic factors*

Socioeconomic deprivation is a multi-faceted concept and not easily defined. Health and social researchers use various composite and individual measures of socioeconomic deprivation. Associations between socioeconomic deprivation and health outcomes are generally complex, moderated and mediated by various factors. The results of the systematic literature review of epidemiology studies, presented in chapter two of this thesis, indicates that there are inconsistent associations between measures of socioeconomic deprivation and cold-weather-related adverse health outcomes. The most consistent associations were found between two individual measures of socioeconomic deprivation, namely low income and household crowding, and adverse health outcomes in relation to cold weather and winter season.

The UK Census data contains an occupancy variable, which is a measure of overcrowded and under-occupied households in England and Wales. There are two measures of household occupancy, based on the number of (i) rooms and (ii) bedrooms, in relation to inhabitants. Household occupancy is calculated as the number of rooms and bedrooms which are required in a household, based on the number, age and relationships between its inhabitants, subtracted from the number of rooms/bedrooms available in the household accommodation. An occupancy rating of -1 indicates that a household has one fewer room/bedroom than needed, whilst an occupancy rating of +1 implies that the household has one more extra room/bedroom than required (361).

The measure of occupancy that is based on the number of bedrooms is only available from the 2011 Census. This is because it was developed after the 2003 publication of The Housing (Overcrowding) Bill, which defined situations where a separate bedroom is required for inhabitants based on their age, sex and relationship (361). The household occupancy measure that is based on the number of rooms in relation to inhabitants of a household is available at LAD level from the ONS, based on data from the 2011 Census (361). These data are unavailable at LAD level from the 2001 Census. I obtained the 2001 occupancy data at MSOA level from the UK data service's INFUSE website (362) and aggregated these data to LAD level. However, there were missing data for LADs from the 2001 data, which meant that I was unable to include these data in the analyses because the statistical programme will not analyse data with missing values. Consequently, I used only the 2011 Census data in the analyses.

Questions regarding household income are not included in UK Census questionnaires, due to their unpopularity, which is likely to undermine response rates and validity (363). The UK Census contains a question on economic activity, but this is not necessarily an accurate indicator of household income, for reasons including that it does not take into account income received through welfare support, nor provide information about savings derived from being economically active.

The English Indices of Multiple Deprivation (IMD) are an alternative source of aggregate data on household income. These were developed in 2000 at Oxford University's Social Disadvantage Research Centre (334). IMD data are calculated using small area level administrative data sources and the purpose of these data are to rank small geographical areas across England, from most deprived to least deprived on different dimensions of deprivation and a composite measure of multiple deprivation (364). The IMD includes an 'income deprivation' domain, which measures the proportion of the population of English Lower Super Output Areas (LSOAs) that live in income deprived families, calculated by adding the proportion of each area which is in receipt of various social welfare allowances (364). IMD income deprivation data are available for the years 2000, 2004, 2007 and 2010. However, there are various problems associated with using IMD data to assess the potential impacts of aspects of deprivation, including income deprivation, on health in temporal regression analyses. Firstly, different methodologies were used to calculate deprivation indices between years. There were no changes to the Income Deprivation domain between 2007 and 2010. Changes to the social welfare system between 2004 and 2007, including the introduction of Pension Credit, Working Tax Credit and Child Tax Credit, caused significant changes to the indicators included in the 2004 and 2007 Income Deprivation domain (334). However, the research team that created the IMD aimed to maximise comparability between 2004 and later years and IMD 2004 - 2010 scores broadly comparable (364). Significantly different methods were used to calculate IMD 2000, which contains fewer domains compared to later IMDs and changed indicators within domains, which include changes to the Income Deprivation domain. Also, IMD-2000 data were released at ward, as opposed to LSOA level, unlike later IMDs (364).

IMD data are also arguably unsuitable for use in temporal regression analyses, which measure changes in deprivation between years as they provide rank scores that measure aspects of deprivation relative to other areas (364). Consequently, a change in rank score of one area may reflect that income deprivation has changed in other areas. This can alter the rank position of areas for which the proportion of income deprived households has remained the

same over time. In addition, IMD guidance indicates that changes in IMD income data between years may reflect changes in population estimates over time rather than indicating real changes in deprivation (364). Income deprivation scores, as opposed to ranks, are also available from the IMD. Index of Multiple Deprivation scores represent the actual number of deprived people in an area, meaning that they can potentially be used to measure absolute change in deprivation within areas through time (364). However, IMD guidance advises against using IMD scores in regression analyses as they are not true interval level data – they have been transformed to an exponential distribution to allow better identification of the most deprived areas (364).

IMD data are available at ward level for IMD-2000, at LSOA and regional levels for IMDs 2004-10 and at MSOA and LAD levels for 2010 (calculated using population weighted averages from the LSOA data) (364). The MSOA and LAD data are unavailable for earlier years.

Based on the limitations of including the IMD data in temporal analyses, I used only the LAD level IMD-2010 data in my analysis. The data that I obtained were from the website of the Department of Communities and Local Government and provided number of income deprived people per LAD (334). I used these and population data from the ONS to create a variable that measured proportion of income deprived people per LAD in 2010.

The characteristics of the data considered to represent socioeconomic variables in the statistical analyses are summarised in table 5.6, below.

Table 5.6: Sources of data to represent socioeconomic variables in statistical analyses†

Data	Source	Time period	Temporal units	Geographic area	Spatial units	Representativeness
Household crowding	UK Data Service, INFUSE Census Support	2001 and 2011	Decennial	England	2001 data available at MSOA level, which can be aggregated to LAD level; 2011 data are available for LADs in England and Wales	The most representative data source in England for this variable as all UK households are legally required to complete and return their Census questionnaire; however, non-response rate for the 2001 and 2011 Censuses were estimated to be 2% and 4%, respectively. The 2011 data for this variable are currently unavailable at MSOA level.
Income deprivation	Indices of Multiple Deprivation	2000, 2004, 2007 and 2010	Approximately triennial	England	2010 data are available at MSOA and LAD level	The Department of Work and Pensions data used to calculate population income have 100% coverage

5.3.7.   *Housing-related factors*

Housing-related factors discussed in chapter four are: rural/urban location, fuel poverty and household occupancy, tenure and thermal efficiency.

Following the 2001 and 2011 Censuses, the UK Department for Communities and Local Government characterised small areas of the UK as being urban or rural using two ordinal classification systems. The first system classifies areas as being rural if the population of the area its wider surroundings is <10,000 people. Areas are classified as being urban if their population and the population of their wider surroundings is ≥10,000. The second classification system categorizes areas based on the proportions of residents living in different types of physical settlements (i.e. town, village and urban fringe), and also in relation to the population density of each area and its surroundings. The assignment of areas as rural or urban occurs at output area level. Super Output Areas are allocated rural or urban status in reference to the status to which the majority of their constituent output areas are assigned (365).

LADs were classified in relation to their rural-urban status in 2001, 2009 and 2011 (Rural-Urban Classification for LADs (RUCLAD) 2001, 2009 and 2011) (365). LADs are generally larger in relation to their geography and population sizes, compared to super output areas and output areas. Consequently, many LADs incorporate urban and rural areas and due to population growth, urbanisation, house building and infrastructure development, there is a strong tendency to find a preponderance of urban residents in most LADs. In order to reflect this, the 2011 Rural-Urban classification system categorizes LADs on a scale from one to six in relation to the percentage of the total resident population living within rural areas, urban areas and areas with rural and urban interdependence (365). The RUCLAD 2001, 2009 and 2011 systems are broadly comparable, however there are some differences between the methods used to classify areas in 2011 compared to earlier years, which underlie changed assignments in some areas. The RUCLAD 2011 data are available on-line, from the Department for Energy, Food and Rural Affairs' website. These data apply to the 2011 LAD classification, which most other data in this project relate to. The 2001 and 2009 RUCLAD relate to previous LAD boundaries which are unavailable on-line. I therefore decided to use data from the RUCLAD 2011 in my analyses.

I also included a second variable, namely 'population density', defined as the population count of each LAD per square km, to measure urban-rural dwelling. This was created using annual data (from 2001-12) on the population count of each MSOA (2011 boundaries) (the numerator), from census and mid-year population data (see section 5.3.5 for details). I

aggregated these data across LADs and divided by the number of square kilometres of each LAD (denominator), which were calculated using standard area measurement data from the ONS Geography Portal (366). Unlike the RUCLAD 2011 data, population density could be measured for each year of interest in this research, from 2001-12, which enabled the temporal association with cold-related mortality and other explanatory variables to be measured. Also, although not interval level data, population density values enabled increased potential for modelling associations with other variables, compared to the ordinal RUCLAD 2011 data.

Fuel poverty data are available from the website of the Department of Energy and Climate Change (DECC) (367). However, annual fuel poverty prevalence data which are calculated using the new definition of fuel poverty are currently only available at sub-regional levels for the years 2011 and 2012.

Sub-regional fuel poverty data are modelled estimates, using data on household composition, characteristics and self-reported household income, from the English Housing Survey and energy price data from sources including the DECC and the ONS and Sutherland tables (367). These data are available at LSOA and LAD level. The LAD data have been found to be robust, therefore accurate estimates of fuel poverty prevalence, although the data have been found to provide unreliable estimates at LSOA level. Despite LAD data based on the new definition of fuel poverty only being available for two years during my study period, I used these data as opposed to the data based on the old fuel poverty definition, which are available for more years. This was in order to ensure that the results of my research will be relevant to current and future English policies, which use the new definition of fuel poverty.

Low household thermal efficiency has been identified as a risk factor for fuel poverty and is associated with cold-weather-related adverse health outcomes. Household thermal efficiency is officially assessed in the UK using Standard Assessment Procedure (SAP) criteria, which were developed by the Building Research Establishment in 1992, in order to support the development of energy policies (368). The English Housing Survey is a national survey of people's housing circumstances, housing condition and thermal efficiency, commissioned by the Department for Communities and Local Government, which has taken place annually since 2008 (369). The English Housing Survey has two components, an interview survey of approximately 13,300 households and a physical inspection of a sub-sample of around 6,200 of these properties, which is conducted by a qualified surveyor (369). Data from the English Housing Survey are nationally representative and are available at national, regional and LSOA levels. From 1991-2008, the English Housing Condition Survey collected SAP data, for the years 1991, 1996, 2001 and annually from 2003 (369); consequently, these data are

available for most years of this study. SAP data are available on the UK Data Archive website, from the English Housing Condition Survey/English Housing Survey biennially for the years from 2001-12 at LSOA level. However, these data are only available through a secure access system and I would have been required to obtain permission to import data for each of my other datasets into the system and to perform data linkage and analyses within the system. SAP data are used in the calculation of sub-regional fuel poverty statistics from the DECC. I therefore decided to exclude the SAP due to the impracticability of including these data and in order to avoid mathematical coupling by including the same variable twice in my analyses. Also, different methodologies were developed to calculate SAP ratings in 2001, 2004 and 2009 and although the data are broadly comparable over time, I considered this to be a further justification for excluding SAP data from my analyses.

Cold housing is associated with cold-weather-related excess adverse health outcomes. Data on indoor temperatures and indoor energy behaviour are unavailable for the study period (2001-12). The English Housing Condition Survey collected hall temperature data during physical property inspections up until the mid-1990s but this question was removed in 1996, as it was not considered to provide a good indication of general indoor temperatures. Research studies have generally used external temperature data and thermal efficiency ratings, assessed using the Department of Energy and Climate Change's Standard Assessment Procedure (SAP) to approximate indoor temperatures, but homes can be insufficiently warm for health and wellbeing even when outdoor temperatures are mild. As part of the 2011-12 English Housing Survey there was an Energy follow-up survey which monitored indoor temperatures and electricity use in 1000 households. However, these data are unavailable below regional level (370).

Research suggests that privately rented households have increased risk of fuel poverty and cold-weather-related adverse health outcomes, which is likely to be attributable to less stringent building regulations for private compared to social housing landlords (371). I obtained data on the percentage of privately rented households per LAD from the ONS. These data came from the 2001 and 2011 Censuses. The 2001 data were based on the 2001 LAD boundaries. The ONS does not provide geographical lookup tool to match data between LAD 2001 and 2011 boundaries. Consequently, it was not possible to assign a value for the percentage of privately rented households for six LADs areas for 2011 in the linked dataset. I could not analyse the data from 2001, as the statistical programme used for the analyses requires complete data. I therefore, used only data for this variable from the 2011 Census.

The characteristics of housing variables from section 5.3.7 are summarised in table 5.7.

Table 5.7: _Sources of data to represent housing variables in statistical analyses_†

Data	Source	Time period	Temporal units	Geographic area	Spatial units	Representativeness
Rural and urban dwelling	Office for National Statistics (ONS) website	2011	Decennial	England	Local Authority Districts (LADs)	Yes
Population count (used to measure population density)	ONS website	2001-12	Annual	England	Middle Super Output Areas (MSOAs), aggregated to Local Authority District (LAD) level	Yes
Thermal efficiency performance (SAP) scores	UK Data Service, 2001-7 English Housing Condition Survey; 2008-11 English Housing Survey	2001-12	Biennial (2001-3), annual from 2003 onwards	England	National data are readily available on-line; regional data are available through the UK Data Service website. Lower Super Output Area (LSOA) data are available via secure access, these data can be aggregate to LAD level	
Fuel Poverty prevalence (High Cost, Low Income measure)	Department for Energy and Climate Change (DECC) website	2003-12* 2011 and 2012**	Annual	England	*Regional **LAD and LSOA level data (LSOA data un-robust)	LAD modelled estimates have been found to be robust
Fuel Poverty prevalence (10% measure)	DECC website	2006, 2008-11, 2012	Annual	England	LAD	

Table 5.7 *(continued)* †

Data	Source	Time period	Temporal units	Geographic area	Spatial units	Representativeness
Household occupancy (no. rooms) and tenure	UK Data Service, INFUSE Census Support	2001 and 2011	Decennial	England	2001 data available at MSOA level, which can be aggregated to LAD level; 2011 data are available at LAD level	The most representative data source in England for this variable as all UK households are legally required to complete and return their Census questionnaire; however, non-response rate for the 2001 and 2011 Censuses were estimated to be 2% and 4%, respectively. Also, the 2011 data for this variable are currently unavailable at MSOA level.

5.3.8.   *Lifestyle-related factors*

i.   *Physical activity*

Moderate intensity physical activity has been associated with increased thermo-genesis and reduced blood pressure, which reduces cardiac risk. In order to assess the potential impact of physical activity on cold-weather-related health outcomes, I used data from Sport England's Active People Survey, which is described in section 5.3.4. The dataset that I used measured participation in 30 minutes of moderate intensity physical activity at least once per week in the 28 days prior to being surveyed. These data were collected during the years 2005-6 and 2007-8 to 2012-13.

As discussed in section 5.3.4., a general weakness of data collected from lifestyle surveys, potentially including the Active People Survey, is the potential for bias. It has been suggested that tendency to exaggerate participation in physical activity has increased over recent years, due to increased media coverage of diet and fitness issues over this time period (372). This potentially false upward trend in physical activity levels over time could affect the results and subsequent interpretation of analyses of temporal variations in physical activity levels in relation to cold-weather-related mortality rates. A systematic review of the literature reported no clear trends in disparities between objective and subjective measures of physical activity and no clear differences between population groups (373).

ii.   *Saturated fat intake*

High intake of saturated fat is associated with high blood levels of low density lipoprotein cholesterol, which is a risk factor for cardiac events. Data on saturated fat intake data are available from various sources, as follows. The National Diet and Nutrition Survey is a national survey of the dietary habits and nutritional status of individuals in private households across the UK population, which was initially started in 1992 and included four cross-sectional surveys (374). In 2008, a new annual survey was initiated that collects data from a cross-sectional target population of 1000 individuals each year, half of whom are adults and half are children. Data on self-reported (food diary based) saturated fat intake are available, collected from a stratified random sample of the population. The combined survey response rate for the first two years of collection of the new continuous National Diet and Nutrition Survey (2008-9 and 2009-10) was 55% (374). Results are nationally representative and are available at national and regional levels from 2008. However, the data are unavailable at LAD level or for lower geographic units.

Additional sources of data on saturated fat intake are available also from the Expenditure and Food Survey (up to 2007) and from the Living Costs and Food Survey (from 2008 onwards), from the Health and Social Care Information Centre and the UK Data Archive (375). Up to 2007, the data are available at post code and ward levels, but they are only available at regional levels from 2008 onwards. The Expenditure and Food Survey is an annual survey of spending and living costs that has been conducted in the UK since 2001 by the ONS, and includes an annual sample of around 6,000 people (375). In 2008, it became known as the Living Costs and Food Survey and was incorporated into the Integrated Household Survey, which is an amalgamation of ONS household surveys which collects data from over 400,000 respondents (376). Data on household saturated fat intake are available from this data source from the Health and Social Care Information Centre, at national and regional levels from 2001 to 2013 (375). However, these data are only collected from private households, and crucially, the data are unavailable at LAD level or for lower geographic units, which make these data inappropriate for inclusion in my analyses.

The Low Income Diet and Nutrition Survey was commissioned by the Food Standards Agency (377). It provides nationally representative data in relation to the diet and nutritional status of the population from low income households. This survey is based on a sample of 3728 adults and children (aged 4 and above) from 2477 households across the UK who were surveyed between November 2003 and January 2005 (378). However, these data are not provided at geographical small area levels.

Saturated fat intake is associated with adverse circulatory health outcomes via cholesterol and with circulatory and respiratory adverse health outcomes via obesity, which is a cardiac risk factor and is associated with reduced lung function. Obesity data have been identified to include in the model (see section 5.3.4), therefore I decided not to include data separately on saturated fat intake.

iii.   Smoking

The General Lifestyle Survey (known as the General Household Survey pre 2006), was a multi-purpose inter-departmental survey carried out by the Office for National Statistics and collected information on a range of topics from private households in Great Britain until its discontinuation in January 2012 (379). Smoking questions were included in the survey every year since 2000 and were answered by 13,488 individuals in 2009. Smoking data from these sources are available from Public Health England at national and regional levels only.

The Integrated Household Survey provides the biggest source of social data after the UK Census, in relation to its number of respondents (376). Robust smoking data are available at

regional and local authority levels, albeit with wide confidence intervals, but not at MSOA level. These are surveyed, rather than modelled data, unlike data from the Health Survey for England, and are used by Public Health England to assess smoking prevalence across small geographic areas (LADs) of England. The survey commenced in 2009 and data for earlier years are therefore unavailable. Public Health England use data from the Health Survey for England to provide smoking estimates for earlier years (380). These smoking data are available as modelled estimates at MSOA level for the 2006-8. However, these data are modelled estimates. I used the integrated household survey data due to their availability at LAD level and because these are surveyed data.

The characteristics of the lifestyle data discussed in section 5.3.8 are summarised in table 5.8, below.

Table 5.8: *Sources of data to represent lifestyle-related variables from chapter four in statistical analyses†*

Data	Source	Time period	Temporal units	Geographical coverage	Spatial units	Representativeness
Saturated fat intake	The National Diet and Nutrition Survey	1992-1993 (survey covered 1.5-4.5 year olds) 1997 (survey covered 4-18 year olds) 1994-6 (survey covered ≥65 year olds) 2000-2001 (survey covered 19-64 year olds) 2008 onwards (adults and children)	Four cross-sectional surveys conducted between 1992 and 2001; annual surveys conducted from 2008 onwards	National (UK); the data are available for English regions	National and regional levels	Representative at national (UK) but not smaller area levels

Table 5.8 (continued) †

Data	Source	Time period	Temporal units	Geographical coverage	Spatial units	Representativeness
Saturated fat intake	Expenditure and Food Survey (up to 2007) and from the Living Costs and Food Survey (from 2008 onwards)	2001 onwards	Annual	National (UK); the data are available for English regions	National and regional levels	These data are only collected from private households
	The Low Income Diet and Nutrition Survey	2003-5 (one dataset)	One-off survey	National (UK); the data are available for English regions	National and regional levels	These data are representative at national, but not smaller area levels
Adult smoking prevalence (%)	Integrated Household Survey (IHS)	IHS 2009 onwards	Annual	England	LAD	Representative of the UK population
	Health Survey for England	2003-5 (un-available) 2006-8	One available dataset which is modelled to small area (MSOA) level	England	MSOA	
Physical activity	Active people survey	Data are available for 2005-6 and 2007-8 to 2012-13	Annual	England	LAD	Response rate is low

5.3.9   *Medical access data*

During the analyses presented in chapter eight, I observed counterintuitive findings of strong, inverse associations between measures of air pollution and mortality. In relation to the discussion in chapter four (section 4.4.6), it is possible that closer proximity to hospitals in urban compared to rural areas contribute to reduced winter- and cold-related mortality rates in areas with high population density. Urban areas also generate higher levels of air pollution compared to rural areas. Consequently, increased medical access could confound the inverse association between air pollution levels and mortality rates. In order to test this hypothesis, I created variables to measure medical access to include in the analyses. I obtained spreadsheets containing the names and addresses of organisations that provide (i) cardiology services, (ii) respiratory medicine and (iii) Accident and Emergency departments in England, via personal communication with staff from NHS Choices (381). These data were only available for the year when I applied, namely 2015. I used these data to calculate variables that measured the number of organisations providing each type of medical facility per square km of each LAD using Standard Area Measurement data from the ONS (366). The characteristics of the medical access data are presented in table 5.9, below.

Table 5.9: *Sources of data to represent medical access variables in statistical analyses†*

Data	Source	Time period	Temporal units	Geographic area	Spatial units	Representativeness
Names and addresses of organisations providing: (i) Cardiology services (ii) Respiratory medicine (iii) A&E departments	NHS Choices; sourced from the Organisation Data Service, which is part of the Health & Social Care Information Centre.	2015	N/A	England	Postcodes, can be aggregated to calculate numbers per local authority district	These datasets contain details of all organisations in England (in 2015) providing each medical service

5.4 Summary

In this chapter, I have presented the problems I encountered in obtaining data for the variables identified in chapter four and required for the analyses (chapter eight). Difficulties obtaining data were due to limitations in data availability at various levels of spatial and temporal aggregation and significant changes to the release of data for research purposes also impacted on the availability of data on influenza and hospitalisations. The inability of various systems to provide access to data for research on important health and social problems, including cold-weather-related morbidities and mortality, undermines the ability to conduct robust research to investigate the aetiology of these issues. This undermines the capabilities of health and social commissioners and providers to develop effective interventions and to target these where they will be most effective.

It is essential to identify the limitations of each data source selected. The available outcome data do not include a measure of morbidity and are not disaggregated by age and sex. Consequently, I am unable to compare factors associated with spatial and temporal variations in excess morbidities and mortality, and between demographic groups. These analyses may have provided information to develop and direct interventions more effectively.

The main limitations of the covariate data were their general lack of availability at the temporal units of interest (months). As a consequence, I will need to assign annual data to constituent months in my analyses and will be unable to model the seasonal effects of most of the data. The meteorological and air pollution data that I obtained also contain a large proportion of missing values reducing the validity of modelled estimates of these data across LADs and time points and potentially, the results of associations between explanatory and outcome variables in the analyses. None of this is unique to my study and is a generic problem for modelling complex phenomena. It is therefore crucial that the outputs are interpreted with these caveats in mind and the implications of this are picked up in the discussion (chapter nine).

In chapter six, I describe the procedures used to format and link the data identified in chapter five in order to prepare for the statistical analyses.

Chapter Six.

Methods (ii): Linking data from routine sources

6.1 Introduction

This second methods chapter describes the procedures that I used to format and link the data identified from chapter five, which represent variables identified in chapter four.

6.2 Creating a spreadsheet for data linkage

I created linked datasets containing LAD level data for the variables identified in chapter four as comma-separated value (CSV) files in Microsoft Excel (382). Microsoft Excel was used as this software includes functions to sort, link and format data. I chose to use CSV files to produce and store the linked datasets because most of the data used in this project were available in that format.

As a basis for data linkage, I created a spreadsheet containing columns to identify the spatial and temporal identifiers of interest in this research, namely Government Office Region (GORs, boundary codes used were from 1999 onwards) and Local Authority District 2011 (LAD11) names and codes, year and month of observation. Although I performed all analyses at LAD level, the inclusion of GOR codes enabled me to identify regional variations in explanatory and outcome variables from the datasets. This allowed me to conceptualise the processes by which some of the exposures were associated with spatial variations in mortality rates across LADs, which I attributed to processes that could be generalised to regional level (e.g. in relation to the association between measures of air pollution and mortality in predominantly urban regions, see chapter eight).

In addition, although months were the temporal unit of interest in the analyses, I included a column to identify the year of observation in order to include data that were only collected annually or for specific years. The values of data collected for specific years, which were either calendar years, academic years or financial years, were assigned to constituent months. This does not allow the assessment of the associations between exposure and outcome variables across the year, but reflects the limited availability of some of the data.

I produced the spreadsheet for data linkage using a GOR to LAD conversion tool from the ONS (383). I transformed the file so that the GOR and LAD codes and names were repeated

for the temporal units of interest this study (months 1-12 (January – December) from 2001 to 2012). This was performed in R Studio (384). I also created a column containing month identifiers in the format 1-144, to enable linkage of variables with months listed in this format.

A screen shot of the top of this file is shown in appendix C. After creating the file, I was able to link explanatory and outcome variables, consisting of data that were referenced in space (LAD 2011) and time (months 1-12, years from 2001-12; or months from 1-144).

6.3 Formatting and linking the data

6.3.1 Mortality data

A summary of the method that I used to format the ONS mortality data and link these with other variables is provided below. Technical details are presented in table 6.1.

The mortality dataset I received from the ONS is described in chapter five (section 5.3.1) and can be viewed online (385). These data were aggregated from MSOA level, which I was originally going to use as the spatial areas of analysis, to LAD level, using a geographic MSOA2001 to LAD11 conversion tool from the ONS (383). I formatted the data to include columns for: LAD11, year of observation, month of observation, circulatory mortality counts and respiratory mortality counts. The mortality count data could then be linked to the spreadsheet described in section 6.2, by LAD11 area, year and month of observation. All formatting and linkage of the mortality data was performed in R Studio.

Table 6.1: *Summary of the formatting and linking of mortality data*

Data	Format received	Transformation performed	Data for the model	Temporal linkage	Spatial linkage	Variable name(s)
Mortality counts for all-causes, circulatory and respiratory conditions by MSOA and month, from 2001-12	CSV file with the following columns: Region, MSOA01, Cause, Month, 2001, 2002, 2003…etc.	Rows 1-13 of the ONS mortality count dataset, which contained descriptive information about the data, were deleted. 'Stack' command used to stack multiple year columns into one column. 'Unstack' command used to create a separate column containing mortality counts for each cause of death (condition group). LAD11 area codes linked with MSOA2001 area codes in the ONS mortality count dataset, using ONS geographic conversion tool and 'v lookup' command in Microsoft Excel. The data were aggregated from MSOA to LAD level for each year and month using the 'aggregate' command in R Studio.	CSV file with the following columns: Region code, Region name, LAD11code, LAD11 name, Year, Month, all cause death counts, circulatory death counts, respiratory death counts	Linked to other LAD11 data by year (2001-12) and month (1-12)	Linked to other data by LAD11 code	Circ_count Resp_count

6.3.2 Environmental data

A summary of the method that I used to format the data for environmental variables and link these with other variables is provided below. Technical details are shown in table 6.2.

I downloaded North Atlantic Oscillation (NAO) Indices from the National Oceanic and Atmospheric Administration website (386), in ASCII file format. The file contained NAO index values for each month and year of interest in this study. I copied these data into a CSV file to facilitate linkage with other data. There is evidence that the NAO is linked to the frequency of weather types in Northern England on a monthly and annual time scale (267). However, I anticipated that there may be a time lag between NAO index values, meteorological parameters and mortality, so I created a lead variable to explore the association between NAO indices from the previous month with mortality. The NAO data were linked to the dataset described in section 6.2, by month and year of observation. NAO indices are not measured over different areas of England. Consequently, this is not a spatial variable and the same values were applied to all LADs for each month of this study (January 2001 – December 2012).

The weather variables used in the analyses are described in chapter five (section 5.3.3). I obtained monthly values for each variable in text files for the whole study period (2001-12). Each file contained average values for the data for each variable in 5 by 5 km grid squares. In R Studio, I used a graphical overlay tool to produce average monthly values for each weather variable for 2011 LADs, and I exported the data as CSV files in Microsoft Excel. Each spreadsheet, one for each weather variable, was linked to the spreadsheet described in section 6.2 by LAD11 code and month of observation (from 1-144).

I obtained the data for annual mean modelled levels of $PM_{2.5}$ and NO_2 from DEFRA's UK-AIR website (338). These data were available as CSV files, one for each year from 2001-12 (for NO_2) and 2002-12 (for $PM_{2.5}$), and contained values for air pollution concentrations averaged over 1 km by 1km grid squares, with corresponding spatial coordinates. In R Studio, I used a graphical overlay tool to produce average annual values for air pollution concentrations for each LAD11. I collated the data from each year into one file and linked these data to the spreadsheet described in section 6.2 by LAD11 code and year.

Table 6.2: Summary of the formatting and linking of environmental data

Data	Format received	Transformation performed	Data for the model	Temporal linkage	Spatial linkage	Variable name(s)
Monthly mean NAO indices January 2001-December 2012	ASCII format with columns for year, month and NAO index value (no column headers)	The data from Jan. 2001 – Dec.2012 were copied into Excel; a lead (month (t) -1) variable was created; column headers were created.	CSV file with the following columns: Year, Month, NAO index, NAOt-1	Linked to other data by year (2001-12) and month (1-12)	Not applicable	NAO NAOt-1
Annual mean modelled levels of $PM_{2.5}$ and NO_2 across 1 x 1 km grid squares of the UK, from 2001/2-12	CSV files, one per year of data from 2001-12 for NO_2 and 2002-12 for $PM_{2.5}$, each with columns for spatial coordinates and associated values of $PM_{2.5}$ or NO_2	The data were averaged over English LADs (2011 boundaries); data for each year and pollutant were collated into one file with data from 2001-12 (for NO_2) and 2002-12 (for $PM_{2.5}$)	CSV file with the following columns: LADs 2011, Year, air pollutant ($PM_{2.5}$ or NO_2)	Linked to other LAD data by year (2001/2-12)	Linked to other LAD data by LAD code (2011)	NO_2 $PM_{2.5}$

Data	Format received	Transformation performed	Data for the model	Temporal linkage	Spatial linkage	Variable name(s)
Mean minimum daily temperature (^{0}C) per month for 5 x 5 km grid squares Mean air temperature (^{0}C) per month for 5 x 5 km grid squares Mean maximum daily temperature (^{0}C) per month for 5 x 5 km grid squares Days of air frost - count of days when the air minimum temperature is below 0°C Sunshine duration - duration of bright sunshine during the month (hours per day) Mean wind speed at 10m - Hourly mean wind speed (knots) at a height of 10m above ground level averaged over the month Mean relative humidity - Hourly (or 3-hourly) relative humidity (%) averaged over the month	text file format, no defined columns	The data were averaged over English LADs (2011 boundaries) and stacked by year; column headers were created.	CSV file with the following columns: LAD11, Year, Month, Mint, Mea, Max, Fro, Sun, Win, Hum	Linked to other LADs data by month (1-144)	Linked to other LAD data by LAD code (2011)	Min Mea Max Fro Sun Win Hum

6.3.3 Population data

A summary of the method that I used to format the population data and link these with other variables is provided below. Technical details are shown in table 6.3.

I downloaded annual mid-year population counts by one-year age group for English MSOAs (2011 boundaries) from the ONS website (387). One file contained the data from 2002-11 and two individual files contained the data from 2001 and 2012 as CSV files. I summed the number of people aged ≥65 years for each area, each year. I then produced a file containing MSOA area code, total population count and number of people aged ≥65 years. I divided the number of persons aged ≥65 years per year and MSOA (the numerator) by the total population count for the same year and area (the denominator) and multiplied the result by 100 to create a variable which measured the proportion of older people in each population. I retained the variable containing total population size for each area, as this information was used to calculate the expected number of deaths for the analyses. I aggregated the data to LAD11 using an MSOA to LAD11 lookup tool in R Studio. I linked the population data to the spreadsheet described in section 6.2 by LAD11 code and year.

As discussed earlier, there is a lack of consistent evidence that gender impacts on vulnerability to cold-weather-related mortality from circulatory and respiratory conditions. Consequently, data for the proportions of males and females in each LAD11 were not obtained.

I obtained Standard Area Measurements for Local Authority Districts (area of the realm in hectares) from the ONS geography portal (383). I calculated the area size of each LAD in square kilometres by dividing the number of hectares in each LAD by 100. I then calculated the population density by dividing the annual population count of each LAD by the number of square km in each LAD. I linked these data to the spreadsheet described in section 6.2, by LAD11 code and year.

Table 6.3: *Summary of the formatting and linking of population data*

Data	Format received	Transformation performed	Data for the model	Temporal linkage	Spatial linkage	Variable name(s)
Census and mid-year population estimates, from 2001-12	Excel format, one file per year of data, each containing columns with following columns: MSOA code, MSOA name, Population count (all ages), Population count (age / age group)	Population counts for persons of all ages and for persons aged ≥65 years per MSOA were calculated for each year. The data for each year were collated into a single file. The data were aggregated to LAD level using the 'aggregate' command in R Studio. Data for the number of people aged ≥65 years (numerator) per year were divided by total LAD population per year (denominator) and the answer multiplied by 100 to calculate proportion of LAD population aged ≥65 years for each year from 2001-12	CSV file with the following columns: LAD11CD, Year, Month, Population size (all ages), Proportion of the population aged ≥65 years	Linked to other LAD data by year (2001-12)	Linked to other LAD data by LAD code (2011)	All ages, Age ≥65 years%

Data	Format received	Transformation performed	Data for the model	Temporal linkage	Spatial linkage	Variable name(s)
Population density of LADs	Excel spreadsheets containing population counts for MSOAs each year from 2001-12	Total population count data for separate years were collated into one Excel CSV file, with columns for: MSOA, year and population count MSOA to LAD lookup tool used to add an LAD11 column The population count data were aggregated to LAD11 level, for each year	CSV file with the following columns: LAD11 code, Year, population density	Linked to other LAD data by year (2001-12)	Linked to other LAD data by LAD code	Popdens
	Standard Area Measurement data for LADs (2013 boundaries) in Excel CSV file format	LAD (2013) boundaries mapped to LAD 2011 boundaries. Area of the realm in hectares converted to sq km for each LAD sq km for each LAD mapped to population count data for each LAD / year, using LAD code as spatial identifier Population counts per LAD per year were divided by number of sq km per LAD				

6.3.4 Income deprivation data

A summary of the method that I used to format the income deprivation data and link these with other variables is provided below. Technical details are shown in table 6.4.

I downloaded IMD-10 income deprivation data with LAD11 codes as a CSV from the Department for Communities and Local Government website (334). I added a column to identify the year for which these are applicable (i.e. 2010). I linked these data to the spreadsheet described in section 6.2 by LAD11 code and year. I used the population count data in this spreadsheet to create a variable that measured the proportion of income deprived population for each LAD for 2010.

Table 6.4: *Summary of the formatting and linking of socioeconomic data*

Data	Format received	Transformation performed	Data for the model	Temporal linkage	Spatial linkage	Variable name(s)
Number of income deprived persons in 2010 for English LADs	Excel format, with columns for LAD name and number of income deprived persons	Columns added containing LAD11 code and year. Numbers of income deprived persons were divided by the population count for each LAD in 2010. The results were multiplied by 100 to create a percentage.	CSV file with the following columns: LAD11 code, LAD11 name, Year, Month, Income deprivation %	Linked to other LAD data by year (2010)	Linked to other LAD data by LAD code	Incomedep%

6.3.5 Housing data

A summary of the method that I used to format the data for housing variables and link these with other variables is provided below. Technical details are shown in table 6.5.

I downloaded data for the percentage of fuel poor households per LAD11 from the Department of Energy and Climate Change website (367) as two separate CSV files for 2011 and 2012. These data were collated into a single file and a column was produced that identified the year (2011 or 2012) when each observation was made. I linked these data to the spreadsheet described in section 6.2 by LAD11 code and year.

I downloaded household occupancy data from the 2011 UK census as a CSV file from the ONS website (388). This file contained the percentages of households with different occupancy levels for LADs. I summed the percentage of households with too few rooms (by -1 or less). I extracted these data, along with their corresponding LAD area codes and created a file which contained columns with LAD codes, reference years and indicator (percentage of over-occupied households) values. I linked these data to the spreadsheet described in section 6.2 by LAD11 code and year.

I obtained a dataset containing percentages of households by tenure for LADs from the 2011 census as a CSV file from the ONS website (389). I summed the percentages of households from two private-rented tenure categories: i) rented from a private landlord or letting agency and ii) privately rented from another source and extracted this variable along with corresponding area code into another file, which contained columns for LAD code, year of observation and the indicator value. These data were linked to the other data by LAD (2011) code and year.

I downloaded a dataset which contained the 2011 Rural-Urban classification of LADs as CSV files from DEFRA and formatted this by adding a column to identify the year for which these data were applicable (i.e. 2011). I linked these data to the spreadsheet described in section 6.2 by LAD11 code and year.

Table 6.5: *Summary of the formatting and linking of housing data*

Data	Format received	Transformation performed	Data for the model	Temporal linkage	Spatial linkage	Variable name(s)
% of fuel poor households per LAD, for 2011 and 2012	CSV format, one file per year of data, each with columns for LAD code (4 digit), LAD name, GOR, total households (n), fuel poor households (n), fuel poor households (%)	Columns containing LAD code and % of fuel poor households were extracted from the file containing the 2011 and 2012 data. These data were collated into one file, with a column to identify the year (2011 or 2012) of observations.	CSV file with the following columns: LAD11 code, Year, FPov%	Linked to other LAD data by year (2011 and 2012)	Linked to other LAD data by LAD code	FPov%
Census occupancy data, for 2011	CSV format, 2011 data with columns for area codes (including LAD 2011), total households, and % of households with each occupancy rating	2011 data: non-LAD area codes deleted aggregation of % of households with -1 or less rooms than needed.	CSV file with the following columns: LAD11 code, Year, Crowded%	Linked to other LAD data by year (2011)	Linked to other LAD data by LAD code	Crowded%

Table 6.5 (continued)

Data	Format received	Transformation performed	Data for the model	Temporal linkage	Spatial linkage	Variable name(s)
Census tenure data, for 2011	CSV format, 2011 data with columns for area code (including LADs), area name (including LADs), counts and percentages of households with different tenures	Percentage of private rented households (data from two tenure categories) were collated in a CSV file	CSV file with the following columns: LAD11 code, Year, %PrivRent	Linked to other LAD data by year (for 2011)	Linked to other LAD data by LAD code	PrivRent%
2011 Rural and Urban classification (RUC) of LADs	Excel format, with columns for LAD11 code, LAD11 name, Year, RUC score, RUC score description	LAD11 name and RUC score description deleted	CSV file with the following columns: LAD11 code, Year, RUC score	Linked to other LAD data by year (for 2011)	Linked to other LAD data by LAD code	RUC score

6.3.6 Lifestyle-related data

A summary of the method I used to format the data for lifestyle-related variables and link these with other variables is provided below. The technical summary is on table 6.6.

Data for the percentage of adults classified as being overweight or obese were downloaded in a CSV file from the Public Health England's Public Health Outcomes Framework website (390). This file contained multiple public health indicators. The adult overweight and obesity data and their associated LAD code were extracted onto a new file. A column was added to identify the year which these data were collected (during 2012). I linked these data with other LAD data by LAD code and year.

Data for the percentage of overweight or obese children aged 10 and 11 years were extracted from the same Public Health Outcomes Framework indicator worksheet as the adult overweight and obesity data. Child overweight and obesity data are available for years, rather than months. However, the data are available for school years (e.g. September 2009-August 2010) rather than calendar years (e.g. 2009, 2010 etc.), from 09/2009 onwards. I extracted the indicator data onto a separate CSV file and linked these indicator data with corresponding LAD codes by month (i.e. data collected during the academic year September 2009- August 2010 were linked with corresponding LADs for months during the same period). I linked these data with other LAD data by LAD code, month and year.

Data on the percentage of adults who smoke were downloaded as CSV files, each of which contained annual data for one financial year (e.g. April 2009-March 2010), from 04/2009-03/2010 to 04/2011-03/2012. As with the child obesity data, adult smoking data were unavailable for calendar years. I therefore extracted the indicator data with corresponding LAD codes onto a CSV file and linked the adult smoking prevalence data with LADs by month. I linked these to other data in the LAD dataset by LAD code, month and year.

Finally, I downloaded data which measured physical activity in adults from the Active People Survey website (391). These were annual data that were available from October one year to September of the following year. I extracted the indicator data with corresponding LAD codes onto a CSV file and linked the data to LAD codes by month. I linked these data with other data in the LAD dataset by LAD code, year and month.

Table 6.6: *Summary of the formatting and linking of lifestyle-related data*

Data	Format received	Transformation performed	Data for the model	Temporal linkage	Spatial linkage	Variable name(s)
Percentage of overweight or obese adults (aged ≥16 years)	Excel format, with columns for indicator name, time period, LAD code, LAD name, value (%overweight or obese adults), lower and upper CIs, count, denominator, sex, age	Percentage of overweight or obese adults (aged ≥16 years) data extracted in to a separate file with associated columns containing LAD code, LAD name, year (2012) and value (%Ad_overwe),	CSV file with the following columns: LAD11 code, Year, %Ad_overwe	Linked to other LAD data by year (for 2012)	Linked to other LAD data by LAD code	Ad_overwe%
Percentage of overweight or obese children (in year 6, aged 10 and 11 years)	Excel format, with columns for indicator name, time period (school year, e.g. 2009/10), LAD code, LAD name, value (%overweight or obese children), lower and upper CIs, count, denominator, sex, age	Percentage of overweight or obese children (aged 10 and 11 years) data extracted in to a separate file with associated columns containing LAD code, LAD name, year (from 2006 to 2012), month (1-12) and value (%Y6_overwe),	CSV file with the following columns: LAD11 code, Year, Month, %Y6_overwe	Linked to other LAD data by year and month (from Oct. 2006 to Dec. 2012)	Linked to other LAD data by LAD code	Y6_overwe%

Table 6.6 (continued)

Data	Format received	Transformation performed	Data for the model	Temporal linkage	Spatial linkage	Variable name(s)
Percentage of adults (aged ≥18 years) who smoke	Excel files with data from financial years 04/09-03/10 04/10-03/11 04/11-03/12, each with columns including LAD code, LAD name, period, indicator value (% adult smokers)	Columns containing LAD code, year, month (1-12), indicator value (% adult smokers) for each financial year extracted and collated into one file	CSV file with the following columns: LAD11 code, Year, month, %smok	Linked to other LAD data by month and year (from 04/09 to Dec. 03/12)	Linked to other LAD data by LAD code	Smok%
% of adults who participated in moderate intensity sport for at least 30 minutes per week over the last 28 days from being surveyed	Excel file with columns for LAD codes, LAD names, %s and numbers of the indicator for Oct. 05-06 and from Oct. 07-08- Oct. 12-13	Columns containing LAD code, period, indicator value (%) from each season extracted and collated into one file	CSV file with the following columns: LAD11 code, Year, month, %sport	Linked to other LAD data by month and year (from Oct.05-06 and from Oct.07-Dec.12)	Linked to other LAD data by LAD code	Activ%

6.3.7 Medical access data

Technical details of the process used to create medical access variables are shown in table 6.7.

Variables to measure medical access were created during the analyses, in order to make sense of counterintuitive findings about the nature of the relationship between measures of air pollution, urban dwelling and mortality (see chapter eight). I obtained CSV files containing the names and addresses of organisations that provide (i) cardiology services, (ii) respiratory medicine and (iii) Accident and Emergency (A&E) departments in England for the year 2015, via personal communication with staff from NHS Choices (381). This information was unavailable for previous years. I calculated the number of each organisation type per LAD by mapping the postcodes of each organisation to English LADs (2011 boundaries) using a postcode to LAD lookup, obtained from the ONS geography portal (383).

Also from the ONS geography portal, I obtained Standard Area Measurements for Local Authority Districts (area of the realm in hectares) (383). I calculated the area size of each LAD in square km by dividing the number of hectares in each LAD by 100. I then calculated the density of A&E departments, hospitals providing cardiology services and hospitals providing respiratory medicine by dividing the number of each medical service in each LAD by the number of square km in each LAD. I multiplied the results by 1000, so that the numbers were large enough to be rounded to one decimal place, without having lots of zero values. The analyses in this thesis assess relative differences in the values of data for each variable, so multiplication by 1000 would not have affected the results. I linked each medical access variable with the other data in the LAD dataset by LAD code.

Table 6.7: *Summary of the formatting and linking of medical access data*

Data	Format received	Transformation performed	Data for the model	Temporal linkage	Spatial linkage	Variable name(s)
Names and addresses of organisations providing: (i) Cardiology services (ii) Respiratory medicine (iii) Accident and Emergency (A&E) departments	Excel format, one spreadsheet for each type of service (i-iii) with columns for the organisation details, including name, address and postcode	Organisation postcodes were linked with relevant LAD codes Number of organisations per LAD was calculated using the 'aggregate' command in R Studio. ONS standard area measurement data were used to calculate the number of each organisation per sq. km x 1000 per LAD11	CSV file with the following columns: LAD11 code, Cardiology hospitals, Respiratory Medicine, A&E departments	Values from 2015 were applied to all months in the study	Linked to other LAD data by LAD code	Cardiology Resp. Med A&E

6.4 Summary

In this chapter, I described the procedures used to format and link data to represent variables from chapter four in the analyses. In chapter seven, I introduce and describe the statistical methods that were used for the analyses performed and described in chapter eight.

Chapter Seven.

Methods (iii): Statistical methods used for the analyses

7.1 Introduction

In this final methods chapter, I describe the statistical methods that are used in the analysis to address two research questions, which have been adapted from the initial questions set out in the introduction (section 1.2) as a result of the investigations into data availability:

Adapted research question three: Which factors, identified in chapter four, are associated with spatial and temporal variations in winter- and cold-weather-related mortality rates across English LADs?

Adapted research question four: Are the same factors associated with spatial and temporal variations in winter- and cold-weather-related mortality rates from circulatory and respiratory conditions across English LADs?

The reason for the modifications to these research questions is the limited availability of data, outlined in chapter five. I have, therefore, explored the factors associated with spatial and temporal variations in mortality between circulatory and respiratory conditions, rather than between general morbidity and mortality.

In section 7.2 of this chapter, I present an introduction to spatial and temporal epidemiology and introduce the two main types of spatial epidemiology study design used in the analyses presented in chapter eight. In section 7.3, I discuss methodological challenges associated with small area level spatial epidemiology studies and describe how these can be addressed using Bayesian inference. In section 7.4, I describe the data analysis methods and provide a rationale for this strategy.

7.2 Introduction to spatial and temporal epidemiology

Spatial epidemiology refers to: '*the description and analysis of geographic variations in disease with respect to demographic, environmental, behavioural, socioeconomic, genetic, and infectious risk factors*' (392, p.998). This approach to public health research originated during the 1800s, when disease rates were initially mapped to characterize associations

between infectious disease outbreaks and possible causes (392). John Snow's famous mapping of deaths from cholera in London in 1854 demonstrated that cases clustered around a water pump on Broad Street. This provided evidence to suggest that cholera was caused by a water-borne disease agent, rather than being air-borne, as previously thought (393).

Since this time, there have been huge advances in the investigation of local geographical health variations in relation to environmental and other factors, due to better technology, improved statistical methods and the increased availability of geographically referenced data on health outcomes and potential risk factors (392). Geographically referenced data refer to data that are assigned to a particular location, a point in space (e.g. a geographical coordinate, a street or home address, or an area which could be defined by a postcode or LAD etc.) (392).

Types of design used in spatial epidemiology studies include disease risk mapping and geographical correlation studies (392). Disease risk maps are diagrammatic illustrations of the spatial distribution of health outcomes or disease risk factors, across defined areas. These enable the identification of areas with high risk of disease, which is useful for directing public health interventions and other resources to where they are most needed. Public Health England's Knowledge and Intelligence Network produce disease risk maps to assess the prevalence (total number of cases of a disease in a population at a single point in time) and incidence (number of new cases of disease in a population that occur over a given time period) of various health outcomes and health inequalities. One example is the 'Excess Winter Deaths Atlas', which illustrates excess winter death indices across geographical areas of England and through time (394). An EWM reduction scheme that is currently being undertaken across County Durham uses area-based mapping of household thermal efficiency ratings to identify individuals who are at risk of fuel poverty, in order to provide effective targeting of interventions (395).

Disease risk maps generally show mortality or morbidity incidence ratios for geographic areas such as LADs (392). These ratios can be standardised (e.g. for age and sex, when the outcome data are broken down by these categories). This produces standardised mortality ratios (SMRs). These are used to calculate the rate of a specific outcome (e.g. circulatory deaths) in each area using the formula O_i/E_i. In this formula, O_i is the observed number of cases of the outcome of interest (e.g. circulatory deaths) in area i and E_i is the expected number of deaths in area i, calculated by applying age (and sex, where this is likely to affect spatial variations in the number of cases of the outcome of interest) specific death rates to population counts for the area (392).

Disease risk maps provide accessible information to identify areas at high risk of specific health outcomes, to compare disease burden between areas and to monitor changes or disease trends through time. They also enable generation of hypotheses about the potential causes of diseases. Limitations include that disease risk maps with more areas are often difficult to interpret. Additionally, when the geographical size of included areas varies dramatically, larger areas can stand out more, whereas smaller areas with high disease risk can be overlooked. Also, the way that risk categories are classified influences the appearance of the maps (392).

Geographic correlation studies, also known as ecological regression analyses, involve examination of geographic (ecologic) variations across population groups in exposures in relation to health outcomes that are also measured at ecologic scale (392). This approach can be used to assess the proportion of spatial variation in a particular health outcome (e.g. mortality from circulatory conditions) that is accounted for by individual and combinations of explanatory factors. However, these analyses are restricted to include data that are available at a particular ecological level.

Ecological data are also generally available with temporal referencing. Most of the data that are used in the analyses presented in chapter eight of this thesis are available for multiple time points (e.g. mortality count data were obtained by month from January 2001 to December 2012). Temporal analyses provide information about the temporal trend in disease risk (396) in relation to explanatory variables.

Spatial and temporal information can be combined to provide information regarding the linkage between spatial and temporal effects (i.e. spatiotemporal interaction effects) in relation to health or other variables. Examples of spatiotemporal interaction effects in relation to this thesis, which are analogies from scenarios presented by Brunsdon et al. (2004) (397) are as follows. In relation to weather, mean temperatures are generally lower, by several degrees, in the North East of England compared to London (i.e. mean temperature shows a spatial pattern). Mean monthly temperatures are also generally lower in the winter compared to the summer months (i.e. mean temperature shows a temporal pattern). The lowest mean temperatures in England are often recorded in January in the North East region (i.e. there is a spatiotemporal interaction effect for mean temperature in England).

Alternatively, there may be an absence of spatiotemporal effect. For example, heart attack rates are generally higher in the most socioeconomically deprived LADs of England (spatial effect). Heart attack rates are generally higher in the winter compared to the summer months (temporal effect). However, heart attack rates are consistently high throughout the year in

many deprived areas and do not show seasonal patterns (i.e. there is no spatiotemporal interaction effect for heart attack in many areas of England).

In my analyses, the methods of which are described in section 7.4, I use disease risk mapping to identify the spatial distribution of circulatory and respiratory deaths across English LADs during colder and warmer periods of 2011. I also use ecological and spatiotemporal regression analyses to investigate factors associated with the spatial and spatiotemporal patterning of condition-group-specific mortality risk between English LADs and through time, during 2011 and across winter seasons from 2001/2 to 2011/12.

7.3. Methodological issues in spatial and temporal epidemiology studies

Despite the improved potential for undertaking spatial epidemiology studies over the last century, these analyses create problems for making valid inferences regarding associations between exposure and outcome variables. In the following paragraphs, I discuss the issues that are relevant to the data and analyses presented in this thesis and how these problems can be addressed using Bayesian inference.

Data from local populations can produce small numbers. These are potentially unreliable and are likely to be influenced by random factors, including local variations in the quality of the data (392). For example, in relation to the weather data, I calculated average monthly values for meteorological variables across English LADs, based on measurements taken over five by five km grid squares of England. However, there were missing values within these data and the amount of missing data differed between areas and months. Also, there will have been variations in the accuracy of measuring equipment for these variables between recording sites and through time. Consequently, the level of error in the accuracy of weather data is likely to differ between LADs and across time points.

There are various reasons why mortality data could also be unreliable. Firstly, due to inaccuracies in the cause of death noted by doctors on death certificates; and secondly, the mortality data exclude deaths for which the month of occurrence was not registered. Also, the ONS mortality data excluded deaths that were not registered during the study period (January 2001 to December 2012). For example, in the UK, deaths can be registered up to six weeks after occurrence. Consequently, deaths that occurred towards the end of 2012 but were not registered until early 2013 were excluded from the dataset. The extent to which each factor affected, and therefore caused error within, the mortality data, is likely to have varied between LADs and months in the dataset. Investigations that are conducted using data at broader

geographical scales (e.g. comparisons between regions or countries) normally generate larger numbers, which are likely to cancel these random effects (392).

The unreliable nature of data from small populations can reduce the ability to identify areas that are at high risk of a particular health outcome (e.g. mortality from circulatory conditions). For this reason, Bayesian approaches are recommended for use in small area level epidemiological studies in order to improve the quality of estimates for exposure and outcome variables (392, 398). This provides more accurate information about disease prevalence and associations between exposure and outcome variables to inform policies, including those aimed at reducing adverse health outcomes (392, 398).

Bayesian inference provides an alternative to the approach used in classical (Frequentist) statistics. The same statistical techniques can generally be employed in the context of both Bayesian and Frequentist inference. For example, the use of Poisson regression to quantify the association between explanatory variables and mortality counts. An explanation of the two approaches, the difference between them and the reasons why Bayesian methods are appropriate for spatial and temporal studies that involve the collection of data consisting of small numbers, is outlined below.

Relative risk (RR) estimates are one type of statistic that can be obtained from regression analyses to summarise the magnitude of association between exposure and outcome variables. These are calculated as the incidence rate of an outcome in a population with a particular exposure divided by the incidence rate in a non-exposed population (230). When analysing data from an investigation (e.g. to assess the association between various exposures and the incidence of respiratory mortality across English LADs), RR values can be generated to quantify the variation in risk of the outcome between population with different levels of exposure to individual or combinations of variables. Relative risk values of <1, 1 and >1 indicate, respectively, that there is a reduced, equal or increased risk of an outcome in an exposed population. In the context of Frequentist inference, a statistical distribution of RR values (or other relevant statistic) is generated, which depicts the probability of obtaining specific RR values, based on the number of times that each value would have been obtained if the experiment was repeated many times. This is quantified as a probability 'p'-value, which is generated along with an RR value for an exposure-outcome variable association in an actual investigation. P-values of ≤0.05 indicate that the observed RR value would have occurred in 5% or fewer instances if the experiment was repeated many times. This is generally considered to indicate that an observed association between variables is unlikely to have occurred by chance. In addition, confidence intervals can be produced, which are a range of

values around the outcome statistic (e.g. RR estimate) for which there is a defined probability (usually 95%) that the true population mean value of the parameter (association) lies within.

Frequentist inferences are made based on the data themselves. Alternatively, Bayesian approaches combine 'prior' information about the values of data with the observed data to generate 'posterior' values to quantify the association between exposure and outcome variables. An example of prior information that can be integrated with the observed data in the analyses presented in this thesis, are values of exposure and outcome variables from other areas and time points (or time periods). This enables calculation of RR estimates (e.g. RR of circulatory mortality in a particular LAD relative to the whole of England) that represent a compromise between the local observed values for explanatory and outcome variables and a mean value for the same parameters in other areas (e.g. neighbouring LADs or the whole study area) (392). Similarly, in relation to temporal effects, RR of mortality for specific time periods (e.g. winter seasons) are calculated based on the observed values of exposure variables and mortality incidence during a single time period and a mean value for the same parameters for other time periods (e.g. preceding and subsequent winters, or across all winter seasons in the analysis). This is achieved through specification of the neighbourhood and temporal structure of the data before the analysis is undertaken.

The process of integrating prior and observed data is called 'smoothing'. Values for the observed data in each area and for each time point can be overwhelmed by data from adjacent areas and time points. This can reduce the ability to detect areas with high risk of a health outcome of interest (a process that is termed 'over-smoothing') (392). The level of smoothing can be controlled by specifying different types of prior data. In the analyses that are presented in chapter eight, I use a 'minimally informative prior'. This means that the observed data are the principal force in producing the statistical estimates (399) with minimal influence from the values of the data in other areas and during other time periods.

A second issue that arises from spatial epidemiology studies is serial dependency effects, which are also referred to as 'statistical autocorrelation'. Statistical autocorrelation refers to the association between values of a statistical parameter (e.g. mortality rates from circulatory conditions) between areas (spatial autocorrelation) and time points (temporal autocorrelation) (400). Data that are from areas in closer spatial proximity and time are likely to be more similar compared to data from areas and times that that are further apart.

Statistical autocorrelation is mainly caused by unmeasured confounding, where variables that are spatially and, or temporally correlated and affect the value of the dependent variable (i.e. mortality rate), are not formally included as explanatory variables in the statistical regression

model. However, the influence of these variables is picked up in the residual (error) variance of the regression equation (399).

An example of spatial autocorrelation is that suicide rates in London LADs are likely to be more similar to each other than more distant LADs, due to similar social, economic and cultural characteristics associated with suicidal behaviour (e.g. high deprivation, low social cohesion) between neighbouring London LADs (399). An example of temporal autocorrelation is that influenza rates are likely to be more highly correlated between neighbouring winter months (e.g. December and January) than between a winter and a summer month (e.g. December and June), because factors including indoor crowding that may facilitate influenza transmission occurs more in winter than summer months.

The spatial (and, or temporal) structure of relevant covariates induces spatial (and, or temporal) autocorrelation into the values of the dependent variable between areas (or time points), which cannot be accounted for in the regression model (399). This creates 'noise' in the data, which needs to be controlled for in order to provide more robust estimates of the effects of predictor variables which are formally specified in a statistical model, on disease risk.

In addition, the validity of the output from regression models are based on the assumption that values for each parameter included in the regression models are independent between areas and time points. The outcome parameters that I used for the analyses in chapter eight are condition-group-specific mortality ratios, which are calculated using observed mortality counts divided by the expected mortality counts for each condition group. Expected mortality counts are calculated using observed mortality counts from the whole study area and time period in each analysis (see section 7.4 for more details about this calculation). Consequently, the outcome data are not independent. However, in order to address this, statistical dependency effects between exposure and outcome data can be controlled for using Bayesian methods. This is achieved by defining the neighbourhood and temporal structure of the data and including measures of space and time effects as explanatory variables in the regression models. The effects of space and time can be estimated in the regression equation using different types of statistical model. Each model makes a different assumption about the spatial and temporal structure of the data. For example, in a besag model, the spatial effect in the regression analysis is calculated on the assumption that the value of the outcome variable (e.g. mortality ratio, 'y') in each area is a function of the average values of y in physically adjacent areas in relation to the number of neighbouring areas (401). Details of the spatial and

temporal effects included in the regression models in chapter eight are presented in section 7.4, below.

7.4 Analytic strategy to investigate associations between explanatory factors and spatial and temporal variations in mortality from circulatory and respiratory conditions across England, in relation to cold weather and winter season.

7.4.1 Methods to identify temporal and spatiotemporal variations in mortality from circulatory and respiratory conditions between years and winter seasons in England from 2001-12

The analyses presented in chapter eight were undertaken in stages. I initially investigated the changing incidence of annual mortality rates from circulatory and respiratory conditions across English LADs over the study period from 2001-12. I also calculated excess winter mortality indices to identify spatiotemporal variations in mortality from all-causes, circulatory and respiratory conditions for the whole of England, over the winter seasons from 2001/2 to 2011/12, using the ONS' method (402).

Excess winter mortality indices control for potential bias from factors including differences in age structure and population size between areas and through time, by scaling the data to express the number of excess winter deaths as a percentage change compared with the number of non-winter deaths (402).

The changing incidence of condition-group-specific mortality from 2001-12 and of excess winter mortality indices from all-causes, circulatory and respiratory conditions are presented graphically in chapter eight, section 8.2.

7.4.2 Methods to identify spatial variations in mortality from circulatory and respiratory conditions between cold and warm periods

In the next stage of my analysis, I used disease risk mapping to explore the spatial patterning of mortality from circulatory and respiratory conditions across English LADs between the coldest and warmest 3-consecutive month periods of the year, using data from a five year period (from 2008-12). I identified the months January to March as being generally the coldest consecutive 3-month period and June to August as being generally the warmest consecutive 3-month period, by calculating values for the mean daily minimum temperatures (°C) for each month across England for the years of interest (i.e. 2008-12). The methods I used to create the disease risk maps and to implement ecological regression analyses (described in section 7.4.3), are from Blangiardo and Cameletti (2015) (396, p.179-188).

I used Poisson regression models for the disease risk mapping, ecological and spatiotemporal regression analyses that are presented in chapter eight and described in this chapter. These are appropriate when outcome data are counts and consist of small numbers (rare events), or for larger numbers when offset against an exposure variable (e.g. in relation to the time period in which the data were collected, population size or expected number of events relative to other areas and times) (403). This creates rate data, defined as number of events (e.g. condition-group-specific deaths) in relation to exposure (e.g. expected number of deaths) (403). Rare event data are positively skewed, with the bulk of the statistical distribution being concentrated to the left of the histogram and with a longer tail to the right. These data are inappropriate for analysis using an ordinary linear regression model, for which the data should be normally distributed.

Poisson regression models can be used to analyse spatial and temporal data (i.e. data that are aggregated over areas and time units, respectively). The outcome variables used in the analyses presented in chapter eight are condition-group-specific mortality ratios. The mortality ratio is calculated as the proportion of observed to expected deaths (O_i/E_i). Mortality ratios of <1, 1 and >1 indicate, respectively, that observed mortality is below, equal to, or in excess of, the expected mortality in relation to mortality rates across the whole study area. In order for the mortality ratio to be calculated in the analyses, I provided the condition-group-specific observed and expected death counts per area (LAD) per time unit of interest. For the disease risk maps, observed deaths were condition-group-specific mortality counts for each of the 3-consecutive month periods of interest (i.e. January to March and June to August), aggregated for the years 2008-12. Expected deaths were calculated for the disease risk maps using the following formula:

Expected number of deaths per condition group in area LAD*i* over the time period of interest (i.e. Jan-Mar 2008-12 <u>or</u> Jun-Aug 2008-12) = (total number of condition-group-specific deaths in England that occurred over the three month period of interest from 2008-12 / aggregated annual population sizes of England from 2008-12) x aggregated annual population sizes of LAD*i* from 2008-12

The mortality data that I obtained from the ONS were not broken down by demographic groups. Consequently, I was unable to produce SMRs and therefore my outcome variables are condition-group-specific crude mortality ratios.

I conducted the disease risk mapping exercise, and ecological regression analyses (described in section 7.4.3), using a Bayesian approach, to address the methodological issues of small

numbers and statistical dependency effects identified in section 7.3, using Integrated Laplace Approximation (INLA) methods in R (R-INLA). This programme provides a computationally efficient method for estimating of the effects of covariates on outcome variables from epidemiological data with a spatial and, or temporal structure, whilst accounting for spatial or temporal effects within the model (404).

I performed the disease risk mapping exercise separately for circulatory conditions and respiratory conditions for each 3-month period of interest (using data from 2008-12), so that results could be compared.

Before generating the disease risk maps, I produced an adjacency diagram to define the neighbourhood structure for the study areas (i.e. to assign neighbours to each LAD). Two LADs, namely the Isles of Scilly and Wight, were excluded from the analyses as they do not have physical neighbours. Consequently, a spatial effect could not be calculated for these areas. The remaining 324 English LADs all had physical neighbours and were included in the analyses.

The basic formula statement for the disease risk map model is:

>formula <- y ~ 1 + f(ID, model="bym", graph=England.adj)

(Adapted from Blangiardo and Cameletti (2015) (404), page no. 182).

In this equation, 'y' represents the outcome variable, namely the proportion of observed to expected deaths (condition-group-specific, crude mortality ratio). The symbol 'f' specifies the inclusion of a function in the regression model. The f function was used to include parameters for spatial dependency effects in the disease risk maps, and ecological regression models (described in section 7.4.3). This function is used to specify different types of model, each of which introduces parameters that assume specific types of spatial (temporal and spatiotemporal) structure and dependency effects exist within the data (396).

I used a 'bym' model (405) to specify the spatial effect for the disease risk maps, and the ecological regression analyses (described in section 7.4.3). This calculates the spatial effects for each area (ID) in relation to the neighbourhood structure of the data (404). The 'bym' model includes two types of effect, namely i) spatially structured (statistically dependent) and ii) spatially unstructured (statistically independent, area-specific) effects as covariates in the model. The spatially structured effect assumes that there is a pattern within the outcome data, whereby the value of y in each area is assumed to be a function of the average values of y in physically adjacent areas in relation to the number of neighbouring areas (401). The spatially

unstructured effect accounts for the residual (remaining) variance that is statistically independent between areas.

In Poisson regression analysis, the parameters in the model are transformed onto the logarithmic scale for analysis. The basic regression equation for the Poisson regression analysis that was used in the disease risk mapping exercise is:

Log (y) = b0 + ui + vi

= Log (observed / expected deaths) = b0 + spatially structured residual + spatially independent residual

(Adapted from Blangiardo and Cameletti (2015) (396), page no. 180).

In the equation shown above, *b0* is the intercept, where the regression line crosses the y axis. The symbols '*ui*' and '*vi*' represent the spatially structured and unstructured effects, respectively.

Variables in the statistical model are converted onto the log scale using the 'scale.model' function in R Studio. I used a minimally informative prior (described in section 7.3) for the analyses. This was in order to prevent 'over-smoothing' and consequent dilution of excess risk estimates for individual areas. This type of prior was specified in the model statement using the 'hyper' function. The formula used to create the disease risk map, adapted from Blangiardo and Cameletti (2015) (396) (page no. 183) was:

formula.disease_risk_map <- y ~ 1 + f(ID, model="bym",graph=England.adj, scale.model=TRUE,

        hyper=list(prec.unstruct=list(prior="loggamma",param=c(1,0.001)), prec.spatial=list(prior="loggamma",param=c(1,0.001)))))

In the disease risk maps, I classified areas as having lower than average risk of excess mortality (RR 0.1-0.9), average risk (RR 0.9-1.1) or higher than average risk (RR 1.1-1.9).

7.4.3 Methods to identify spatial variations in mortality from circulatory and respiratory conditions between cold and warm periods in 2011, in relation to explanatory factors

In the next stage of my analyses, I performed ecological regression analyses to identify individual and combinations of factors associated with the spatial variations in mortality from circulatory and respiratory conditions. The methods I used for these analyses are from Blangiardo and Cameletti (2015) (396, p.179-188).

I chose to use the year 2011 for the initial regression analyses, as most of the covariates of interest were available for this year (e.g. data from the 2011 Census). This enabled me to implement regression models that included a comprehensive range of factors, allowing consideration of the mechanisms by which different factors could interact to influence mortality. The periods January to March and July to September were identified as the coldest and warmest consecutive 3 month periods for 2011, based on the mean daily minimum temperatures (°C) for each month across England.

The ecological regression analyses from 2011 enabled me to compare spatial variations in mortality and associated factors between condition groups and during periods of colder and warmer weather. However, these data were only from one year and the results from the analyses are unlikely to reflect long-term trends in excess cold-weather-related mortality in relation to explanatory variables.

Expected deaths were calculated for the ecological regression models for the three month periods of 2011 using the following method:

Expected number of deaths per condition group in area LAD*i* over the 3-month period of interest (e.g. Jan-Mar 2011) = (total number of condition-group-specific deaths in England that occurred over the 3-month period of interest / total population size of England in 2011) x population size of LAD*i* in 2011

The ecological regression analyses to identify individual and combinations of factors associated with the spatial variations in mortality risk between colder and warmer periods of 2011 for each condition group. In R Studio, I adapted the script that I used to produce the disease risk maps so that explanatory variables could be included in addition to the structured and unstructured spatial effects. The methods that I used are based on those presented in Blangiardo and Cameletti (2015) section 6.2 (396, pp.186-188), in which they used a dataset from a previous study (406) to investigate suicide mortality across 32 London boroughs in relation to two explanatory factors (social deprivation and social fragmentation). The formula for the ecological regression analysis is extended from the formula used to generate the disease risk maps, by adding covariates, for example:

Variable (covariate) $x1$ = prevalence (%) of adult smokers

log (y) = b0 + b1x1+ui + vi

Log mortality ratio = b0 + b1 x (value of covariate x1) + spatially structured residual + spatially independent residual

(Adapted from Blangiardo and Cameletti (2015) (396), pp. 186-7).

Estimates from the output from Poisson regression models can be interpreted as relative risk values if they are converted back to the natural scale (i.e. exponentiated), from the log scale in which parameters in the regression model are analysed. This can be performed using the exponential ('exp') function in R (396).

The formula statement that was specified in R to implement the ecological regression analysis with a single covariate (x1) is:

formula.eco.reg <- y ~ 1 + x1+ f (ID, model="bym",graph=England.adj, scale.model=TRUE,

hyper=list(prec.unstruct=list(prior="loggamma",param=c(1,0.001)), prec.spatial=list(prior="loggamma",param=c(1,0.001)))))

(Adapted from Blangiardo and Cameletti (2015) (396), page no. 187).

The addition of covariates to the regression model containing spatial effects that I used to produce the disease risk maps (null model) adds more information to the model, which potentially accounts for more of the variance in excess mortality across English LADs.

I implemented the ecological regression models separately for the circulatory and respiratory data, each for the periods January to March and July to September 2011. In each set of analyses, I initially ran the ecological regression models containing the spatial information and individual covariates, to derive regression estimates and RR values with 95% credible intervals (the Bayesian alternative to Frequentist confidence intervals) and Deviance Information Criterion (DIC) values. DIC values provide a measure of how well the statistical model explains variance within the data. DIC values take account of the number of included covariates in the model and penalize (increases the DIC value) models with increased number of covariates. This is because, models with more covariates will generally have lower DIC value by nature of the fact that their included covariates in combination explain more of the variance within the outcome data compared to a model with fewer covariates.

I obtained a DIC value for the null model that contained spatial effects (specified using a 'bym' model) without other covariates (i.e. the models used to produce the disease risk maps) and for ecological regression models containing individual covariates (the variables described in chapter six). I identified models containing spatial effects with individual covariates (e.g. smoking prevalence) associated with lower DIC values compared to the null model. Ecological regression models containing spatial effects with individual covariates and had DIC values that were lower than for the null model were considered for inclusion in multivariable regression models. Prior to developing ecological regression models with

combinations of factors, I used variance inflation factor (VIF) tests to identify independent variables that were highly correlated (collinear) with other exposure variables. Where VIF values are above one, this indicates collinearity. The inclusion of co-linear independent variables in multiple regression models is problematic due to the fact that these variables account for a large proportion of the variance in the outcome variable, which distorts and sometimes reverses the direction of effect of other explanatory variables on the outcome variable in the model. This can lead to misinterpretation of the results from the multiple regression model (407). For example, by policy makers or public health professionals who lack statistical knowledge of this issue and use the results as a basis for developing public health interventions.

Various thresholds have been proposed for excluding variables from multivariable regression models based on their VIF values. I chose to exclude variables with VIF values ≥3. This threshold was chosen because pilot analyses indicted that inclusion of variables with higher VIF values in multivariable models severely distorted the effects of other variables, in comparison to their effects in single variable models.

Once variables with VIF values ≥3 had been excluded, I developed multivariable regression models with the remaining variables using a forward stepwise approach for each condition group and time period. This involved identifying the single variable (univariable) regression model with the lowest DIC value, adding the variable from the univariable model with the next lowest DIC value to create a multivariable regression model and observing the effect on the DIC value. If this value was reduced, both variables were retained and another variable, with the third lowest DIC value, was added. Where an additional variable increased the DIC value from the previous model, the variable was removed from the model. This process was continued until all eligible variables (with DIC value lower than the null model and VIF score ≤3) had been tested in the multivariable regression model. Regression output was then generated for variables in the multivariable regression model. Variables with 95% credible intervals for the regression estimates which crossed one were removed from the model, until a final regression model was generated containing only variables with effects for which their 95% credible intervals were entirely above or below one (taken as an indication of significance, an approach adopted in (300)).

7.4.4 Methods to identify spatiotemporal variations in monthly mortality rates from circulatory and respiratory across 2011, in relation to explanatory factors

The next stage of analysis involved identifying factors associated with spatiotemporal variations in monthly mortality from circulatory and respiratory conditions from January to December 2011. I undertook these analyses to identify meteorological and other factors associated with year-round excess mortality, as England has a maritime climate and cold-weather can affect health outside of the winter period. I calculated expected deaths for these analyses using the following method:

Expected total number of deaths per condition group in LAD*i* per month in 2011 = (total condition-group-specific deaths in England over the 12-months in 2011/ sum of population sizes of English LADs over the 12 months) x population size of LAD*i* in the month of interest in 2011.

The methods I used to analyse the data in this section are from Blangiardo and Cameletti (2015) section 7.1.1 (396, pp.238-245). The formulae used in the temporal and spatiotemporal analyses are adapted from that used in the disease risk mapping and ecological regression analyses, described in sections 7.4.2-3. Parameters were included in the temporal and spatiotemporal regression equations to model the temporally structured and unstructured effects. Temporally structured and unstructured effects are analogous to the structured and unstructured spatial effects described in section 7.4.2. The temporally structured effect models an autoregressive structure within the outcome data, in which the values of the outcome parameter (e.g. proportion of excess deaths) at a specified time are correlated with the proportion of excess deaths for previous and subsequent months. Conversely, the unstructured temporal effect models the variance within the outcome data that is independent between time points. The formula that was used in the temporal and spatiotemporal analyses also included a parameter that enables the risk of excess mortality to increase and decrease through time (404). Without this parameter, the models would impose a linearity constraint on the temporal trend, which would be inappropriate for use with my data, as I would expect excess mortality decrease from the winter to the summer months and subsequently increase towards to subsequent winter season, rather than to follow a positive or negative linear trend across the year.

I analysed the circulatory and respiratory mortality data from 2011 separately. This enabled me to compare factors associated with spatiotemporal variations in mortality between condition groups.

Initially, I performed temporal analyses, to identify trends in condition- group-specific monthly mortality over the year. I generated graphs to illustrate the posterior temporal trend of condition-group-specific mortality for the structured and unstructured effects.

I generated DIC values for regression models containing temporal effects, as well as three different types of spatiotemporal interaction effect, for circulatory and respiratory conditions. An explanation of each spatiotemporal effect is as follows, based on methods developed by Blangiardo et al (396):

1. Type 1 space-time interaction (ST1) assumes there is no spatial or temporal structure in the data. Consequently, there is no interaction between spatial and temporal effects.

2. Type 2 space-time interaction (ST2) (structured time interacts with unstructured space). In this model, there is a temporal structure within the outcome data for each area, but the temporal structures of the data are independent between areas.

3. Type 3 space-time interaction (ST3) (structured space interacts with unstructured time). Here, there is a spatial structure within the data at each time point, but the spatial structures are independent between different time points.

I ran models for temporal and three types of space-time interaction effect to assess which model accounted for the greatest proportion of variation in the morality data. The model containing the effect with the lowest DIC value was used as the null model.

As with the seasonal models, I incorporated individual covariates into the relevant null model and generated RR estimates, 95% credible interval and DIC value, to assess the association between the factor and spatiotemporal variations in condition-group specific mortality across the year. I used the DIC values to assess whether each covariate improved the model from the null model.

After producing these univariable regression models, I produced multivariable models using the forward stepwise regression approach described in section 7.4.3. Collinear variables that had VIF values ≥3 were not included in the multivariable models. Variables that had 95% credible intervals for their regression estimates that crossed one (indicating a non-significant effect) were removed from the multivariable models.

7.4.5 Methods to identify spatiotemporal variations in excess winter mortality from circulatory and respiratory across winter seasons from 2001/2 to 2011/12, in relation to climatic factors

In the next stage of my analysis, I explored spatiotemporal variations in condition-group-specific mortality, in relation to meteorological factors. Previous investigations of cold-weather-related mortality have focused on associations between temperature and adverse health and social outcomes. However, it is possible that other aspects of English weather also contribute to spatiotemporal variations in excess mortality and other adverse outcomes between winter seasons (see chapter four, section 4.4.2 for a brief discussion). Large temporal variations in excess mortality between winter seasons are likely to be related to factors that can vary significantly from one year to the next, potentially including climatic factors.

Data for the climatic variables were available from January 2001-December 2012. I aggregated mortality counts for each condition group and calculated average values for the climatic variables over the four month winter periods of each season. Each official winter period incorporates months from two different calendar years (e.g. December 2010 and January to March 2011), and population sizes are calculated each year and generally vary from one year to the next in each area. Consequently, average population sizes of LADs across the months of interest from each winter period were used to calculate the expected number of deaths, which was used as an offset in the regression models, using the following formula:

Expected total number of deaths per condition group in LADi per winter season = (total number of condition-group-specific deaths in England over the winter seasons included in the analysis (e.g. 2001-2 and 2011-12) / sum of population sizes of English LADs over the winter seasons included (calculated by summing the average population sizes of English LADs across the four months of each winter season) * average population size of LADi per winter season

I used the same procedure as described in section 7.4.4 to identify a suitable null model for the analyses by comparing DIC values from models including temporal and spatiotemporal effects, and to develop individual and multivariable regression models, which contained NAO indices and other meteorological variables produced in chapter six.

7.4.6 Methods to identify spatiotemporal variations in excess winter mortality from circulatory and respiratory causes across winter seasons between 2001/2 and 2011/12, in relation to climatic factors and other individual covariates

Most of the data on non-climatic factors were unavailable for 2001-12, all of the years of interest in this investigation. It is possible to assign values from years when data for particular variables are available to other years (e.g. linear interpolation of data from the 2001 and 2011 Census for the non-Census, between years from 2002-10; or, assignment of the values of Census data from 2001 to the years 2001-6 and data from the 2011 Census assigned to the years 2007-12). However, this involves making arbitrary decisions.

In relation to the variable proportion of privately rented housing, it is likely that values for this variable increased from 2008 onwards, when home purchasing decreased due to the 'credit crunch' as banks stopped lending money. The number of over-occupied households is likely to have increased from the same year, as individuals tried to reduce housing costs. However, there is a lack of data on the exact trends in these Census variables on which to base data linkage decisions. I therefore decided to assess the individual effects of variables in relation to climatic factors for the years when the data were available.

The analyses in this section also enabled comparison with the results from sections 7.4.3-5, to examine whether the same associations between variables were apparent from the 2011 analyses and the winter periods 2001/2 – 2011/12.

The methods used to analyse the data are based on those used in sections 7.4.2 – 7.4.5. Aggregated mortality counts were used for each condition group over the four month winter periods of each season. The climatic variables included in the analyses for circulatory and respiratory conditions were based on those that were associated with spatiotemporal variations in excess mortality from each condition group from the analyses in section 7.4.5. Average values for the climatic variables across the four months of each winter season were used. The variables for individual non-climatic covariates included in each regression model were analysed in relation to mortality and climatic data for the closest winter seasons for which data were available. In some cases, the data were only analysed for one winter season. For example, the proportion of under-occupied housing from the 2011 Census was analysed in relation to excess mortality data from the winter season 2010/11, the closest winter season to the collection of the Census data, in April 2011. There were missing data for this variable at LAD level from the 2001 Census, which prevented them being analysed by R-INLA. Consequently, this variable was only included in an analysis in relation to one winter season. Other data were available for multiple or all seasons (e.g. data that measured $PM_{2.5}$

concentrations and proportion of older population data, which were available from 2002-12 and 2001-12, respectively). Ecological regression models were implemented when the data were only available for one winter season, whereas spatiotemporal regression models were used when data were available in relation to multiple winter seasons.

The same procedures were used to develop regression models containing individual and combinations of covariates, as described in sections 7.4.3-5.

7.5 Summary

This chapter describes the methods used to analyse data to address adapted research questions, examining which factors drive spatial and temporal variations in mortality across English LADs in relation to cold weather and winter season, and whether the same combination of factors are associated with spatiotemporal variations in cold-weather-related mortality from circulatory and respiratory conditions. In the next chapter, I present the results from the analyses.

Chapter Eight.

Results from analyses to investigate spatial and temporal variations in winter- and cold-weather-related mortality from circulatory and respiratory conditions across England in relation to explanatory factors

8.1 Introduction

In this chapter, I present the results from analyses to explore spatiotemporal variations in mortality from circulatory and respiratory conditions in relation to cold weather, winter season and other factors identified from the systematic reviews and conceptual modelling in chapters two-four, for which data were available (see chapter five).

Section 8.2 shows graphs illustrating temporal trends in circulatory and respiratory mortality rates over the study period from 2001-12. Graphs are also used to illustrate spatiotemporal variations in excess winter mortality indices from the same condition groups over the winter periods selected for this study (2001/2 – 2011/12).

Disease risk maps that illustrate spatial variations in condition-group-specific mortality ratios across English LADs, which incorporate data from climatically warmer and colder periods of the year from 2008-12, are presented in section 8.3.

In section 8.4, I present the results from ecological regression analyses to investigate spatial variations in condition-group-specific excess mortality between cold and warm periods of 2011, in relation to a comprehensive range of explanatory factors. I also present results from an investigation of associations between exposure variables and spatiotemporal variations in excess mortality from January to December 2011 in this section.

In section 8.5, I present results from spatiotemporal regression analyses of associations between climatic factors and variations in condition-group-specific excess mortality across winter seasons, from 2001/2 to 2011/12.

Results from analyses that investigate associations between combinations of climatic and individual non-climatic factors, in relation to spatial and spatiotemporal variations in excess mortality between English LADs across winter seasons are given in section 8.6.

Finally, in section 8.7, I summarise the results and examine the extent to which the results from analyses in the current chapter address adapted research questions three and four, by identifying commonalities and differences in relation to factors associated with spatial and spatiotemporal variations in excess winter and cold-related mortality between circulatory and respiratory conditions.

8.2 Temporal and spatiotemporal variations in mortality from circulatory and respiratory condition groups in England across years and winter seasons from 2001-12
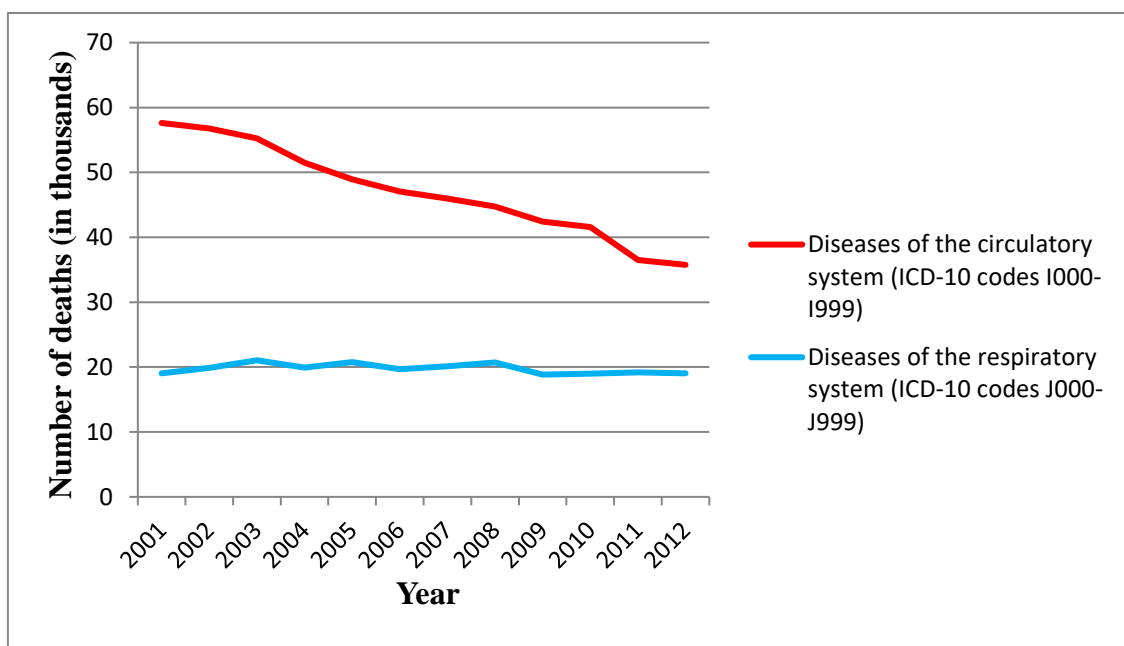
Figure 8.1: *Temporal trend in mortality from circulatory and respiratory conditions across England from 2001-12*

Figure 8.1 shows that circulatory mortality rates have fallen over the study period from 2001-12, whereas respiratory mortality rates have not shown an overall decline over the same time period.
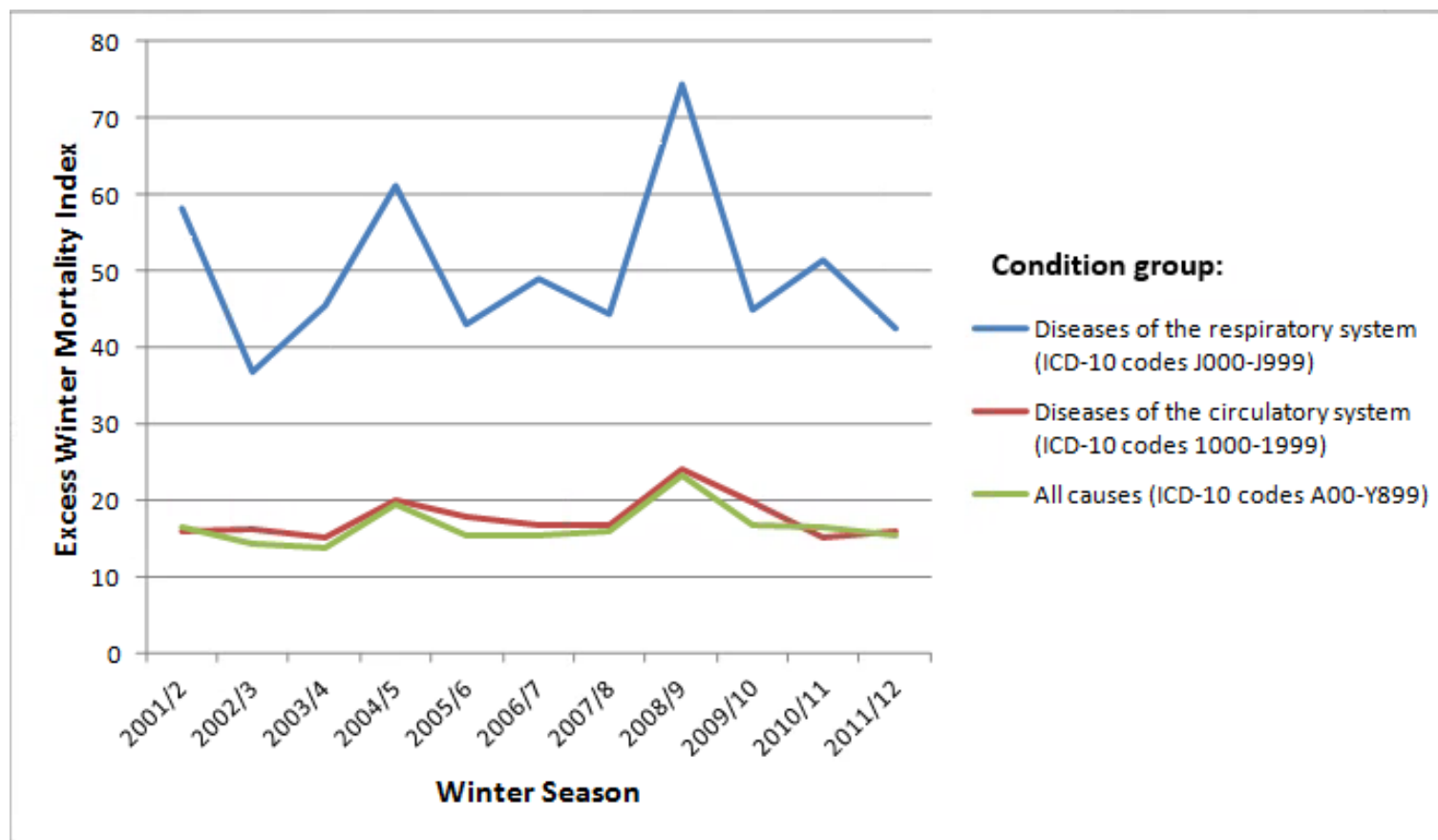
Figure 8.2: *Temporal variations in excess winter mortality indices from all-causes, circulatory and respiratory conditions across England for the winter periods 2001/2 – 2011/12*
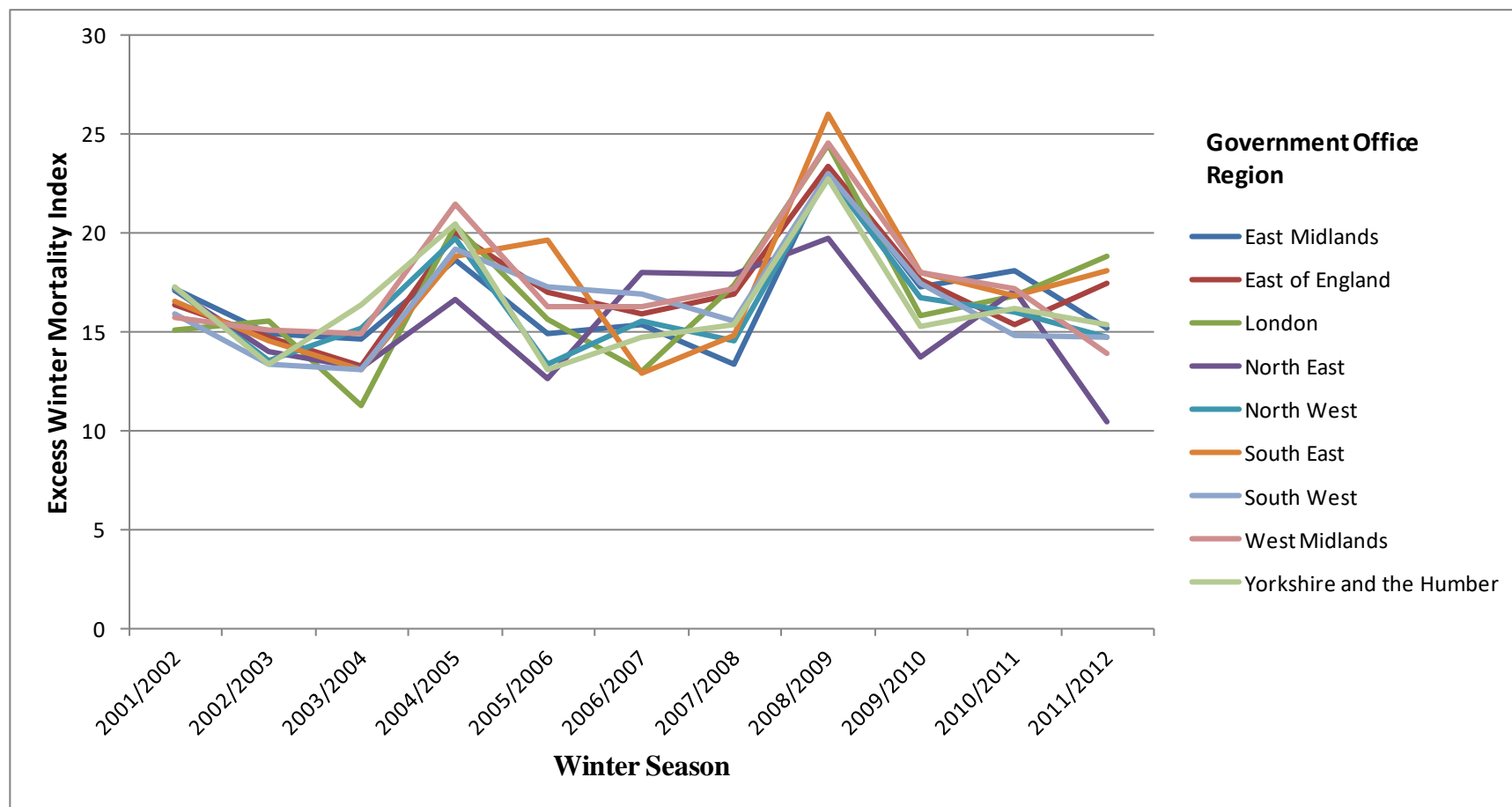
Figure 8.3: *Spatial and temporal variations in excess winter mortality indices from all-causes (ICD-10 codes A00-Y899) across English regions for the winter periods 2001/2 – 2011/12*
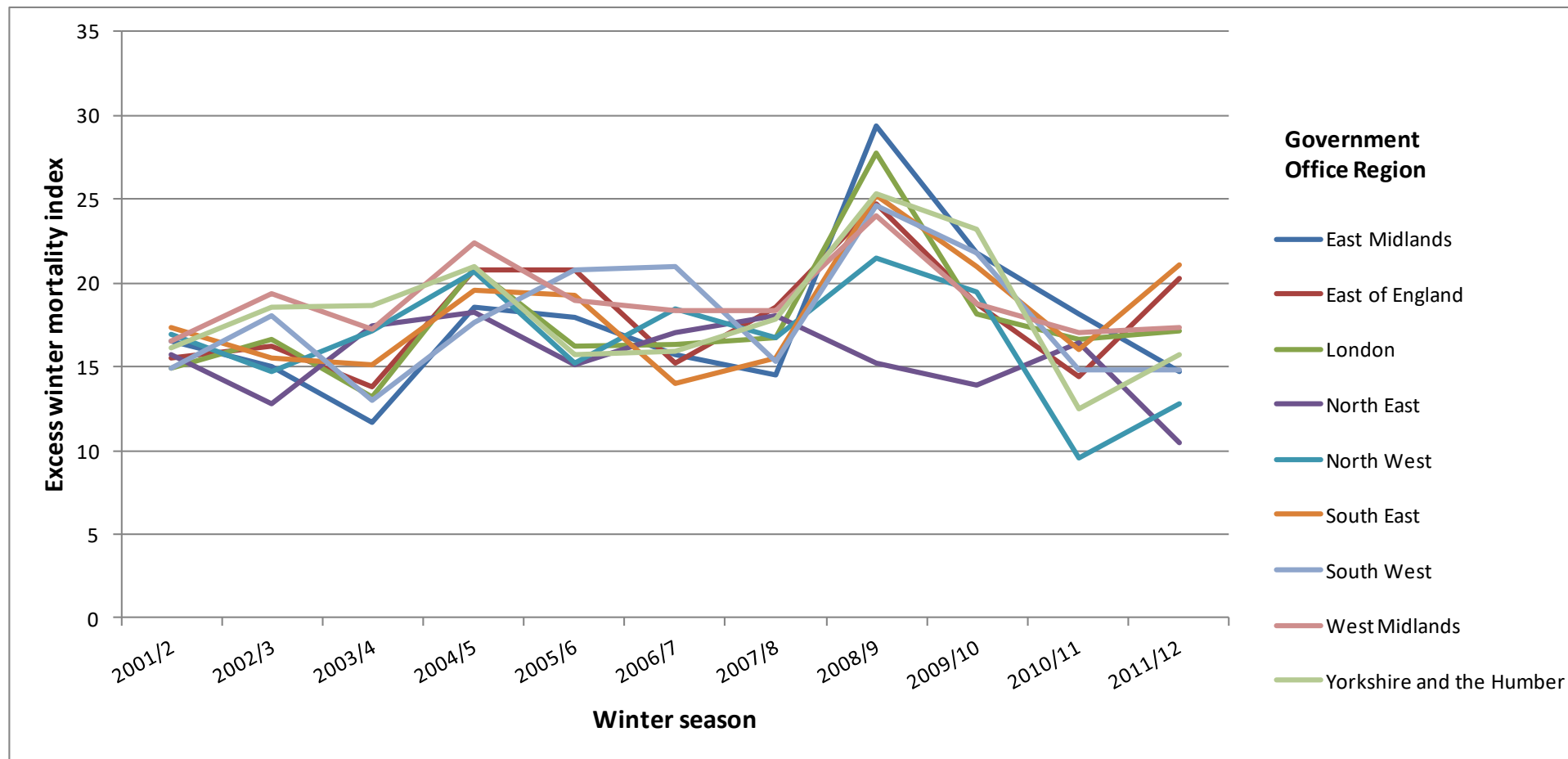
Figure 8.4: *Spatial and temporal variations in excess winter mortality indices from circulatory conditions (ICD-10 codes I000-1999) across English regions for the winter periods 2001/2 – 2011/12*
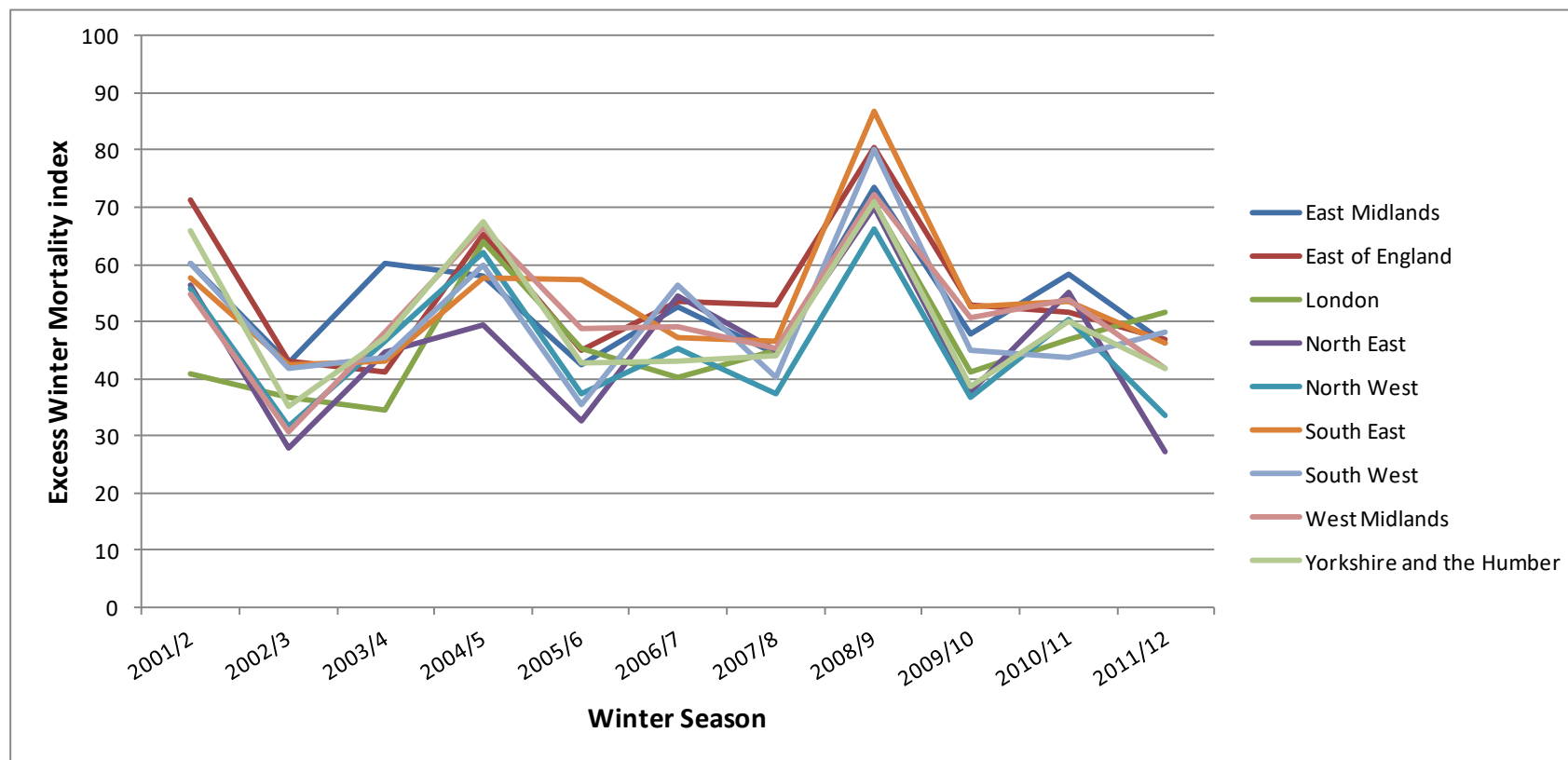
Figure 8.5: *Spatial and temporal variations in excess winter mortality indices from respiratory conditions (ICD-10 codes J000-J999) across English regions for the winter periods 2001/2 – 2011/12*

Figures 8.2-5 demonstrate spatial and temporal trends in excess winter mortality indices from all-causes, circulatory and respiratory conditions across the study period of interest, from 2001/2 – 2011/12. Figure 8.2 illustrates that respiratory conditions account for a greater proportion of excess winter deaths compared to circulatory conditions and all-causes.

Similar general trends in terms of peaks and troughs in excess winter mortality indices are shown for all-causes, respiratory and circulatory conditions across winter seasons in figures 8.2-5. Spatial variations in excess winter mortality indices are relatively synchronized between English regions for most winter seasons. Temporal variations in excess winter mortality indices are less synchronized, except for a general trend towards a peak in excess winter mortality indices for one winter season, followed by a trough during the subsequent winter.

8.3 Disease risk mapping of mortality from circulatory and respiratory conditions across English LADs using data from warm and colder periods of 2008-12

The English Local Authority Districts shown in the disease risk maps in figures 8.6 A-D can be identified using Public Health England's interactive mapping tool (408), which shows each area in relation to several health indicators and their level of deprivation. The disease risk maps in this thesis show a lack of apparent spatial or seasonal patterning in excess mortality from circulatory and respiratory conditions across England during warmer and colder periods (January-March and June-August, respectively), based on data from 2008-12.

In relation to the general, non-seasonal and non-condition-group-specific patterning of the disease risk maps in figures 8.6 A-D, my interpretation is as follows. Socioeconomic deprivation is associated with generally worse health outcomes, including higher rates of mortality from circulatory and respiratory conditions, as risk factors for these adverse health outcomes (e.g. smoking and obesity), are generally higher in more deprived areas. Figures 8.6 A-D show that certain LADs with high levels of deprivation (e.g. Carlisle, County Durham and Middlesbrough) have consistently high mortality risk, whereas some of the least socioeconomically deprived areas (e.g. Harrogate and Hambleton) have lower than average mortality risk. However, there are exceptions to this pattern, for example, Sunderland, Gateshead, Newcastle-upon-Tyne and South Tyneside are in the highest quintile of socioeconomically deprived English LADs, despite having below average (RR 0.1-0.9) or average (RR 0.9-1.1) mortality risk in the disease risk maps in figures 8.6 A-D . In addition, there are examples of socioeconomically less deprived LADs in the disease risk maps that have consistently high mortality risk (e.g. Eden, Test Valley and New Forest). This disparity may indicate that the data used to create the disease risk maps in figures 8.6 A-D do not reflect long term or year-round trends in mortality risk. Alternatively, different risk factors may influence mortality risk within certain English LADs to a greater extent than deprivation.

Rurality is one factor that may be a key determinant of increased mortality risk. For example, Eden (a less deprived LAD) and Torridge (a more deprived LAD), which are rural areas, have above average mortality risk in figures 8.6 A-D. Population exposure to cold weather conditions is likely to be greater in more rural LADs, which are generally situated in more exposed locations (e.g. by the coast). Rural housing stock is also generally older and larger, with more solid-walled properties compared to urban areas. In addition, many rural areas also have reduced access to gas networks, which provide a relatively economical fuel source for household heating. Also, rural areas have less industry, reduced traffic flow and fewer

buildings compared to urban areas, which means that less heat is generated and retained by the infrastructural characteristics of rural areas. However, the disease risk maps in figure 8.6 A-D also show examples of rural LADs with consistently low mortality risk (e.g. North Norfolk and Waveney). This also indicates that the effects of different factors on circulatory and respiratory mortality are likely to vary between LADs.
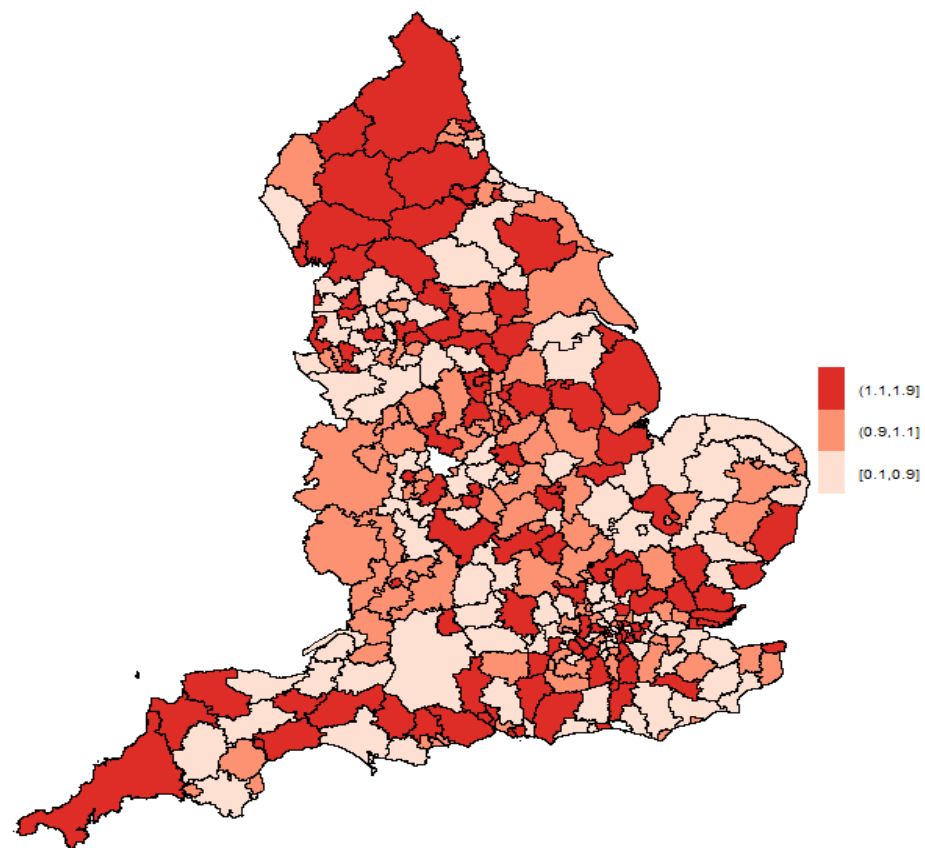
Figure 8.6 A: *Disease risk map showing relative risk of excess mortality from circulatory conditions during the coldest average 3-month period (January-March) from 2008-12. Areas are classified as having below average risk (RR 0.1-0.9), average risk (RR 0.9-1.1) or above average risk (RR 1.1-1.9).*
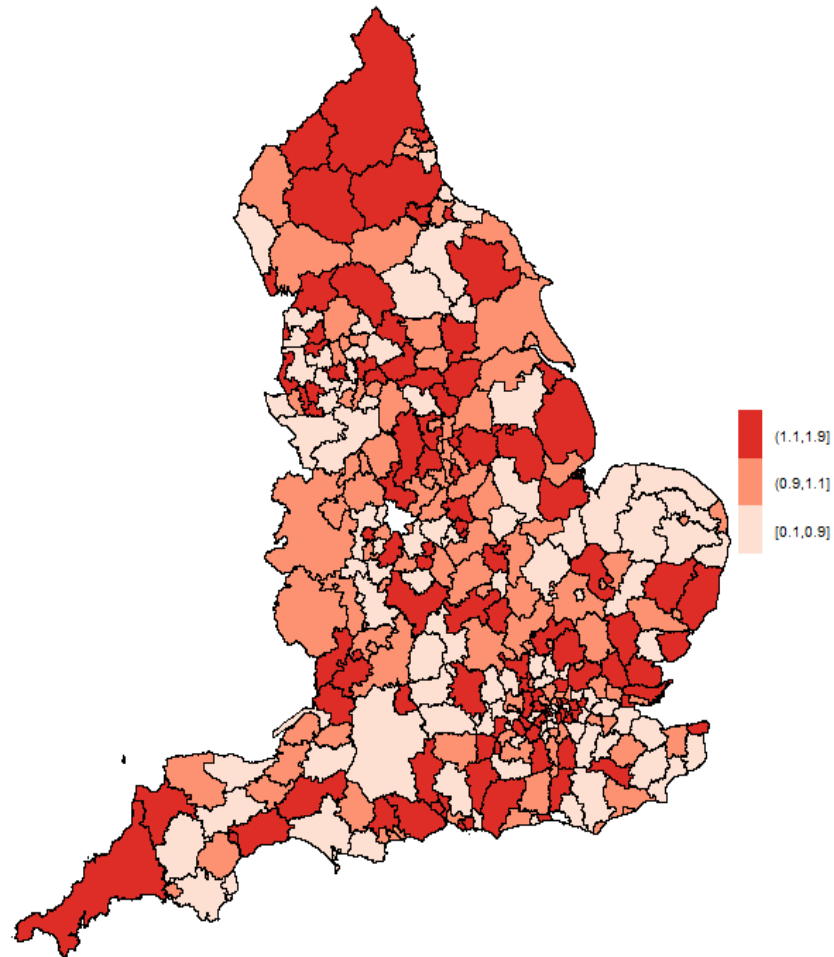
Figure 8.6 B: *Disease risk map showing relative risk of excess mortality from circulatory conditions during the warmest average 3-month period (June-August) from 2008-12. Areas are classified as having below average risk (RR 0.1-0.9), average risk (RR 0.9-1.1) or above average risk (RR 1.1-1.9).*
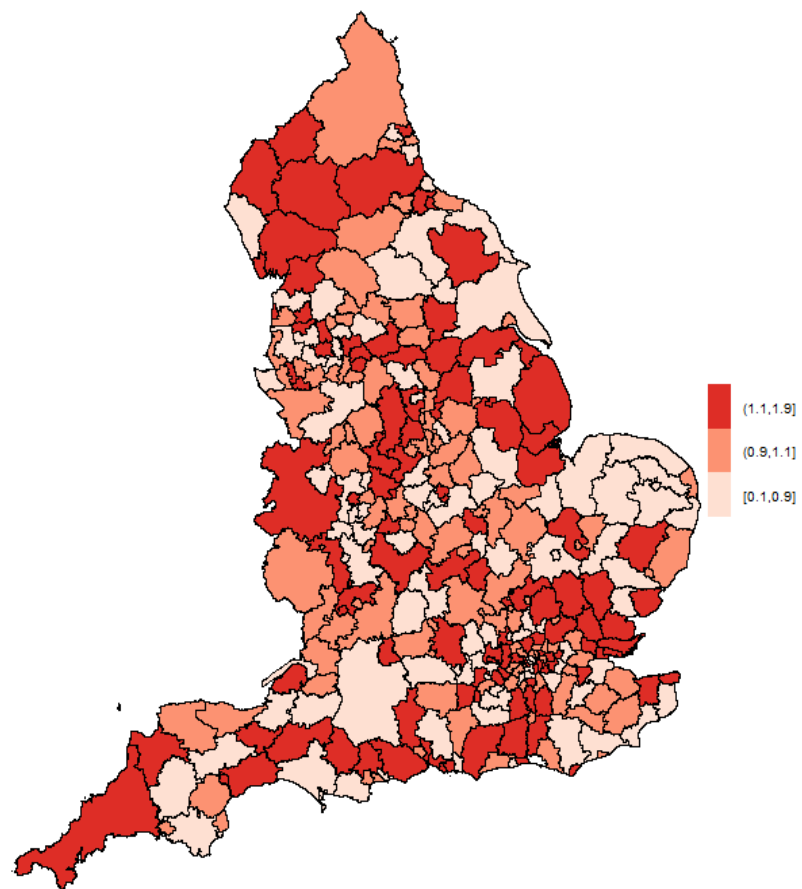
Figure 8.6 C: *Disease risk map showing relative risk of excess mortality from respiratory conditions during the coldest average 3-month period (January-March) from 2008-12. Areas are classified as having below average risk (RR 0.1-0.9), average risk (RR 0.9-1.1) or above average risk (RR 1.1-1.9).*
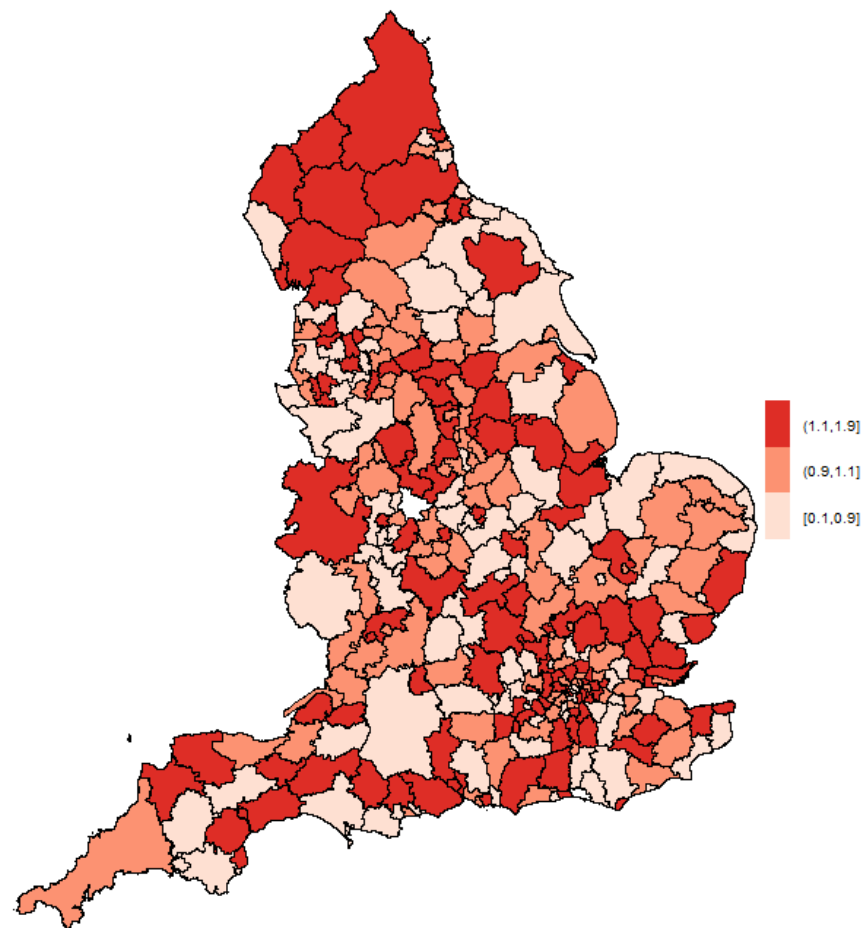
Figure 8.6 D: *Disease risk map showing relative risk of excess mortality from respiratory conditions during the warmest average 3-month period (June-August) from 2008-12. Areas are classified as having below average risk (RR 0.1-0.9), average risk (RR 0.9-1.1) or above average risk (RR 1.1-1.9).*

8.4 Regression analyses from 2011

8.4.1 Associations between explanatory variables

Correlation matrices were produced to identify associations between explanatory variables for each 3-month time period January to March (coldest 3-month period) and July to September (warmest 3-month period) from 2011. These data showed similar associations between exposure variables during the coldest and warmest periods. During the cold period, the correlations between explanatory variables (shown in appendix D) show that values of mean daily minimum temperatures (°C) per month, averaged across the 3 months, are most strongly associated with $PM_{2.5}$ (correlation coefficient 0.7); household crowding, population density and NO_2 (correlation coefficients all 0.6); proportion of privately rented households (correlation coefficient 0.5) and excess weight in adults (correlation coefficient - 0.5). As expected, fuel poverty was moderately, negatively correlated with mean minimum temperature (-0.4).

8.4.2 Results from the ecological regression analyses

Outputs from the univariable ecological regression analyses to investigate factors associated with spatial variations in excess mortality from circulatory and respiratory conditions during the coldest and warmest three month periods of 2011 are presented in appendices E-H.

The outputs from the univariable models (containing spatial effects and individual explanatory variables) show that mean daily minimum temperatures (°C) accounted for the greatest proportion of variance in the outcome data for circulatory and respiratory conditions, compared to other climatic factors during the cold and warmer periods. Most of the non-climatic explanatory variables in the analyses improved the model fit, in terms of reducing the DIC value compared to the null model for circulatory and respiratory conditions, during both time periods in the analyses. Measures of air pollution (especially $PM_{2.5}$), proportion of over-crowded households and population density were most commonly associated with lowest DIC values compared to the null models and other univariable regression models; these variables were all associated with reduced excess mortality across condition groups and seasons.

The final multivariable regression models for each condition group and time period are shown in figure 8.7.

Relative risk (RR) values and associated 95% Bayesian credible intervals (abbreviated to BCI in the figures in this chapter) for individual explanatory variables in the multivariable models are shown in green cells with row names for corresponding variables. Variables were

excluded from the multivariable models, which (i) did not improve the model fit (i.e. reduce the DIC value) (white cells), (ii) had a VIF value ≥3 (black cells), (iii) were inapplicable to the outcome variables (e.g. organisations providing cardiology services, in relation to excess respiratory deaths) (blue cells) or (iv) were not significant (had a 95% BCI that crossed one in the multivariable model) (red cells). Comparisons can only be made between variables included in the models for respiratory and circulatory conditions and between cold and warm periods in relation to variables that were eligible for inclusion (indicated by white, green and red cells).

Excess weight in adults and proportion of older people per LAD were included in the multivariable regression models for circulatory and respiratory conditions during the colder and warmer periods. Excess weight in adults was associated with increased risk of mortality from each condition group and for each period, whereas, counter-intuitively, the proportion of older population was associated with reduced excess mortality between LADs.

The prevalence of adult participation in moderate intensity physical activity and proportion of fuel poor households were included in the multivariable model for circulatory conditions during colder and warmer periods; physical activity was associated with reduced excess mortality and fuel poverty was associated with increased excess mortality from circulatory conditions. Neither of these variables was included in the multivariable regression models to explain spatial variations in excess respiratory mortality for either period.

Humidity was included in the multivariable models to explain excess circulatory and respiratory deaths during the cold period only and was associated with reduced excess deaths for both condition groups. Mean minimum temperature was included in the multivariable model to explain respiratory mortality during the cold period only and was inversely associated with excess mortality from this condition group. This variable was not significant in the final multivariable model for excess circulatory deaths during the cold period.

Smoking was included in the multivariable model for respiratory conditions only and was associated with increased excess mortality during the colder and warmer periods.

Variable	Excess circulatory deaths Jan-Mar 2011	Excess circulatory deaths Jul-Sep 2011	Excess respiratory deaths Jan-Mar 2011	Excess respiratory deaths Jul-Sep 2011
A&E				
Crowded%				
Ad_overwe%	RR 1.07, 95% BCI (1.04-1.10)	RR 1.09, 95% BCI (1.06-1.12)	RR 1.10, 95% BCI (1.06-1.13)	RR 1.09, 95% BCI (1.06-1.13)
FPov%	RR 1.05, 95% BCI (1.03-1.08)	RR 1.05, 95% BCI (1.02-1.07)		
Fro				
Hum	RR 0.96, 95% BCI (0.94-0.98)		RR 0.97, 95% BCI (0.95-1.0)	
Income dep%				
Max				
Mea				
Min	(red)		RR 0.96, 95% BCI (0.93-0.98)	
$N0_2$				
Y6_overwe%	RR 0.92, 95% BCI (0.89-0.94)	RR 0.92, 95% BCI (0.89-0.94)		
Age ≥65 years%	RR 0.95, 95% BCI (0.92-0.97)	RR 0.97, 95% BCI (0.94-0.99)	RR 0.94, 95% BCI (0.92-0.97)	RR 0.95, 95% BCI (0.92-0.98)
$PM_{2.5}$				
Popdens				
PrivRent%				
Cardiology				
Resp. Med				
Smok%			RR 1.04, 95% BCI (1.01-1.07)	RR 1.06, 95% BCI (1.03 - 1.09)
Activ%	RR 0.94, 95% BCI (0.92-0.97)	RR 0.93, 95% BCI (0.91-0.96)		
Sun				
RUC score				
Win				

Colour key

Variable included in the multivariable model

Variable excluded because it did not improve the model fit

Variable excluded because it had a VIF>3

Variable excluded because it was non-significant in the multivariable model

Variable excluded because it was inapplicable to the outcome variable

Variable key: A&E: Number of accidents and emergency departments per sq km *1000; **Crowded%:** Proportion of over-crowded households; **Ad_overwe%:** Proportion of overweight or obese adults; **FPov%** Proportion of fuel poor households; **Fro:** Days of air frost; **Hum:** Mean relative humidity; **Incomedep%:** Proportion of income deprived households; **Max:** Mean daily maximum temperature; **Mea** Mean daily air temperature; **Min** Mean minimum daily temperature; **N0₂** Annual mean modelled concentration of N0₂; **Y6_overwe%** Proportion of overweight or obese children aged 10-11 years; **Age ≥65 years%** Proportion of the population aged ≥65 years; **PM₂.₅** Annual mean modelled concentration of PM₂.₅; **Popdens** Population density, number per sq km; **PrivRent%:** Proportion of privately-rented households; **Cardiology:** Number of organisations providing cardiology services per sq km *1000; **Resp. Med:** Number of organisations providing respiratory medicine per sq km *1000; **Smok%** Adult smoking prevalence; **Activ%** Proportion of adults participating in 30 minutes of moderate intensity physical activity at least four times over the last 28 days; **Sun:** Sunshine duration; **RUC score:** Rural Urban classification score; **Win** Mean wind speed

Figure 8.7: *Combinations of factors included in the final multivariable regression models for circulatory and respiratory conditions during colder (January-March) and warmer (July-September) periods of 2011.*

8.4.3 Temporal and spatiotemporal regression analyses from 2011

Figures 8.8-8.9 show how the RR of excess mortality changes across the twelve months of 2011 for circulatory and respiratory conditions, respectively. The RR values show variation throughout the year for circulatory conditions, but much less so for respiratory conditions. In relation to circulatory conditions, the structured effect (explained in chapter seven, section 7.4) shows a general decline in RR of excess mortality from the winter to summer months of 2011 and a subsequent increase towards the next winter season.
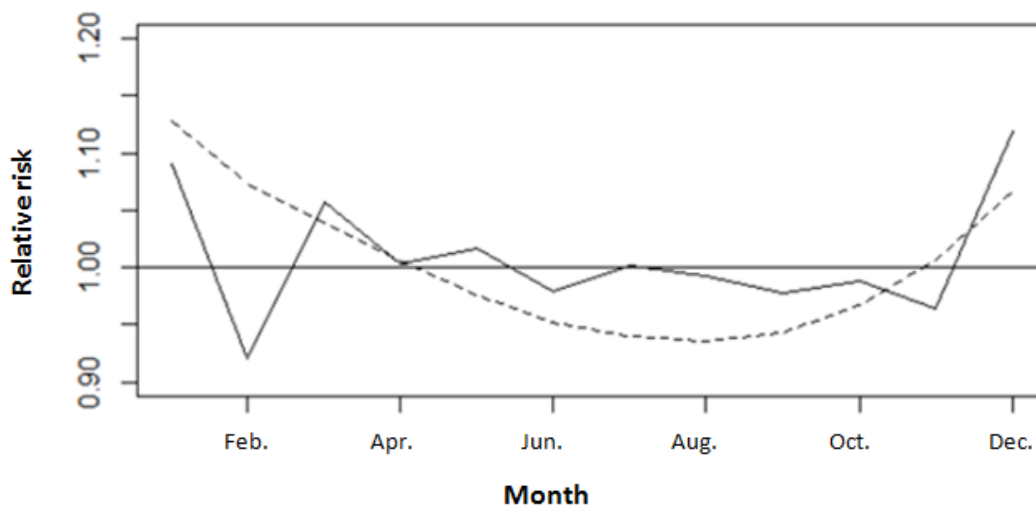
Figure 8.8: Posterior temporal trend for monthly deaths from circulatory conditions across England during 2011, showing structured and unstructured effects of time (dashed and solid lines, respectively).
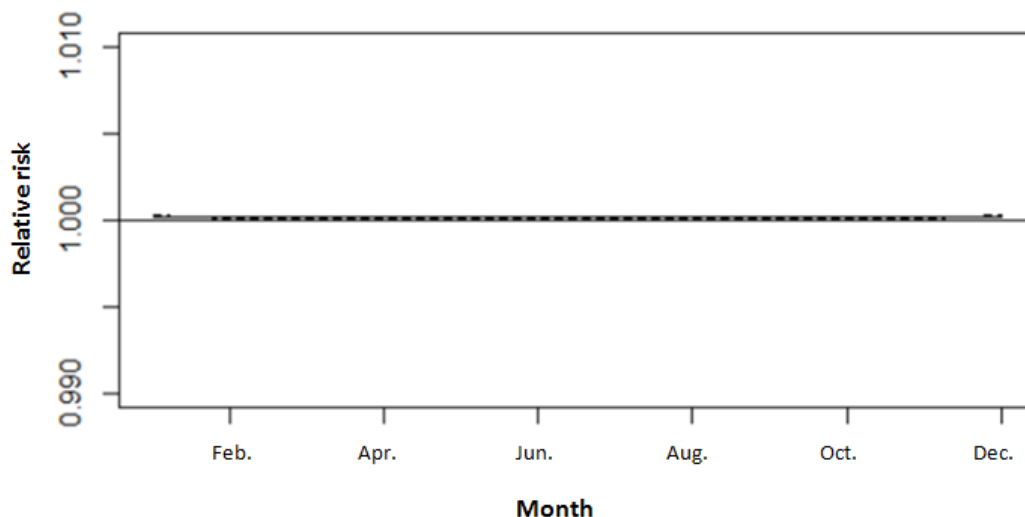
Figure 8.9: Posterior temporal trend for monthly deaths from respiratory conditions across England during 2011, showing structured and unstructured effects of time (dashed and solid lines, respectively).

Output from the regression analyses to investigate factors associated with and spatiotemporal variations in excess mortality from circulatory and respiratory conditions across English LADs for the twelve months of 2011 are presented in appendices I-J.

The output in table 8.1 shows the DIC values for regression models that contained temporal effects, as well as three different types of spatiotemporal interaction effect, for circulatory and respiratory conditions. Spatiotemporal model 'ST1' (no spatial or temporal structure or space-time interaction within the data) had the lowest DIC value, representing the best model fit for both condition groups and was therefore used as the null model (an explanation of each type of spatiotemporal effect is presented in section 7.4).

Table 8.1: *DIC values for null models (without covariates), with different types of temporal and spatiotemporal interaction effect for respiratory and circulatory conditions. The model with the lowest DIC value for each condition group is asterisked.*

Condition group	Effect	DIC value
Respiratory	Temporal	31878.22
Respiratory	ST1	19834.38*
Respiratory	ST2	20504.72
Respiratory	ST3	19844.88
Circulatory	Temporal	34424.31
Circulatory	ST1	24595.76*
Circulatory	ST2	24921.65
Circulatory	ST3	24597.93

The output and RR values for univariable regression analyses, which contain individual exposures (shown in appendices I-J), show that more of the included explanatory factors account for a greater proportion of the variance in excess mortality from circulatory conditions (compared to the null 'ST1' model, without covariates), than for respiratory conditions, across LADs from January to December 2011.

The best fitting univariable model (i.e. with lowest DIC value) to explain spatiotemporal variations in excess respiratory mortality across English LADs from January to December 2011 of those tested contained the measure of the proportion of fuel poor households, which was associated with increased excess mortality. For circulatory conditions, the model with the

lowest DIC value contained the covariate $PM_{2.5}$, which, counter-intuitively, was associated with reduced excess mortality.

The results of the multivariable regression models are shown in figure 8.10. The prevalence of excess weight in adults and of fuel poor households were included in the multivariable model to explain spatiotemporal variations in excess monthly respiratory deaths across English LADs from January – December 2011. The multivariable model with the lowest DIC value for circulatory conditions contained two variables, however, one of which (humidity) was non-significant (i.e. has a 95% BCI that crossed one in the multivariable model).

Variable	Excess circulatory deaths, Jan-Dec 2011	Excess respiratory mortality, Jan-Dec 2011
A&E		
Crowded%		
Ad_overwe%	RR 1.13, 95% BCI (1.09-1.16)	RR 1.14, 95% BCI (1.10-1.19)
FPov%		RR 1.08, 95% BCI (1.04-1.13)
Fro		
Hum		
Income dep%		
Max		
Mea		
Min		
N02		
Y6_overw%		
Age ≥65 years%		
PM2.5		
Popdens		
PrivRent%		
Cardiology		
Resp. Med		
Smok%		
Activ%		
Sun		
RUC score		
Win		
NAO		
NAOt-1		

Colour key

Variable was included in the multivariable model	(green)
Variable excluded because it did not improve the model fit	(white)
Variable excluded because it had a VIF>3	(black)
Variable excluded because it was non-significant in the multivariable model	(red)
Variable excluded because it was inapplicable to the outcome variable	(light blue)

Variable key: A&E: Number of accident and emergency departments per sq km *1000; **Crowded%:** Proportion of over-crowded households; **Ad_overwe%:** Proportion of overweight or obese adults; **FPov%** Proportion of fuel poor households; **Fro:** Days of air frost; **Hum:** Mean relative humidity; **Incomedep%:** Proportion of income deprived persons; **Max:** Mean daily maximum temperature; **Mea** Mean daily air temperature; **Min** Mean minimum daily temperature; **N0₂** Annual mean modelled concentration of N0₂; **Y6_overw%** Proportion of overweight or obese children aged 10-11 years; **Age ≥65 years%** Proportion of the population aged ≥65 years; **PM₂.₅** Annual mean modelled concentration of PM₂.₅; **Popdens** Population density, number per sq km; **PrivRent%:** Proportion of privately-rented households; **Cardiology:** Number of organisations providing cardiology services per sq km *1000; **Resp. Med:** Number of organisations providing respiratory medicine per sq km *1000; **Smok%** Adult smoking prevalence; **Activ%** Proportion of adults participating in 30 minutes of moderate intensity physical activity at least four times over the last 28 days; **Sun:** Sunshine duration; **RUC score:** Rural Urban classification score; **Win** Mean wind speed; **NAO:** North Atlantic Oscillation Index; **NAOt-1:** NAO value from the previous month

Figure 8.10: *Combinations of factors in the final multivariable regression models for circulatory and respiratory conditions from January – December 2011.*

8.5 Associations between climatic factors and spatiotemporal variations in excess mortality from circulatory and respiratory conditions for the winter seasons 2001/2-2011/12

Figures 8.11-12 show the temporal trends in RR of excess mortality for circulatory and respiratory conditions over the eleven winter seasons of the study period. The structured effect for excess mortality from circulatory conditions indicates an overall decline in excess circulatory deaths across the study period; whereas the structured effect for excess respiratory conditions shows a shallow wave effect, with a decrease in excess respiratory mortality from the first winter season in the analysis (2001/2) which levels off at around 2006/7 and increases from 2008/9.
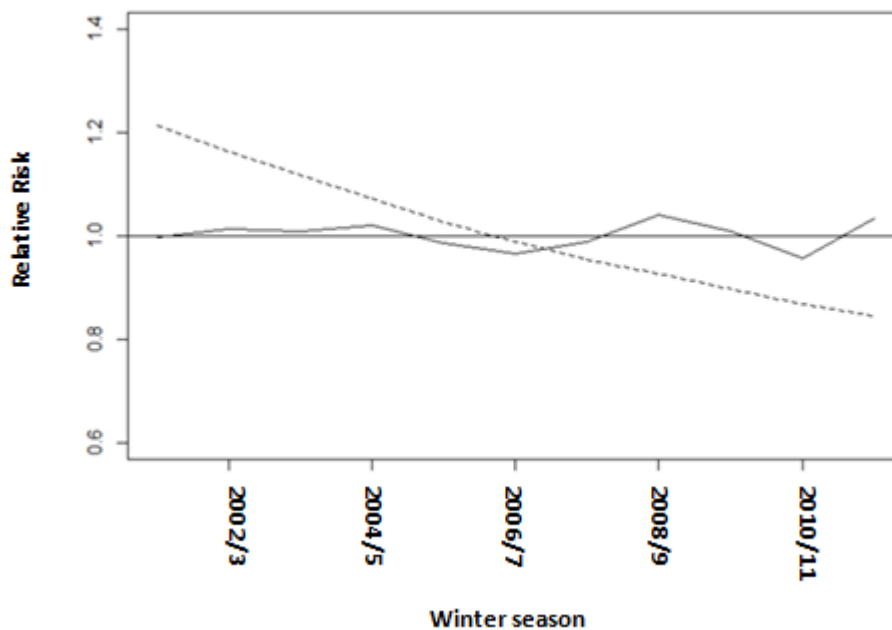
Figure 8.11: Posterior temporal trend for the relative risk of excess deaths from circulatory conditions across England over the winter seasons 2001/2 to 2011/12, showing structured and unstructured effects of time (dashed and solid lines, respectively).
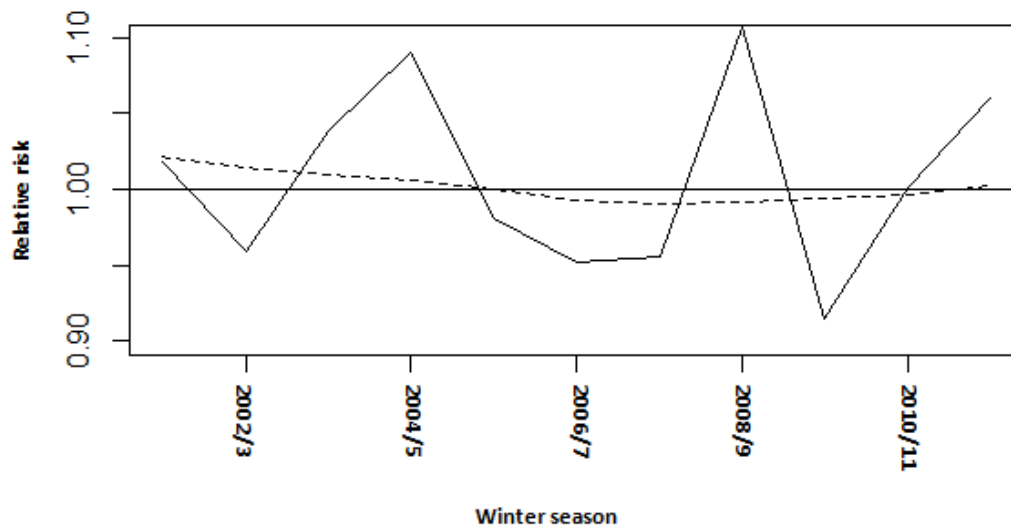
Figure 8.12: *Posterior temporal trend for the relative risk of excess deaths from respiratory conditions across England over the winter seasons 2001/2 to 2011/12, showing structured and unstructured effects of time (dashed and solid lines, respectively).*

The DIC values in table 8.2 show that model ST2 explained more of the variance in the data compared to temporal and other spatiotemporal models. Model ST2 was therefore used as the null model for the analyses.

Table 8.2: *DIC values for null models (without covariates) containing temporal and spatiotemporal interaction effects for respiratory and circulatory conditions. The model with the lowest DIC value for each condition group is asterisked.*
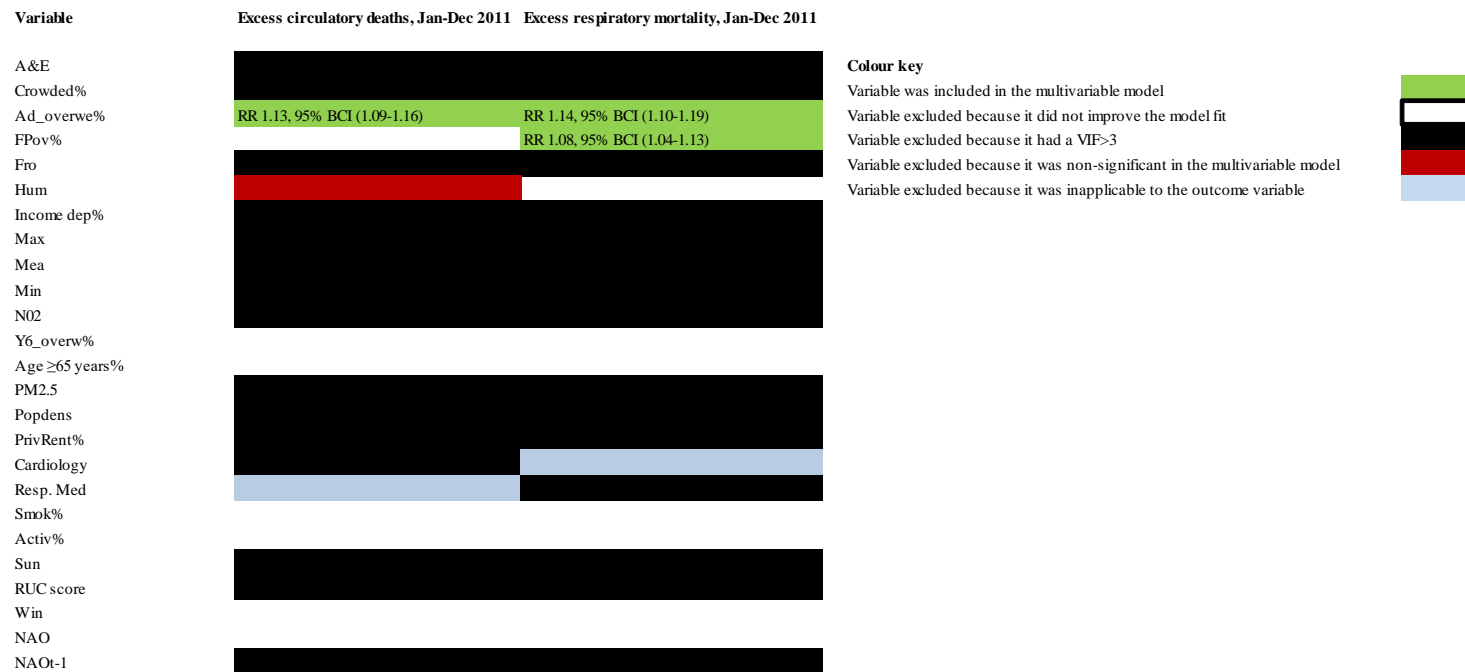
Condition group	Effect	DIC value
Respiratory	Temporal	44486.13
Respiratory	ST1	26964
Respiratory	ST2	26947.75*
Respiratory	ST3	27184.18
Circulatory	Temporal	71631.95
Circulatory	ST1	29870.42
Circulatory	ST2	29524.01*
Circulatory	ST3	30063.12

The results from the regression models including ST2 space-time interaction effects and individual explanatory variables for circulatory and respiratory conditions for the winter seasons 2001/2 to 2011/12 are presented in appendices K-L. For circulatory conditions, minimum mean temperature, relative humidity, air frost and mean air temperature reduced the DIC value from the null model. However, air frost and mean air temperature had VIF values >3 and were therefore excluded from the multivariable models. Mean minimum temperature and humidity were non-significant (had 95% BCIs that crossed one) in the univariable and multivariable models, therefore multivariable models were not created. For respiratory conditions, simple regression models that contained the temperature measures: maximum, mean and minimum air temperature, had lower DIC values than the null model (ST2), but only minimum temperature had a VIF score <3. I therefore, did not create multivariable models, because the effects of minimum temperature would be likely to be distorted by the two other temperature variables.

8.6 Associations between climatic and non-climatic factors and spatial or spatiotemporal variations in excess mortality from circulatory and respiratory conditions for the winter seasons 2001/2-2011/12

In the final stage of the analyses, I investigated combinations of climatic and individual non-climatic factors in relation to spatial and spatiotemporal variations in excess winter mortality from circulatory and respiratory conditions, over winter seasons for which the data are available. Figures 8.13 - 8.21 show the results of multivariable regression models from these analyses.

Climatic data are available for the whole study period (winter seasons 2001/2-2011/12). In situations where data were only available for one winter season for individual explanatory variables (e.g. fuel poverty prevalence), I used ecological regression to identify factors associated with spatial variations in excess winter mortality across English LADs and used 'bym' as the null model. For analyses which included individual variables that were available for multiple winter seasons, I identified an appropriate null model to specify space-time effects in the regression model (i.e. temporal, ST1, ST2 or ST3) using the procedure described in chapter seven (section 7.4). In each analysis, I included climatic factors in the analyses for each condition group which i) were associated with reduced DIC values from the null models and ii) did not have VIF values >3 in section 8.5. Minimum temperature was therefore tested in models for circulatory and respiratory conditions; humidity was also tested in the models for circulatory conditions.

Model	Excess circulatory deaths	Excess respiratory deaths
Popdens	RR 0.74 (95% BCI 0.69-0.79)	RR 0.71 (95% BCI 0.65-0.78)
Min		RR 0.98 (95% BCI 0.97-1.0)
Hum		
Null model used: ST2		
Variable key:		
Popdens (population density per sq km)		
Min (mean daily minimum temperature, averaged across the month)		
Hum (mean relative humidity, averaged across the month)		
Colour key:		
Variable included in the final multivariable model		
Variable was non-significant in the multivariable model		
Climatic variable (humidity) not assessed in relation to the outcome variable		

Figure 8.13: RR values and 95% credible intervals for variables included in the multivariable models including population density and climatic factors, in relation to condition-group-specific excess mortality across the winter seasons 2002/1 – 2011/12

Figure 8.13 shows that population density is associated with a significantly reduced RR of excess mortality for circulatory and respiratory conditions across LADs for the winter periods 2001/2-2011/12. Mean minimum temperature was included in the multivariable model for respiratory conditions. Increased values for this variable were associated with a reduction in excess mortality from this condition group.

Model	Excess circulatory deaths	Excess respiratory deaths
Age≥65 years%	RR 1.12 (95% BCI 1.09-1.13)	RR 1.11 (95% BCI 1.09-1.14)
Min		
Hum		
Null model used: ST2		
Variable key:		
Age≥65 years% (proportion of the population aged ≥65 years)		
Min (mean daily minimum temperature, averaged across the month)		
Hum (mean relative humidity, averaged across the month)		
Colour key:		
Variable included in the final multivariable model		
Variable was non-significant in the multivariable model		
Climatic variable (humidity) not assessed in relation to the outcome variable		

Figure 8.14: RR values and 95% credible intervals for variables included in the multivariable models including proportion of the population aged ≥65 years and climatic factors, in relation to condition-group-specific excess mortality across the winter seasons 2001/2 – 2011/12

Increased proportion of older population was associated with increased excess mortality from circulatory and respiratory conditions across English LADs based on data from the winter seasons 2001/2 – 2011/12. Climatic variables were not included in the final model for either condition group.

Model	Excess circulatory deaths	Excess respiratory deaths
Fpov%	RR 1.04 (95% BCI 1.01-1.08)	
Min	RR 0.96 (95% BCI 0.93-0.99)	RR 0.96 (95% BCI 0.93-0.99)
Hum		
Null model used: bym		
Variable key:		
Fpov% (proportion of fuel poor households)		
Min (mean daily minimum temperature, averaged across the month)		
Hum (mean relative humidity, averaged across the month)		
Colour key:		
Variable included in the final multivariable model		
Variable was non-significant in the multivariable model		
Climatic variable (humidity) not assessed in relation to the outcome variable		

Figure 8.15: RR values and 95% credible intervals for variables included in the multivariable models including percentage of fuel poor households and climatic factors, in relation to condition-group-specific excess mortality for the winter season 2011/12

Increased proportion of fuel poor households and reduced mean minimum temperature were associated with increased excess circulatory deaths between LADs over the winter season 2011/12. Fuel poverty was not included in the final multivariable model for respiratory conditions during this winter period.

Model	Excess circulatory deaths	Excess respiratory deaths
Ad_overwe%	RR 1.12 (95% BCI 1.08-1.15)	RR 1.10 (95% BCI 1.07-1.14)
Min		
Hum		
Null model used: bym		
Variable key:		
Ad_overwe% (proportion of overweight and obese adults)		
Min (mean daily minimum temperature, averaged across the month)		
Hum (mean relative humidity, averaged across the month)		
Colour key:		
Variable included in the final multivariable model		
Variable was non-significant in the multivariable model		
Climatic variable (humidity) not assessed in relation to the outcome variable		

Figure 8.16: RR values and 95% credible intervals for variables included in the multivariable models including percentage of overweight or obese adults and climatic factors in relation to condition-group-specific excess mortality for the winter season 2011/12

Excess weight in adults was associated with increased risk of excess mortality between LADs for the winter season 2011/12. Climatic factors were not included in the final models for circulatory or respiratory conditions.

Model	Excess circulatory deaths	Excess respiratory deaths
Incomedep%	RR 0.95 (95% BCI 0.92-0.98)	
Min	RR 0.93 (95% BCI 0.90-0.96)	RR 0.93 (95% BCI 0.90-0.96)
Hum		
Null model used: bym		
Variable key:		
Incomedep% (proportion of income deprived persons)		
Min (mean daily minimum temperature, averaged across the month)		
Hum (mean relative humidity, averaged across the month)		
Colour key:		
Variable included in the final multivariable model		
Variable was non-significant in the multivariable model		
Climatic variable (humidity) not assessed in relation to the outcome variable		

Figure 8.17: RR values and 95% credible intervals for variables included in the multivariable models including percentage of income deprived individuals and climatic factors, in relation to condition-group-specific excess mortality for the winter season 2009/10

Income deprivation and mean minimum temperature were included in the final model to explain spatial variation in excess circulatory mortality across LADs during the winter period 2009/10. Income deprivation was associated with reduced excess mortality.

Model	Excess circulatory deaths	Excess respiratory deaths
RUC score	RR 0.89 (95% BCI 0.87-0.92)	
Min	RR 0.94 (95% BCI 0.91-0.97)	RR 0.90 (95% BCI 0.87-0.93)
Hum	RR 0.96 (95% BCI 0.93-0.99)	
Null model used: bym		
Variable key:		
RUC score (urban classification score)		
Min (mean daily minimum temperature, averaged across the month)		
Hum (mean relative humidity, averaged across the month)		
Colour key:		
Variable included in the final multivariable model		
Variable was non-significant in the multivariable model		
Climatic variable (humidity) not assessed in relation to the outcome variable		

Figure 8.18: RR values and 95% credible intervals for variables included in the multivariable models including urban score and climatic factors, in relation to condition-group-specific excess mortality for the winter season 2010/11

Urban dwelling, mean minimum temperature and humidity were all associated with reduced risk of circulatory mortality in the final multivariable model. The final model for excess respiratory mortality contained only mean minimum temperature.

Model	Excess circulatory deaths	Excess respiratory deaths
Crowded%	RR 0.83 (95% BCI 0.81-0.85)	RR 0.84 (95% BCI 0.81-0.86)
Min		
Hum	RR 0.97 (95% BCI 0.95-1.0)	
Null model used: bym		
Variable key:		
Crowded% (proportion of over-occupied households)		
Min (mean daily minimum temperature, averaged across the month)		
Hum (mean relative humidity, averaged across the month)		
Colour key:		
Variable included in the final multivariable model		
Variable was non-significant in the multivariable model		
Climatic variable (humidity) not assessed in relation to the outcome variable		

Figure 8.19: *RR values and 95% credible intervals for variables included in the multivariable models including percentage of over-crowded households and climatic factors, in relation to condition-group-specific excess mortality for the winter season 2010/11*

Proportion of over-crowded households was also associated with reduced excess circulatory and respiratory mortality for the winter period 2009/10. Humidity was also included in the multivariable model for circulatory conditions and was associated with reduced excess mortality.

Model	Excess circulatory deaths	Excess respiratory deaths
PrivRent%	RR 0.90 (95% BCI 0.87-0.94)	RR 0.94 (95% BCI 0.91-0.97)
Min	RR 0.95 (95% BCI 0.92-0.99)	RR 0.91 (95% BCI 0.88-0.94)
Hum	RR 0.96 (95% BCI 0.93-0.99)	
Null model used: bym		
Variable key:		
PrivRent% (proportion of privately rented households)		
Min (mean daily minimum temperature, averaged across the month)		
Hum (mean relative humidity, averaged across the month)		
Colour key:		
Variable included in the final multivariable model		
Variable was non-significant in the multivariable model		
Climatic variable (humidity) not assessed in relation to the outcome variable		

Figure 8.20: *RR values and 95% credible intervals for variables included in the multivariable models including percentage of privately rented households and climatic factors, in relation to condition-group-specific excess mortality for the winter season 2010/11*

Private rented housing, minimum temperature and humidity were associated with reduced excess mortality in the final multivariable model for circulatory conditions. Privately rented housing and minimum temperature were also in the final model for respiratory conditions.

Model	Excess circulatory deaths	Excess respiratory deaths
Activ%	RR 0.98 (95% BCI 0.98-0.99)	
Min		RR 0.95 (95% BCI 0.93-0.97)
Hum		
Null model used: ST1		
Variable key:		
Activ% (proportion of adults participating in 30 mins moderate intensity physical activity at least four times within the last 28 days)		
Min (mean daily minimum temperature, averaged across the month)		
Hum (mean relative humidity, averaged across the month)		
Colour key:		
Variable included in the final multivariable model		
Variable was non-significant in the multivariable model		
Climatic variable (humidity) not assessed in relation to the outcome variable		

Figure 8.21: RR values and 95% credible intervals for variables included in the multivariable models including percentage of adults participating in moderate intensity physical activity and climatic factors, in relation to condition-group-specific excess mortality for the winter season 2005/6-2011/12

Increased participation in physical activity alone was the best model of those tested to explain spatiotemporal variations in excess mortality from circulatory conditions across LADs over the winter periods from 2005/6-2011/12. Only mean minimum temperature was in the final model for respiratory conditions.

8.7 Discussion

In this chapter, I explored associations between spatial and spatiotemporal variations in excess mortality from circulatory and respiratory conditions in relation to cold weather, winter season and other explanatory factors. The key findings from each set of analyses are summarised below, in relation to the relevant results sections within this chapter.

8.7.1 Results from graphs depicting the changing incidence of condition-group-specific and all-cause mortality in England across years and winter seasons from 2001-12 (section 8.2)

The results from figure 8.1 show that circulatory mortality rates have fallen from 2001-12. This is part of a longer temporal decline in circulatory deaths that has occurred in the UK since the 1970s and is likely to be attributable to factors including a general reduction in certain cardiovascular risk factors (e.g. smoking prevalence and blood pressure) and improved medical interventions (e.g. increased prescription of cholesterol lowering drugs (statins)) for CHD patients (409).

Trends in excess winter mortality indices across winter seasons, shown in figures 8.2-5, illustrate that respiratory conditions account for a greater proportion of excess winter deaths compared to circulatory deaths, which are high all year round. These data also show similar

general geographic and temporal trends in excess winter mortality indices from all-causes and from circulatory and respiratory conditions across the winter seasons 2001/2-2011/12. Spatial variations in excess winter mortality indices are also relatively synchronized between English regions for most winter seasons. Temporal variations in excess winter mortality indices show less synchrony, except for a general trend towards a peak in excess winter mortality indices for one winter season, followed by a trough during the subsequent winter.

8.7.2 Results from the disease risk maps from 2008-12

The disease risk maps in figures 8.6 A-D (section 8.3) showed a lack of obvious spatial pattern in excess mortality from circulatory and respiratory conditions between periods of cold and warmer weather, based on data from a 5-year period (2008-12). In relation to general, non-seasonal or condition-group-specific mortality patterns, certain local authorities with increased socioeconomic deprivation and some rural areas showed above average mortality risk. However, examples of socioeconomically less deprived LADs with consistently high mortality risk and of rural LADs with below average mortality risk were apparent. This may indicate that the data used in the disease risk maps did not reflect long-term or year round mortality risk for English LADs. In addition, the results may illustrate that the key determinants of circulatory and respiratory mortality rates vary between areas.

8.7.3 Results from the ecological regression analyses from 2011(sections 8.4.1-8.4.2)

The results from correlations between explanatory factors show mean daily minimum temperatures (°C) per month, averaged across the 3 months, are most strongly positively associated with measures of air pollution, proportion of over-crowded and privately rented households and population density, and negatively with the proportion of overweight and obese adults and fuel poverty.

The results from ecological regression analyses indicated that mean daily minimum temperatures (°C) accounted for the greatest proportion of variance in the outcome data for excess circulatory and respiratory conditions compared to other climatic factors during the cold and warmer periods. Most of the non-climatic explanatory factors accounted for more variance in spatial variations in excess mortality from circulatory and respiratory conditions during the cold and warmer periods compared to null models without covariates, indicating a possible non-seasonal effect of these factors. Measures of air pollution (especially $PM_{2.5}$), proportion of over-crowded households and population density were most commonly associated with lowest DIC values compared to the null models and other univariable regression models; these variables were all associated with reduced excess mortality across

condition groups and seasons. There was an association between greater proportion of older people in a population and reduced excess mortality between LADs in the analyses from 2011. Percentage of fuel poor households was associated with increased risk of circulatory and respiratory mortality during the colder and warmer periods of 2011. Smoking was included in the final multivariable regression model to explain spatial variations in excess mortality from respiratory conditions across LADs during the colder and warmer periods. However, it was not included in the final multivariable models for circulatory mortality. Humidity was associated with reduced circulatory and respiratory mortality during colder and warmer periods of 2011.

8.7.4. Results from the temporal and spatiotemporal regression analyses from 2011 (section 8.4.3)

Factors associated with urban dwelling, including measures of air pollution, proportion of crowded and privately rented households, population density, urban score and variables that measured the areal density of medical facilities, accounted for most of the variance in circulatory deaths from January to December 2011. Each of these variables was inversely associated with circulatory mortality. Fuel poverty, income deprivation and excess weight in adults were most associated with increased respiratory mortality, whereas medical access and aspects of urban dwelling were most associated with reduced respiratory mortality, across the same period.

8.7.5. Results from the analyses that assessed spatiotemporal variations in mortality in relation to climatic factors across the winter periods from 2001/2 to 2011/12 (section 8.5)

The three (minimum, mean and maximum) temperature variables in the analyses explained most of the variance in excess respiratory deaths across English LADs over the winter periods from 2001/2 – 2011/12. Mean minimum daily temperature was the only temperature variable that was negatively associated with excess deaths from this condition group. For circulatory conditions, mean minimum temperature and humidity were the two climatic factors that accounted for most of the variance in excess mortality from this condition group over the study period.

8.7.6. Results from the analyses that assessed spatiotemporal variations in mortality in relation to climatic factors and non-climatic factors across the winter periods from 2001/2 to 2011/12 (section 8.6)

The following results were obtained in relation to the effects of non-climatic factors on spatial and spatiotemporal variations in excess mortality from circulatory and respiratory mortality, in relation to individual or multiple winter seasons. Population density was associated with a reduced RR of excess mortality for circulatory and respiratory conditions across LADs for the winter periods 2001/2-2011/12. Increased proportion of older population was associated with increased excess mortality from circulatory and respiratory conditions across English LADs, based on data from the winter seasons 2001/2 – 2011/12. This is in contrast to the results from the analyses from 2011. Increased proportion of fuel poor households was independently associated with increased excess circulatory deaths between LADs over the winter season 2011/12. Excess weight in adults was associated with increased risk of excess mortality between LADs for the winter season 2011/12. Urban dwelling was associated with reduced risk of circulatory mortality in a multivariable regression model. Household crowding and private rented housing were associated with reduced excess mortality over the winter period 2010/11. Increased sport participation was associated with reduced excess mortality from circulatory conditions across LADs over the winter periods from 2005/6-2011/12.

8.7.7. To what extent have the analyses addressed modified research questions three and four?

In relation to research question three, namely: which factors, identified in chapter four, are associated with spatial and temporal variations in winter- and cold-weather-related mortality rates across English LADs?, climatically, temperature variables (particularly mean minimum daily temperature) and humidity (in relation to circulatory deaths) were most closely associated with spatiotemporal variations in EWM across winter seasons. In relation to non-climatic factors, increases in the following were associated with reduced excess mortality: (i) population density, (ii) urban score, (iii) prevalence of physically active adults; the proportions of: (iv) over-occupied and (v) privately rented households. The following factors were associated with increased excess mortality across winter seasons: increased proportions of (i) older population, (ii) fuel poor households and (iii) excess weight in adults.

In relation to research question number four, namely: 'are the same combinations of factors associated with spatial and temporal variations in winter- and cold-weather-related mortality rates from circulatory and respiratory conditions across English LADs?' commonalities and

differences were identified. Climatically, temperature variables were most closely associated with spatiotemporal variations in EWM across winter seasons from respiratory conditions; whereas, from circulatory conditions, mean minimum daily temperature and relative humidity accounted for the largest proportion of the variance. The direction and magnitude of effect of non-climatic explanatory variables on mortality were similar between circulatory and respiratory conditions. Thus, interventions could be developed to reduce excess mortality across both condition groups. Most explanatory factors showed similar associations with mortality between analyses across (i) winter seasons, (ii) between cold and warm periods and (iii) across months of 2011, which indicates non-seasonal / cold-weather-specific effects.

8.7.8 Summary

In this chapter, I described the results from analyses that explored associations between explanatory factors and spatial and spatiotemporal variations in excess mortality from circulatory and respiratory conditions across England, in relation to winter season and periods of cold weather. Conclusions from my analyses in relation to research questions three and four are as follows:

Research question three: *which factors, identified in chapter four, are associated with spatial and temporal variations in winter- and cold-weather-related mortality rates across English LADs?*

- Results from the analyses showed that climatic variables were more strongly associated with spatial and temporal variations in excess mortality from circulatory and respiratory conditions across English LADs in relation to the winter period, compared to non-climatic factors.
- In relation to non-climatic factors, increased proportions of older people, fuel poor households and excess weight in adults were associated with increased excess mortality, whereas measures of urbanicity and adult sport participation were associated with reduced mortality, in relation to the winter season. However, these effects were generally also found non-seasonally.

Research question four: *are the same combinations of factors associated with spatial and temporal variations in winter- and cold-weather-related mortality rates from circulatory and respiratory conditions across English LADs?*

- In relation to climatic variables, measures of environmental temperature were most closely associated with spatiotemporal variations in EWM across winter seasons from respiratory conditions, whereas mean minimum daily temperature and relative humidity accounted for the largest proportion of the variance in relation to circulatory conditions.

- The direction and magnitude of the effects of non-climatic explanatory variables on mortality were similar between circulatory and respiratory conditions.

In chapter nine, I discuss the results from each chapter of the thesis in relation to the limitations of the data and the methods used, and I relate the research findings to the wider literature. I also identify the policy implications of the work in this thesis and propose ideas for further research.

Chapter Nine.

Discussion

9.1 Principal findings

In this thesis, I aimed to answer five research questions (specified in chapters one and seven, sections 1.2 and 7.1, respectively). In relation to research question number one (i.e. what are the key social factors that affect vulnerability to excess winter- and cold-related adverse health and social outcomes, according to current research?), I identified a range of socioeconomic, housing and lifestyle-related factors that were associated with modified risk of specific outcomes, in relation to cold weather and winter season, from a systematic literature review (chapters two and three). Most of the evidence related to the impacts of explanatory variables on the circulatory and respiratory systems.

In chapter four, I conceptualised the mechanisms by which environmental, social and biological factors, including those identified from chapters two and three, could moderate and mediate associations between winter season, cold weather and morbidities and mortality from circulatory and respiratory conditions. This chapter aimed to address research question two, namely: what are the mechanisms by which the factors identified from the answer to question one moderate winter- and cold-weather-related morbidities and mortality?

I subsequently identified data to represent explanatory variables from the systematic review and conceptual modelling and undertook ecological regression analyses, in which I explored associations between individual and combinations of factors and spatial and temporal variations in mortality across English LADs, in relation to cold weather and winter season. This was in order to address adapted research question three, namely: which factors, identified in chapter four, are associated with spatial and temporal variations in mortality rates across English LADs, in relation to cold weather and winter season?

I also identified commonalities and differences regarding factors associated with spatial and temporal variations in excess winter-and cold-weather-related mortality from circulatory and respiratory conditions, thereby addressing adapted research question four: are the same factors associated with winter- and cold-weather-related spatial and temporal variations in mortality rates from circulatory and respiratory conditions, across English LADs?

The disease risk maps in figures 8.6 A-D (section 8.3) showed a lack of apparent spatial and seasonal patterning in mortality risk from circulatory and respiratory conditions across English LADs. In relation to non-seasonal effects, certain rural areas and some LADs with high levels of socioeconomic deprivation had above average mortality risk. However, there were also examples of socioeconomically deprived and rural areas with reduced mortality risk.

The results from the ecological regression analyses indicated that in relation to climatic factors, mean minimum daily temperature accounted for the greatest proportion of variance in excess circulatory and respiratory mortality during cold and warmer periods of 2011, which indicates non-seasonal effects. In relation to circulatory deaths, mean minimum temperature, mean air temperature, humidity and air frost accounted for some of the spatiotemporal variation in excess mortality between LADs across winter seasons 2001/2 to 2010/11. Regarding respiratory conditions, mean maximum temperature, mean temperature and mean minimum air temperature were most influential in explaining excess respiratory deaths between LADs across the same winter periods. Each of these meteorological factors was inversely associated with excess mortality, except for mean maximum temperature (for respiratory conditions) and mean air temperature (for circulatory and respiratory conditions), which were positively related to excess mortality rates.

Most of the non-climatic factors in the analyses accounted for more of the variance in spatial and spatiotemporal variations in excess mortality from circulatory and respiratory conditions compared to null models, without explanatory variables. Variables which theoretically characterise the urban environment, including increased population density, urban score, measures of air pollution (particularly $PM_{2.5}$), proportions of over-crowded and privately-rented households and hospital density per square kilometre, were generally associated with reduced excess mortality and accounted for a greater proportion of the variance in excess deaths compared to other variables. These effects were observed across condition groups and time periods investigated (i.e. in analyses between winter seasons, cold and warm periods and months of 2011, for circulatory and respiratory conditions), which indicates non-seasonality.

9.2 Strengths and limitations of the methods

The exploratory research in this thesis represents a novel contribution to the evidence base concerning associations between environmental and social factors and winter-and cold-related illnesses and mortality. It also offers useful insights concerning the strengths, weaknesses and accessibility of secondary data in England for public health and social science research; it represents a novel linkage of a wide range of health, social and environmental variables, and

demonstrates the application of modelling to address questions regarding spatial and temporal variations in health and social outcomes.

Many of this study's limitations stem from the unavailability of data. It was not possible to obtain morbidity data for the statistical project. Mortality data are commonly used as a proxy for health and wellbeing, as they are generally more accessible compared to other health and social outcome data. However, risk factors for cold-related mortality and illnesses may be different. It is estimated that for every excess winter death, there are eight additional hospital admissions (2). Therefore, knowledge about the determinants of excess winter morbidities could enable the development of more effective interventions for reducing cold-related medical consultations and the associated economic costs.

The lack of demographic breakdown of the mortality data prevented me from standardising the outcome data for age. This may have reduced the accuracy results concerning associations between explanatory factors and mortality in regression models without a measure of population age profile, as mortality rates are likely to be higher in areas with a higher proportion of older persons. Lack of demographic breakdown of the mortality data also prevented investigation of the effects of cold-weather and other explanatory variables on mortality in specific demographic groups. This information could have provided useful insight for developing and targeting interventions more effectively to reduce cold-weather-related excess deaths in LADs. However, I included a measure of older population as an explanatory variable in the analyses, the results of which could provide evidence to inform interventions which target resources towards LADs with an increased proportion of older persons, during the winter period.

Most of the explanatory social factors analysed in the statistical project were non-seasonally associated with excess mortality across LADs during the time periods for which the data were available and analysed. This could reflect data limitations, for example, the lack of year-round data on most non-climatic explanatory variables prevented seasonal changes (e.g. in physical activity levels) from being assessed. Also, the data obtained for this project may not be adequate indicators of what they aim to measure (e.g. air pollution measurements in each LAD may not reflect population exposure). In addition, more disaggregated data (e.g. to MSOA level) may have revealed seasonal effects of more of the explanatory factors (e.g. between obesity prevalence and increased risk of excess mortality during cold-weather periods).

Alternatively, the non-seasonal or cold-weather-specific effects of most explanatory variables in the analyses may indicate that factors not considered in the analyses, may determine spatial

and temporal variations in excess winter mortality across English LADs. The explanatory variables considered were predominantly social factors, identified in the systematic literature review from chapters two and three. The prevalence of many socioeconomic, housing and lifestyle-related factors are unlikely to vary significantly across the year or between winter seasons. However, the temporal fluctuations in EWM indices shown in chapter eight (figures 8.2-5) indicate that factors likely to change between years, potentially including climatic factors, in addition to influenza and other infections, may contribute to the temporal patterning of excess winter mortality indices. Infectious disease data would need to be made available to test this hypothesis.

A further limitation is that statistical work in this thesis was conducted at LAD level. LADs are heterogeneous areas in terms of their socioeconomic, demographic and geographical characteristics. More informative results about the nature of cold-related adverse health outcomes could have been derived from research at a smaller area level. However, data for a wide range of indicators of interest were unavailable below LAD level.

Finally, I was unable to test the conceptual pathways described in chapter four due to a lack of longitudinal, individual level data on the exposure status of population sub-groups to a comprehensive range of climatic and non-climatic factors identified from the systematic review.

9.3 Interpretation of findings in relation to study limitations and existing knowledge

The ecological regression analyses in chapter eight indicated a potentially protective urban effect. This may partly explain why some of the least deprived rural LADs in Northern England (e.g. Eden) had a high risk of mortality from circulatory and respiratory conditions in the disease risk maps in figures 8.6 A-D.

The reduced mortality risk in relation to indicators of urban dwelling, particularly air pollution levels, from the analyses in chapter eight may reflect a limitation of the data and analyses in this project. This is because London, which is England's capital city, has very high levels of air pollution compared to other LADs, due to its heavier traffic flow and industry. However, London also has a small resident population, with most of its daily inhabitants commuting from other areas, for employment and tourism. The mortality data used in the analyses in chapter eight were death rates per LAD of residence; consequently, the City of London had very high levels of air pollution, but very low circulatory and respiratory mortality rates. The analyses in chapter eight calculated the mean effects of explanatory variables on mortality rates across England. However, the use of mean average as a measure

of central tendency can be problematic, as anomalous data can produce severely distorted results, potentially including a strong inverse association between air pollution and mortality across England, due to the situation in London. In relation to this methodological consideration and a large, expanding evidence base on the detrimental circulatory and respiratory health impacts of air pollution (described in section 4.4.2), I am unable to conclude that the air pollutants $PM_{2.5}$ and NO_2 are beneficial to population health.

In relation to respiratory conditions, mean minimum temperature was inversely associated with mortality rates across winter seasons, whereas mean maximum temperature and mean air temperature were both positively related to respiratory mortality rates for the same period. This may indicate that distinct processes increase respiratory mortality rates at different temperatures. For example, very cold and dry conditions are likely to increase the occurrence and detrimental health impacts of bronchospasm, whereas warmer and more humid environments may promote the survival and reproduction of respiratory pathogens, thereby increasing the occurrence of respiratory infections. The causes of variations in the incidence of respiratory infections between winter seasons are not well understood. However, there is a growing body of literature in support of an association between temperature, humidity and influenza morbidity rates (e.g. (410, 411)).

In addition, the non-seasonal or cold-weather specific effects of explanatory social variables on circulatory and respiratory mortality, and significant temporal fluctuations in EWM rates between years, may indicate a casual role of factors which fluctuate between winter seasons, potentially including infectious disease activity, on temporal variations in EWM indices. I was unable to obtain data to test this hypothesis, however, an association between influenza activity and seasonal variations in EWM was found in an alternative study (251). Also, the relatively high EWM rate in England during the 2014/15 winter season (shown in chapter one, figure 1.1) was attributed to the fact that the predominant strain of circulating influenza was particularly virulent in older people, an already high risk group (5). There were also a high number of influenza outbreaks in nursing homes for the elderly and the influenza vaccine against the circulating strain of the virus was less effective compared to previous years (5).

Mortality displacement ('cull effect') may also be relevant to temporal variations in excess winter mortality, whereby exposure to cold weather during one winter season hastens mortality amongst elderly and clinically vulnerable individuals. This could produce a more robust population, with increased likelihood of survival during subsequent winter seasons. However, once the population of vulnerable individuals increases (e.g. due to population ageing), EWM rates increase once again (412). This theory is supported by the increased risk

of excess mortality in relation to the proportion of persons aged ≥65 years across winter seasons, found in the analyses in chapter eight, which is consistent with existing knowledge that increased age is a risk factor for EWM.

Regarding the association between urban characteristics and reduced excess mortality across LADs that was observed in chapter eight, a previous study found increased EWM in rural areas of England, particularly in relation to increased deprivation (88). Rurality is also a risk factor for fuel poverty (14). Thus, decreased cold exposure and increased wealth, resources (including medical) and healthier populations (urban score was associated with reduced adult obesity and increased physical activity in the correlations in appendix D) may contribute to this apparently protective 'urban effect'. With regards to medical access, individuals from urban areas may be more likely to seek and receive medical treatment sooner following cardiac events or exacerbations of respiratory conditions, compared to rural dwellers. Thus, urban areas may have reduced circulatory and respiratory mortality rates (observed in chapter eight) but increased medical consultation rates (illustrated in a different study (300)).

There was an inverse association between the proportion of older people and excess mortality between LADs in the analyses during cold and warm periods of 2011. This may reflect confounding, as areas with the highest proportions of older people in 2011 were generally socioeconomically less deprived (e.g. Windsor).

Percentage of fuel poor households was associated with increased risk of circulatory and respiratory mortality during the colder and warmer periods of 2011, possibly due to the fact that low income, an aspect of deprivation, is associated with fuel poverty and also with adverse health outcomes on a non-seasonal basis.

The increased mortality risk in rural compared to urban parts of England that was found in relation to winter and non-winter seasons, may partly reflect the adverse health impacts of social isolation, which tends to be more prevalent in rural areas (413). The potentially detrimental health impacts of social isolation in relation to the winter season are currently under-researched. However, a study from England which explored the nature of vulnerability to fuel poverty, found that financial support between family members enabled some study participants to pay household energy bills during periods of cold weather (414).

9.4 Strengths and weaknesses of the available evidence

The systematic review in chapters two and three, and evidence that I have located since completing this review, indicates there is a large and expanding evidence base in relation to the associations between winter season, cold-exposure and adverse health outcomes.

Since 2013, a number of international ecological studies have been published, from countries including Africa Asia, and Spain, which have explored associations between cold weather and mortality, in relation to demographic and socioeconomic factors (e.g. (415, 416)). A study from France, a country in which research on EWM is lacking, found evidence that fuel poverty is a major determinant of perceived health (417). In addition, the authors of a recent study from Spain, which found that cold weather was associated with increased mortality and that the risk increased with age (418), called for the development of a national Cold Weather Plan for Spain. The increased international awareness of the detrimental health and social impacts of cold exposure is positive from a global health perspective. It also indicates that the relatively sparse body of international evidence that was located for the systematic review in chapters two-three, which included evidence that was published up until 2013, was unlikely to have been due to the fact that my search strategy only identified studies that were published in English.

Within the UK, an increased number of individual level intervention evaluation studies have been commissioned since 2012, which have evaluated, or are currently evaluating, the health and social impacts of housing and economic interventions aimed as reducing cold exposure. These investigations, some of which are ongoing, include several cohort studies, which are generally regarded to provide stronger evidence of potential causality compared to alternative observational research designs. In addition, the new studies investigate a broad range of health indicators and outcomes, including various measures of physical and mental health and health inequalities. This indicates an increased awareness of the scale of the detrimental impacts associated with cold weather and cold housing. There are also new studies which explore the mechanisms by which receipt of household thermal efficiency interventions influence indoor climatic conditions and thereby impact on health. By investigating pathways between household warmth interventions and improved health, this new research could provide stronger evidence that household thermal efficiency interventions cause a reduced risk of adverse health outcomes. The results from UK studies that have been published since I completed the systematic review in chapters two-three are summarised in the following paragraphs.

In relation to the issue of mortality displacement, described in section 9.3, a recent time-series analysis found evidence that most cold-weather-related deaths in London occurred among individuals who would not have died within six months (419). This finding supports the continued implementation of cold-weather-related public health interventions in order to

increase life expectancy. However, the results of this study may not generalise to populations outside of London.

Literature on the mental health impacts of exposure to cold housing has also increased. A review that was published in 2014 developed frameworks for pathways between household warmth interventions and improved mental health and wellbeing, based on evidence from intervention studies from a Cochrane review of the health impacts of housing improvements (192). This review considered the impacts of household thermal efficiency interventions on two aspects of mental health, namely (i) positive mental health, which refers to a person's wellbeing, resilience and ability to contribute to society, and (ii) mental disorders, which are diagnosable medical conditions. The review presented positive but mixed evidence that household warmth interventions had a beneficial impact on mental health. However, the studies included in the review generally had short-term follow-up periods, of approximately one year each.

A weakness of the available evidence is the lack of information regarding the nature of cold-weather-related mortality from dementia and Alzheimer's disease, which are highly seasonal with winter peaks (252). However, a recent study from the UK investigated causal pathways for EWM in relation to these medical conditions, using qualitative and quantitative evidence (a triangulation approach) (420). This study identified a wide range of biological and behavioural factors that could contribute to EWM from dementia and Alzheimer's disease, including reduced thermal perception, which made individuals less likely to increase their level of clothing in relation to temperature decreases; reduced ability to manage household bills in relation to fuel consumption, and inadequate nutrition, with individuals with Alzheimer's disease and related disorders being reported to forget to eat during the winter period, as increased darkness made it more difficult to identify meal times.

There is also currently a lack of information regarding the differential impacts of cold exposure between population sub-groups. Some evidence indicates that the effects of exposure to cold housing differs between age groups (14), although most research has focused on risk factors for cold-related mortality, which mostly affects the elderly and young children. Interventions have also focused on reducing EWM amongst older persons, as this population sub-group is the most vulnerable to winter mortality. This might explain why EWM rates have generally not increased following austerity measures that were implemented across England from 2010 (except during the 2014/15 winter period, in which higher EWM rates were caused by influenza), as older persons continue to be key recipients of cold-weather-related financial subsidies and household warmth interventions.

9.5 Implications for policy and practice

Research question five from the introduction is: what are the implications of the answers to questions 1-4 (see section 9.1), for policy interventions to reduce winter- and cold-weather-related morbidity and mortality? I am unable to make policy recommendations for reducing morbidity due to the unavailability of these data for the analyses. In relation to mortality, I address this question in the following paragraphs.

Inconsistencies were observed in relation to the associations between exposures and outcomes between studies in the systematic review in chapters two and three of this thesis. In addition, the disease risk maps in figures 8.6 A-D indicated a lack of apparent spatial patterning in mortality risk across English LADs. This suggests that the nature of EWM may vary between demographic groups and LADs, and highlights a possible need for policy interventions targeting the needs of specific population groups and specific areas, in order to improve health and wellbeing. Some LADs have already adopted this approach. County Durham, in the North East of England, comprises towns with relatively large population settlements and also remote, rural areas that contain households with low thermal efficiency ratings that are at risk of fuel poverty, which may contribute to excess winter morbidity and mortality rates in this LAD. Durham County Council locates households that are likely to be at high risk of fuel poverty using disease risk mapping to identify SAP ratings of homes within small areas of the County; 'at risk' households are targeted and householders are referred to fuel poverty reduction schemes for which they are eligible (395). Consequently, the development and implementation of cold-weather-related interventions within LADs, which reflect risk factors for adverse health outcomes in specific areas (e.g. in relation to the characteristics of local housing and the demographic profile of the population), may reduce cold-related adverse health and social outcomes, including health inequalities, in relation to cold weather.

The results from my analyses indicate geographical variation in excess mortality during periods of cold weather across English LADs. Local authorities are now responsible for public health in England, but are not obliged to address EWM. Therefore, political and public health interest in tackling cold-weather-related adverse health outcomes will be required to reduce spatial variations in EWM across LADs.

Public health research is important for providing information on the potential causes of adverse health outcomes and ways of improving health in population groups. However, as demonstrated in this thesis, a necessary pre-requisite is access to data on a range of health and social indicators, in order to generate evidence-based knowledge regarding the causes and solutions for population health issues. Although a wide range of health and social data are

collected in England, accessing much of these data for research purposes is highly problematic and presents a significant barrier to research. It is necessary for appropriate guidelines to be in place in order to protect against abuses of these data (e.g. by criminal or profiteering organisations). This is also important to uphold public confidence in order to support the continued collection of the data. However, my inability to obtain and link certain data appeared to be related to system factors. These included unreliable information about the time scale in which data could be obtained; lack of guidance about procedures for accessing data and the apparently arbitrary decisions made by members of staff not to respond to data requests that were, or would have been, made in accordance with specified guidelines. I consider that it is unethical for data to be collected from the public, but not made unavailable for purposes that are in the common interest of population, including for improving health and reducing inequalities in relation to cold-exposure.

The results from chapter eight indicated that minimum temperature was the most consistent climatic determinant of spatial and spatiotemporal variations in mortality from circulatory and respiratory conditions between English LADs and winter seasons. This information supports the use of temperature data for initiating a public health response in relation to the Cold Weather Plan, and for triggering the distribution of Cold Weather Payments in England.

The analyses in chapter eight also identified an increased risk of circulatory and respiratory mortality in relation to rural characteristics (e.g. reduced population density). Consequently, increased medical provision in rural communities (e.g. increased ambulance services in remote areas), particularly during the winter period, may reduce mortality rates in rural locations.

In summary, my investigation has identified the unavailability of data in relation to a range of health and social indicators across small areas of England, which undermines the ability to develop and implement interventions based on robust evidence, in order to protect population health. Strategies for overcoming barriers to data sharing need to be considered within the public health community, in consultation with data providers. The results from my analyses also indicate that the development of public health policies and interventions based on the needs of local populations may be more effective at reducing adverse health outcomes across England compared to national policy interventions.

9.6 Unanswered questions and future research

The final research question (number six) for this thesis is: what further research is needed to identify ways to reduce winter- and cold-weather-related morbidity and mortality? I address

this question as follows. The spatial pattern in mortality risk shown in figures 8.6 A-D indicated that risk factors may influence circulatory and respiratory mortality rates differentially between LADs. In addition, preliminary analyses not reported in this thesis indicated different risk factors were associated with spatial variations in excess mortality between LADs in each English region. Knowledge regarding the different risk factors for spatial variations in cold-related excess mortality between LADs could inform the development and implementation of area-specific intervention across the country.

Despite there being a large and expanding body of evidence concerning risk factors for cold-related excess mortality and a relatively well developed and evolving legislative framework for reducing excess adverse health and social outcomes in England, EWM remains higher in the UK compared to many other Northern European countries. The analyses in this thesis identified predominantly non-seasonal or cold-weather-specific effects of most of the explanatory factors investigated, on spatial and temporal variations in excess mortality. This may indicate that factors that were not included in the analyses in chapter eight drive spatiotemporal variations in excess winter- and cold-related mortality across English LADs.

The inclusion of a measure of social networks in further investigations may provide information regarding risk factors for circulatory and respiratory mortality in relation to the winter season and during periods of cold weather. Various ecological measures of social isolation/ cohesion exist in relation to small areas of England, including indicator 1.18 from the Public Health Outcomes Framework (percentage of adult care users who have as much social contact as they would like) (421) and the Social Fragmentation Index, which is derived from census data on the proportions of privately rented households, single person households (aged <65 years), unmarried persons and mobility in the previous year (422). In addition, investigations regarding the contribution of infectious diseases and mortality displacement (the latter of which could be assessed using measures of disability-free-life-expectancy and the proportion of very old people in the population) to temporal variations in EWM rates may provide additional insights concerning the nature of EWM.

It is possible that data on seasonal variations in health-related behaviours (e.g. physical activity levels, calorie and alcohol intake) may inform our knowledge regarding the causes of seasonal variations in circulatory and respiratory health outcomes, including mortality. Data on seasonal variations in these variables are unavailable for English LADs. However, a follow-up study using individual level primary data on cold exposure and engagement in health-promoting behaviours across the year may verify the potential influence of these factors on winter- and cold-related health outcomes.

Finally, increased research on pathways for specific cold-related health outcomes among population sub-groups may inform the development of policies and interventions to reduce the impacts of cold weather between demographic groups, thereby reducing cold-generated health inequalities.

Ten. References

1. Tanner LM, Moffatt S, Milne EMG, Mills SDH, White M. Socioeconomic and behavioural risk factors for adverse winter health and social outcomes in economically developed countries: A systematic review of quantitative observational studies. *J Epidemiol Community Health* 2013;67(12):1061-7.

2. Yorkshire and Humber Public Health Observatory. *Twin peaks — winter respiratory admissions*. 2012: http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahU KEwiYpZ___KvKAhUBsxQKHWa-DgEQFggcMAA&url=http%3A%2F%2Fwww.yhpho.org.uk%2Fresource%2Fview.as px%3FRID%3D154978&usg=AFQjCNGx7qAEVSjUWMuHiLypqmJ2ztbWmg&bv m=bv.112064104,d.ZWU Accessed 29 February 2016

3. Gascoigne C, Morgan K, Gross H, Goodwin J. Reducing the health risks of severe winter weather among older people in the United Kingdom: An evidence-based intervention. *Ageing Soc* 2010;30(2):275-97.

4. Rudge J, Gilchrist R. Excess winter morbidity among older people at risk of cold homes: a population-based study in a London borough. *Journal of Public Health* 2005;27(4):353-8.

5. Office for National Statistics. *Statistical bulletin: Excess Winter Mortality in England and Wales, 2014/15 (Provisional) and 2013/14 (Final)*. 2014: http://www.ons.gov.uk/ons/rel/subnational-health2/excess-winter-mortality-in-england-and-wales/2013-14--provisional--and-2012-13--final-/stb.html Accessed 29 February 2016

6. Iparraguirre J. Have winter fuel payments reduced excess winter mortality in England and Wales? *Journal of Public Health* 2014;37(1):26-33.

7. Sloan D. Excess winter deaths and morbidity and the health risks associated with cold homes. Lecture presented at National Energy Action Annual Conference; Scarborough, UK; 2014.

8. Healy JD. Excess winter mortality in Europe: a cross country analysis identifying key risk factors. *J Epidemiol Community Health* 2003;57(10):784-9.

9. Fowler T, Southgate RJ, Waite T, Harrell R, Kovats S, Bone A, et al. Excess Winter Deaths in Europe: A multi-country descriptive analysis. *Eur J Public Health* 2015;25(2):339-45.

10. Szucs T. The socio-economic burden of influenza. *J Antimicrob Chemoth* 1999;44(suppl 2):11-5.

11. Collins KJ. Principles and Practice of Geriatric Medicine. 4th edition. England: Wiley; 2006.

12. National Health Service. *Encyclopaedia: Hypothermia*. 2013: http://www.nhsdirect.wales.nhs.uk/encyclopaedia/h/article/hypothermia/ Accessed 29 February 2016

13. Rango N. Old and cold: hypothermia in the elderly. *Geriatrics* 1980;35(11):93, 6.

14. Marmot M, I Geddes, E Bloomer, J JA, Goldblatt. P. The Health Impacts of Cold Homes and Fuel Poverty. Friends of the Earth England and Marmot Review Team, University College London, 2011

15. World Health Organization. *Health inequality and inequity*. 2014: http://www.who.int/hia/about/glos/en/index1.html Accessed 12 March 2015.

16. Sloan D. Biological pathways for Excess Winter Mortality. E-mail to Louise Tanner (l.tanner@ncl.ac.uk) 10 October 2014.

17. National Institute for Health and Care Excellence. *Excess Winter Deaths and Illnesses*. 2015: https://www.nice.org.uk/guidance/indevelopment/gid-phg70 Accessed 29 February 2016

18. Liddell C. Group discussion at Department of Energy and Climate Change evidence workshop on links between fuel poverty and health; London, UK; 2014.

19. Mason V, Roys M. (2011). *Warm homes NHS costs*. Building Research Establishment.

20. Hills J. (2011). *Fuel Poverty: The problem and its measurement interim report of the fuel poverty review*. Department of Energy and Climate Change.

21. Friedman D. (2010). *Social impact of poor housing*. ECOTEC.

22. Bradshaw J, Hutton S. Social policy options and fuel poverty. *J Econ Psychol* 1983;3(3):249-66.

23. Probert LJ, Haines V, Loveday DL. The Hills Fuel Poverty Review Interim Report: assessing proposals and implications. *People Place and Policy Online* 2011;5(3),161-173.

24. Hansard Millbank Systems. *HOMES INSULATION BILL*. 1978: http://hansard.millbanksystems.com/commons/1978/may/19/homes-insulation-bill Accessed 19 February 2016

25. National Energy Action; Department of Energy and Climate Change. *Green Deal and Energy Company Obligation The design and delivery of energy efficiency and fuel poverty advice services to vulnerable citizens summary report [Final Draft]*. 2012:

http://www.nea.org.uk/Resources/NEA/Policy%20and%20Research/Documents/Gree
n%20Deal%20and%20ECO.pdf Accessed 19 February 2015

26. The Telegraph [online newspaper]. *Christmas bonus. Pensioners' £10 Christmas bonus is same as four decades ago*. 2009:
http://www.telegraph.co.uk/news/politics/liberaldemocrats/6865057/Pensioners-10-Christmas-bonus-is-same-as-four-decades-ago.html Accessed 19 February 2015

27. McKie D. Exceptionally Severe Weather Payments: Embarrassment for the Government. *Lancet* 1986;327:567–568

28. Hansard Millbank Systems. Supplementary Benefit (Single Payments). 1986:
http://hansard.millbanksystems.com/commons/1986/dec/18/supplementary-benefit-single-payments Accessed 19 February 2015

29. Gov.uk. *Cold Weather Payment*. 2016:
https://www.gov.uk/cold-weather-payment/overview Accessed 29 February 2016.

30. Boardman B. Fuel Poverty. London: Belhaven Press; 1991.

31. Milne E. personal communication. 19 February 2015.

32. United Nations. *Conference on Environment and Development*. 1992:
http://www.un.org/geninfo/bp/enviro.html Accessed 19 February 2015

33. United Nations. Framework Convention on Climate Change. 1997:
http://unfccc.int/kyoto_protocol/items/2830.php Accessed 19 February 2015

34. Snell C, Thomson H. (2013). 'Reconciling fuel poverty and climate change policy under the Coalition government: Green deal or no deal?' In: Ramia, G. and Farnsworth, K. (eds.) *Social Policy Review* 25: Analysis and debate in social policy. Bristol: Policy Press.

35. Christman B. Making a Case for Legal Research on Fuel Poverty in the UK. Presented at Fuel Poverty Post Graduate Symposium; Sheffield, UK; 2012.

36. Acheson D. *Report of the independent enquiry into inequalities in health*. London: Stationary Office, 1998.

37. Department of Health. *Saving Lives: Our Healthier Nation*. London: Stationary Office, 1999.

38. Department of Trade and Industry. *The UK Fuel Poverty Strategy*. London: 2001

39. Committee on Climate Change. *The Climate Change Act and UK Regulations*. 2008:
http://www.theccc.org.uk/tackling-climate-change/the-legal-landscape/global-action-on-climate-change/ Accessed 29 February 2016

40. Office for National Statistics. *The Impact of the Recession on Household Income, Expenditure and Saving*. Date unavailable:

http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CC
YQFjAA&url=http%3A%2F%2Fwww.ons.gov.uk%2Fons%2Frel%2Fnaa2%2Fquarte
rly-national-accounts%2Fimpact-of-the-recession%2Fthe-impact-of-the-recession-on-
household-income--expenditure-and-
saving.pdf&ei=j7LlVNrFAYvmaOnWgfAG&usg=AFQjCNH-
nqfkXuVXgRCWLwP8sFXYXEVa1w&sig2=_kiDalHX7hruqrZQA5ULxA Accessed
19 February 2015

41. Department of Energy and Climate Change. *Annual Report on Fuel Poverty Statistics*.
London: 2011.

42. GOV.UK. *Fuel Poverty Statistics*. 2015:
https://www.gov.uk/government/collections/fuel-poverty-statistics Accessed 22
January 2016

43. National Energy Action. *Policy update for media*. 2013:
http://www.nea.org.uk/media/press-pack/fuel-poverty-and-policy Accessed 22 April
2013

44. Department of Energy and Climate Change. *Warm Home Discount Scheme: extension
to 2015/16*. 2014:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/359369
/warm_home_discount_extension_to_2015-16.pdf Accessed 29 February 2016-02-29

45. Snell C, Bevan M, Thomson H. F*uel Poverty and disabled people: the impact of
policy change*. 2014: http://www.eagacharitabletrust.org/index.php/projects/item/fuel-
poverty-and-disabled-people-the-impact-of-policy-change Accessed 27 February 2015

46. The Lancet UK Policy Matters. *Evidence Submission: The Green Deal-the effect on
Public Health*. 2012: http://ukpolicymatters.thelancet.com/?p=1735#ref Accessed 14
July 2012

47. Ofgem. *Energy Company Obligation (ECO)*. 2016:
https://www.ofgem.gov.uk/environmental-programmes/energy-companies-obligation-
eco Accessed 29 February 2016

48. National Energy Action. *NEA response to Fuel Poor Consultation*. 2014:
https://www.ofgem.gov.uk/ofgem-
publications/91612/nearesponsetofuelpoorconsultation.pdf Accessed 29 February
2016

49. GOV.UK. *Buying or Selling your home*. 2015: https://www.gov.uk/buy-sell-your-
home/energy-performance-certificates Accessed 29 February 2016

50. HM Government. *Cutting the cost of keeping warm: a fuel poverty strategy for England*. London: Stationary Office, 2015.

51. Department of Energy and Climate Change. *Electricity market reform: policy overview*. 2012: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48371/5349-electricity-market-reform-policy-overview.pdf Accessed 29 February 2016

52. Department of Health. *Cold Weather Plan for England-Protecting health and reducing harm from severe cold weather*. London; 2010.

53. Beveridge M. The Cold Weather and Health Impacts. Lecture presented at Public Policy Exchange Local Authorities and Cold Weather Planning event; London; 2014.

54. Hajat S, Chalabi Z,Wilkinson P, Erens B, Ritchie B, Jones L et al. *Evaluation of Health-Related Impacts of the National Cold Weather Plan for England*. 2013: http://ehp.niehs.nih.gov/isee/o-3-33-03/ Accessed 29 February 2016

55. Walker R, Thomson H, Liddell C. *FUEL POVERTY 1991 – 2012 Commemorating 21 years of action, policy and research*. University of Ulster; The University of York, 2013.

56. National Energy Action. *Developing a social energy target in Europe*. 2014: http://www.jeanlambertmep.org.uk/wp-content/uploads/2014/10/Developing-a-Social-Energy-Target-in-Europe-NEA-24-10-2014.pdf Accessed 29 February 2016

57. Howden-Chapman P, Viggers H, Chapman R, O'Sullivan K, Telfar Barnard L, Lloyd B. Tackling cold housing and fuel poverty in New Zealand: A review of policies, research, and health impacts. *Energy Policy* 2012;49(0):134-42.

58. Telfar Barnard LF, Baker MG, Hales S, Howden-Chapman PL. Excess winter morbidity and mortality: Do housing and socio-economic status have an effect? *Rev Environ Health* 2008;23(3):203-21.

59. Wilkinson P, Armstrong B, Cairns J, Chalabi Z, Hajat S, Jones L, et al. *Review 1: Factors determining vulnerability to winter- and cold- related morbidity / mortality*. 2014: https://www.nice.org.uk/guidance/ng6/evidence/evidence-review-1-factors-determining-vulnerability-to-winter-and-coldrelated-mortalitymorbidity-544621933 Accessed 29 February 2016

60. Thomson H, Thomas S, Sellstrom E, Petticrew M. Housing improvements for health and associated socio-economic outcomes. *The Cochrane database of systematic reviews* 2013;2:Cd008657.

61. Effective Public Health Practice Project. *Quality Assessment Tool for Quantitative Studies*. 1998: http://www.ephpp.ca/tools.html Accessed 26 February 2015

62. Thomas B. A process for systematically reviewing the literature: providing the research evidence for public health nursing interventions. *Evid Based Nurs* 2004;1:176-84.

63. Armijo-Olivo S, Stiles CR, Hagen NA, Biondo PD, Cummings GG. Assessment of study quality for systematic reviews: a comparison of the Cochrane Collaboration Risk of Bias Tool and the Effective Public Health Practice Project Quality Assessment Tool: methodological research. *J Eval Clin Pract* 2012;18(1):12-8.

64. Mills SDH, Tanner LM, Adams J. Systematic literature review of the effects of food and drink advertising on food and drink-related behaviour, attitudes and beliefs in adult populations. *Obes Rev* 2013;14(4):303-14.

65. National Institute of Health and Care Excellence. *The guidelines manual*. 2012: Available from: https://www.nice.org.uk/article/pmg6/chapter/6-reviewing-the-evidence. Accessed 29 August 2015

66. Centre for Reviews and Dissemination. *CRD's guidance for undertaking reviews in health care*. 2008: https://www.york.ac.uk/media/crd/Systematic_Reviews.pdf Accessed 29 February 2016

67. Critical Appraisal Skills Programme. *Making sense of evidence*. 2013: http://casp-uk.net/ Accessed 7 May 2016

68. Noyes J, Booth A, Hannes K, Harden A, Harris J, Lewin S, Lockwood C (editors), *Supplementary Guidance for Inclusion of Qualitative Research in Cochrane Systematic Reviews of Interventions*. 2011: http://cqrmg.cochrane.org/supplemental-handbook-guidance Accessed 29 February 2016

69. Nightingale A. *Can anyone recommend a critical appraisal tool for assessing the quality of an observational study?* 2014: http://www.researchgate.net/post/Can_anyone_recommend_a_critical_appraisal_tool_for_assessing_the_quality_of_an_observational_study Accessed 29 February 2016

70. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS medicine* 2009;6(7):e1000097.

71. Lawlor DA, Harvey D, Dews HG. Investigation of the association between excess winter mortality and socio-economic deprivation. *J Public Health Med* 2000;22(2):176-81.

72. Maheswaran R, Chan D, Fryers PT, McManus C, McCabe H. Socio-economic deprivation and excess winter mortality and emergency hospital admissions in the

South Yorkshire Coalfields Health Action Zone, UK. *Public Health* 2004;118(3):167-76.

73. Wilkinson P, Kovats S, Pattenden S, Armstrong B, Mangtani P, Fletcher A, Mcmichael T. Winter mortality in the elderly in Great Britain: A socio-economic paradox? *Epidemiology* 2003;14(Supplement):S80

74. Christie SM, Fone DL. Does car ownership reflect socio-economic disadvantage in rural areas? A cross-sectional geographical study in Wales, UK. *Public health* 2003;117(2):112-6.

75. GOV.UK. *Travel in urban and rural areas*. 2010: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/230556 /Travel_in_urban_and_rural_areas_personal_travel_factsheet___March_2010.pdf Accessed 29 February 2016

76. GOV.UK. *Right to Buy: buying your council home*. 2015: https://www.gov.uk/right-to-buy-buying-your-council-home/overview Accessed 29 February 2016

77. Davie GS, Baker MG, Hales S, Carlin JB. Trends and determinants of excess winter mortality in New Zealand: 1980 to 2000. *BMC Public Health* 2007;7:263.

78. Hales S, Blakely T, Foster RH, Baker MG, Howden-Chapman P. Seasonal patterns of mortality in relation to social factors. *J Epidemiol Community Health* 2012;66(4):379-84.

79. Atkinson J SC, Crampton P. *NZDep2013 Index of Deprivation*. 2014: http://www.otago.ac.nz/wellington/otago069936.pdf Accessed 29 February 2016

80. The National Institute of Water and Atmospheric Research Ltd. *Overview of New Zealand's Climate.* 2001: https://www.niwa.co.nz/education-and-training/schools/resources/climate/overview Accessed 07 July 2016

81. Gouveia N, Hajat S, Armstrong B. Socioeconomic differentials in the temperature-mortality relationship in Sao Paulo, Brazil. *Int J Epidemiol* 2003;32(3):390-7.

82. Ng CF, Ueda K, Takeuchi A, Nitta H, Konishi S, Bagrowicz R, et al. Sociogeographic variation in the effects of heat and cold on daily mortality in Japan. *J Epidemiol* 2014;24(1):15-24.

83. Wilkinson PA, B.; Landen, M. et al. *Cold comfort: the social and environmental determinants of excess winter deaths in England, 1986-1996*. 2001: https://www.jrf.org.uk/report/cold-comfort-social-and-environmental-determinants-excess-winter-deaths-england-1986-1996 Accessed 29 February 2016

84. van Rossum CT, Shipley MJ, Hemingway H, Grobbee DE, Mackenbach JP, Marmot MG. Seasonal variation in cause-specific mortality: are there high-risk groups? 25-

year follow-up of civil servants from the first Whitehall study. *Int J Epidemiol* 2001;30(5):1109-16.

85. Gemmell I, McLoone P, Boddy FA, Dickinson GJ, Watt GC. Seasonal variation in mortality in Scotland. *Int J Epidemiol* 2000;29(2):274-9.

86. O'Neill MS, Zanobetti A, Schwartz J. Modifiers of the temperature and mortality association in seven US cities. *Am J Epidemiol* 2003;157(12):1074-82.

87. Curriero FC, Heiner KS, Samet JM, Zeger SL, Strug L, Patz JA. Temperature and mortality in 11 cities of the eastern United States. *Am J Epidemiol* 2002;155(1):80-7.

88. Hajat S, Kovats RS, Lachowycz K. Heat-related and cold-related deaths in England and Wales: who is at risk? *Occup Environ Med* 2007;64(2):93-100.

89. Anderson BG, Bell ML. Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. *Epidemiology* 2009;20(2):205-13.

90. Aylin P, Morris S, Wakefield J, Grossinho A, Jarup L, Elliott P. Temperature, housing, deprivation and their relationship to excess winter mortality in Great Britain, 1986-1996. *Int J Epidemiol* 2001;30(5):1100-8.

91. Lawlor DA, Maxwell R, Wheeler BW. Rurality, deprivation, and excess winter mortality: an ecological study. *J Epidemiol Community Health* 2002;56(5):373-4.

92. Public Health England. Causes of Obesity. 2016. https://www.noo.org.uk/NOO_about_obesity/causes Accessed 29 February 2016

93. World Health Organization. *Obesity and overweight*. 2016: http://www.who.int/mediacentre/factsheets/fs311/en/ Accessed 29 February 2016

94. Bayentin L, El Adlouni S, Ouarda TB, Gosselin P, Doyon B, Chebana F. Spatial variability of climate effects on ischemic heart disease hospitalization rates for the period 1989-2006 in Quebec, Canada. *Int J Health Geogr* 2010;9:5.

95. Chen VY, Wu PC, Yang TC, Su HJ. Examining non-stationary effects of social determinants on cardiovascular mortality after cold surges in Taiwan. *Sci Total Environ* 2010;408(9):2042-9.

96. Watkins SJB, D.; McDevitt, M. Winter Morbidity: is it a summer phenomenon*? J Public Health Med* 2001;23:237-41.

97. Gyllerup S, Lanke J, Lindholm LH, Schersten B. Socioeconomic factors in the community fail to explain the high coronary mortality in cold parts of Sweden. *Eur Heart J* 1992;13(7):878-81.

98. Madrigano J, Mittleman MA, Baccarelli A, Goldberg R, Melly S, von Klot S, et al. Temperature, myocardial infarction, and mortality: effect modification by individual- and area-level characteristics. *Epidemiology* 2013;24(3):439-46.

99. Zhang M, Zhao Q, Mills KT, Chen J, Li J, Cao J, et al. Factors associated with blood pressure response to the cold pressor test: the GenSalt Study. *Am J Hypertens* 2013;26(9):1132-9.

100.   Woodhouse P. Seasonal variation of risk factors for cardiovascular disease and diet in older adults. *Int J Circumpolar Health* 2000;59(3-4):204-9.

101.   Mitchell R, Blane D, Bartley M. Elevated risk of high blood pressure: climate and the inverse housing law. *Int J Epidemiol* 2002;31(4):831-8.

102.   Vasconcelos J, Freire E, Morais J, MacHado JR, Santana P, editors. The health impacts of poor housing conditions and thermal discomfort. *Procedia Environ Sci* 2011;4:158-64.

103.   Clinch JP, Healy JD. Housing standards and excess winter mortality. *J Epidemiol Community Health* 2000;54(9):719-20.

104.   Croxford B. The effect of cold homes on health: evidence from the LARES study. In: Ormandy D. (ed.). Housing and health in Europe: the WHO LARES project. Oxford: Routledge; 2009.

105.   Harris J, Hall J, Meltzer H, Jenkins R, Oreszczyn T, McManus S. *Health, Mental Health and Housing Conditions in England*. 2007: https://www.natcen.ac.uk/media/23582/health-mental-health-housing.pdf Accessed 01 March 2016

106.   Middlekauff HR, Park J, Agrawal H, Gornbein JA. Abnormal sympathetic nerve activity in women exposed to cigarette smoke: a potential mechanism to explain increased cardiac risk. *Am J Physiol Heart Circ Physiol* 2013;305(10):H1560-7.

107.   Saloheimo P, Tetri S, Juvela S, Pyhtinen J, Hillbom M. Seasonal variation of intracerebral haemorrhage in subjects with untreated hypertension. *Acta Neurological Scandanavia* 2009;120(1):59-63.

108.   Hopstock LA, Wilsgaard T, Njolstad I, Mannsverk J, Mathiesen EB, Lochen M-L, et al. Seasonal variation in incidence of acute myocardial infarction in a sub-Arctic population: the Tromso Study 1974-2004. *Eur J Cardiovasc Prev Rehabil* 2011;18(2):320-5.

109.   Kim JY, Jung KY, Hong YS, Kim JI, Jang TW, Kim JM. The relationship between cold exposure and hypertension. *J Occup Health* 2003;45(5):300-6.

110.   Chacornac M, Baronne-Rochette G, Schmidt M-H, Savary D, Habold D, Bouvaist H, et al. Characteristics and management of acute ST-segment elevation myocardial infarctions occurring in ski resorts in the French Alps: Impact of an acute coronary care network. *Arch Cardiovasc Dis* 2010;103(8-9):460-8.

111. Jarnardhanan R. The Snow-Shoveler's ST Elevation Myocardial Infarction. *Am J Cardiol* 2010;106:596–600. .

112. Franklin BA, George P, Henry R, Gordon S, Timmis GC, O'Neill WW. Acute myocardial infarction after manual or automated snow removal. *Am J Cardiol* 2001;87(11):1282-3.

113. Shahar DR, Yerushalmi N, Lubin F, Froom P, Shahar A, Kristal-Boneh E. Seasonal variations in dietary intake affect the consistency of dietary assessment. *Eur J Epidemiol* 2001;17(2):129-33.

114. Thomson RL, Spedding S, Brinkworth GD, Noakes M, Buckley JD. Seasonal effects on vitamin D status influence outcomes of lifestyle intervention in overweight and obese women with polycystic ovary syndrome. *Fertil Steril* 2013;99(6):1779-85.

115. Dasgupta K, Joseph L, Pilote L, Strachan I, Sigal RJ, Chan C. Daily steps are low year-round and dip lower in fall/winter: Findings from a longitudinal diabetes cohort. *Cardiovascular Diabetology* 2010;9.

116. Hassi J, Remes J, Kotaniemi P, Kettunen P, Nayha S. Dependence of Cold-Related Coronary and Respiratory Symptoms on Age and Exposure to Cold. *Int J Circumpolar Health* 2000;59:210-5.

117. Jordan RE, Hawker JI, Ayres JG, Adab P, Tunnicliffe W, Olowokure B, et al. Effect of social factors on winter hospital admission for respiratory disease: a case-control study of older people in the UK. *Brit J Gen Pract* 2008;58(551):400-2.

118. McAllister DA, Morling JR, Fischbacher CM, MacNee W, Wild SH. Socioeconomic deprivation increases the effect of winter on admissions to hospital with COPD: retrospective analysis of 10 years of national hospitalisation data. *Prim Care Respir J* 2013;22(3):296-9.

119. Rudge J, Gilchrist R. Measuring the health impact of temperatures in dwellings: Investigating excess winter morbidity and cold homes in the London Borough of Newham. *Energy and Buildings* 2007;39(7):847-58.

120. Yousey-Hindes KM, Hadler JL. Neighborhood socioeconomic status and influenza hospitalizations among children: New Haven County, Connecticut, 2003-2010. *Am J Public Health* 2011;101(9):1785-9.

121. Castagno LA, Lavinsky L. Otitis media in children: seasonal changes and socioeconomic level. *Int J Pediatr Otorhinolaryngol* 2002;62(2):129-34.

122. NHS. *Middle ear infection (otitis media)*. 2014: http://www.nhs.uk/conditions/Otitis-media/Pages/Introduction.aspx Accessed 17 March 2015

123.   Lambert SB, O'Grady KF, Gabriel SH, Nolan TM. Respiratory illness during winter: A cohort study of urban children from temperate Australia. *J Paediatr Child Health* 2005;41(3):125-9.

124.   Chen BY, Chan CC, Han YY, Wu HP, Guo YL. The risk factors and quality of life in children with allergic rhinitis in relation to seasonal attack patterns. *Paediatr Perinat Epidemiol* 2012;26(2):146-55.

125.   Harju T, Makinen T, Nayha S, Laatikainen T, Jousilahti P, Hassi J. Cold-related respiratory symptoms in the general population. *Eur Respir J* 2010;4(3):176-85.

126.   Osman LM, Ayres JG, Garden C, Reglitz K, Lyon J, Douglas JG. Home warmth and health status of COPD patients. *Eur J Public Health* 2008;18(4):399-405.

127.   Butler S, Williams M, Tukuitonga C, Paterson J. Problems with damp and cold housing among Pacific families in New Zealand. *N Z Med J* 2003;116(1177):U494.

128.   Gilchrist R, Kamara A, Rudge J. An insurance type model for the health cost of cold housing: an application of GAMLSS. *Revstat-Stat J* 2009;7(1):55-66.

129.   Walker JJ, Mitchell R, Platt SD, Petticrew MP, Hopton J. Does usage of domestic heating influence internal environmental conditions and health? *Eur J Public Health* 2006;16(5):463-9.

130.   Kotaniemi J-T, Pallasaho P, Sovijärvi ARA, Laitinen LA, Lundbäck B. Respiratory Symptoms and Asthma in Relation to Cold Climate, Inhaled Allergens, and Irritants: A Comparison Between Northern and Southern Finland. *J Asthma* 2002;39(7):649-58.

131.   Kotaniemi JT, Latvala J, Lundback B, Sovijarvi A, Hassi J, Larsson K. Does living in a cold climate or recreational skiing increase the risk for obstructive respiratory diseases or symptoms? *Int J Circumpolar Health* 2003;62(2):142-57.

132.   Gergen PJ, Mitchell H, Lynn H. Understanding the seasonal pattern of childhood asthma: results from the National Cooperative Inner-City Asthma Study (NCICAS). *J Pediatr* 2002;141(5):631-6.

133.   Xu C, Iuliano AD, Chen M, Cheng PY, Chen T, Shi J, et al. Characteristics of Hospitalized Cases with Influenza A (H1N1)pdm09 Infection during First Winter Season of Post-Pandemic in China. *PLoS ONE* 2013;8(2).

134.   Zolotusca L, Jorgensen P, Popovici O, Pistol A, Popovici F, Widdowson MA, et al. Risk factors associated with fatal influenza, Romania, October 2009 - May 2011. *Influenza Other Respir Viruses* 2014;8(1):8-12.

135.   Barboza P, Baudon C, Cherie-Challine L, Gastellu-Etchegorry M, Gueguen J, La Ruche G, et al. Influenza A(H1N1) 2009 in the French Pacific territories: assessment of the epidemic wave during the austral winter. *Clin microbiol infec* 2010;16(4):304-8.

136.   Romero-Ortuno R, Tempany M, Dennis L, O'Riordan D, Silke B. Deprivation in cold weather increases the risk of hospital admission with hypothermia in older people. *Irish J Med Sci* 2013;182(3):513-8.

137.   Pedley DK, Paterson B, Morrison W. Hypothermia in elderly patients presenting to accident & emergency during the onset of winter. *Scott Med J* 2002;47(1):10-1.

138.   Yu J, Cao G, Cui W, Ouyang Q, Zhu Y. People who live in a cold climate: thermal adaptation differences based on availability of heating. *Indoor Air* 2013;23(4):303-10.

139.   Herity B, Daly L, Bourke GJ, Horgan JM. Hypothermia and mortality and morbidity. An epidemiological analysis. *J Epidemiol Community Health* 1991;45(1):19-23.

140.   Healy JD, Clinch JP. Fuel poverty, thermal comfort and occupancy: results of a national household-survey in Ireland. *Appl Energy* 2002;73(3-4):329-43.

141.   Baumgartner EA, Belson M, Rubin C, Patel M. Hypothermia and other cold-related morbidity emergency department visits: United States, 1995-2004. *Wilderness Environ Med* 2008;19(4):233-7.

142.   Kornfalt J, Johansson A. Occurrence of hypothermia in a prehospital setting, southern Sweden. *Int Emerg Nurs* 2010;18(2):76-9.

143.   Lim C, Duflou J. Hypothermia fatalities in a temperate climate: Sydney, Australia. *Pathology* 2008;40(1):46-51.

144.   Anttonen H, Virokannas H. Assessment of cold stress in outdoor work. *Arctic Med Res* 1994;53(1):40-8.

145.   Gao C, Holmer I, Abeysekera J. Slips and falls in a cold climate: underfoot surface, footwear design and worker preferences for preventive measures. *Applied ergonomics* 2008;39(3):385-91.

146.   Bird ML, Hill KD, Robertson IK, Ball MJ, Pittaway J, Williams AD. Serum [25(OH)D] status, ankle strength and activity show seasonal variation in older adults: relevance for winter falls in higher latitudes. *Age Ageing* 2013;42(2):181-5.

147.   Elgán C, Fridlund B. Bone mineral density in relation to body mass index among young women: A prospective cohort study. *Int J Nurs Stud* 2006;43(6):663-72.

148.   Bhattacharya J, DeLeire T, Haider S, Currie J. Heat or eat? Cold-weather shocks and nutrition in poor American families. *Am J Public Health* 2003;93(7):1149-54.

149.	Hyppönen E, Power C. Hypovitaminosis D in British adults at age 45 y: Nationwide cohort study of dietary and lifestyle predictors. *Am J Clin Nutr* 2007;85(3):860-8.

150.	Kull M, Jr., Kallikorm R, Tamm A, Lember M. Seasonal variance of 25-(OH) vitamin D in the general population of Estonia, a Northern European country. *BMC Public Health* 2009;9:22.

151.	Song SJ, Zhou L, Si S, Liu J, Zhou J, Feng K, et al. The high prevalence of vitamin D deficiency and its related maternal factors in pregnant women in Beijing. *PLoS ONE* 2013;8(12):e85081.

152.	Heyman B, Harrington BE, Merleau-Ponty N, Stockton H, Ritchie N, Allan TF. Keeping warm and staying well. Does home energy efficiency mediate the relationship between socio-economic status and the risk of poorer health? *Housing Studies* 2005;20(4):649-64.

153.	Windle GS, Burholt V, Edwards RT. Housing related difficulties, housing tenure and variations in health status: evidence from older people in Wales. *Health & Place* 2006;12(3):267-78.

154.	Yoonhee Kim, Ho Kim, Kim D-S. Association between daily environmental temperature and suicide mortality in Korea (2001-2005). *Psychiatry Res* 2011;390-6.

155.	Critchley R, Gilbertson J, Grimsley M, Green G, Warm Front Study G. Living in cold homes after heating improvements: Evidence from Warm-Front, England's Home Energy Efficiency Scheme. *Applied Energy* 2007;84(2):147-58.

156.	Ortlieb S, Schneider G, Koletzko S, Berdel D, Von Berg A, Bauer CP, et al. Physical activity and its correlates in children: A cross-sectional study (the GINIplus & LISAplus studies). BMC Public Health. 2013;13(1).

157.	Anderson W, White V, Finney A. Coping with low incomes and cold homes. *Energy Policy* 2012;49:40-52.

158.	Burholt V, Windle G. Keeping warm? Self-reported housing and home energy efficiency factors impacting on older people heating homes in North Wales. *Energy Policy* 2006;34(10):1198-208.

159.	Brunner KM, Spitzer M, Christanell A. Experiencing fuel poverty. Coping strategies of low-income households in Vienna/Austria. *Energy Policy* 2012;49:53-9.

160.	Harrington BE, Heyman B, Merleau-Ponty N, Stockton H, Ritchie N, Heyman A. Keeping warm and staying well: findings from the qualitative arm of the Warm Homes Project. *H Soc Care Comm* 2005;13(3):259-67.

161.   O'Neill T, Jinks C, Squire A. "Heating is more important than food": Older women's perceptions of fuel poverty. *J Hous Elderly* 2006;20(3):95-108.

162.   Wright F. Old and cold: Older people and policies failing to address fuel poverty. *Soc Pol Admin* 2004;38(5):488-503.

163.   Steptoe A, Shankar A, Demakakos P, Wardle J. Social isolation, loneliness, and all-cause mortality in older men and women. *PNAS* 2013;110(15):5797-801.

164.   Wilkinson P, Armstrong B, Cairns J, Chalabi Z, Hajat J, Jones L, et al. *Evidence review and economic analysis of excess winter deaths*. 2014: https://www.nice.org.uk/guidance/ng6/evidence/evidence-review-3-delivery-and-implementation-of-approaches-for-the-prevention-of-excess-winter-deaths-and-morbidity-544621935 Accessed 01 March 2016

165.   Thomson H, Thomas S, Sellstrom E, Petticrew M. The health impacts of housing improvement: a systematic review of intervention studies from 1887 to 2007. *Am J Public Health* 2009;99 Suppl 3:S681-92.

166.   El Ansari W, El-Silimy S. Are fuel poverty reduction schemes associated with decreased excess winter mortality in elders? A case study from London, U.K. *Chronic Illness* 2008;4(4):289-94.

167.   Keatinge. Changes in seasonal mortalities with improvement in home heating in England and Wales from 1964 to 1984. *Int J Biometeorol* 1989;33(2):71-6.

168.   Lloyd EL, McCormack C, McKeever M, Syme M. The effect of improving the thermal quality of cold housing on blood pressure and general health: a research note. *J Epidemiol Community Health* 2008;62(9):793-7.

169.   Saeki K, Obayashi K, Iwamoto J, Tanaka Y, Tanaka N, Takata S, et al. Influence of room heating on ambulatory blood pressure in winter: a randomised controlled study. *J Epidemiol Community Health* 2013;67(6):484-90.

170.   Walker J, Mitchell R, Petticrew M, Platt S. The effects on health of a publicly funded domestic heating programme: a prospective controlled study. *J Epidemiol Community Health* 2009;63(1):12-7.

171.   Somerville M, Mackenzie I, Owen P, Miles D. Housing and health: does installing heating in their homes improve the health of children with asthma? *Public Health* 2000;114(6):434-9.

172.   Howden-Chapman P, Matheson A, Crane J, Viggers H, Cunningham M, Blakely T, et al. Effect of insulating existing houses on health inequality: cluster randomised study in the community. *BMJ* 2007;334(7591):460.

173. Howden-Chapman P, Pierse N, Nicholls S, Gillespie-Bennett J, Viggers H, Cunningham M, et al. Effects of improved home heating on asthma in community dwelling children: Randomised controlled trial. *BMJ* 2008;337(7674):852-5.

174. Kiyohara K, Kojimahara N, Sato Y, Yamaguchi N. Changes in COPD mortality rate after amendments to the Preventive Vaccination Law in Japan. *Eur J Public Health* 2013;23(1):133-9.

175. Parry MF, Grant B, Iton A, Parry PD, Baranowsky D. Influenza vaccination: A collaborative effort to improve the health of the community. *Infect Control Hosp Epidemiol* 2004;25(11):929-32.

176. Halpin DM, Laing-Morton T, Spedding S, Levy ML, Coyle P, Lewis J, et al. A randomised controlled trial of the effect of automated interactive calling combined with a health risk forecast on frequency and severity of exacerbations of COPD assessed clinically and using EXACT PRO. *Prim Care Respir J* 2011;20(3):324-31.

177. Maheswaran R, Pearson T, Hoysal N, Campbell MJ. Evaluation of the impact of a health forecast alert service on admissions for chronic obstructive pulmonary disease in Bradford and Airedale. *Journal of public health* 2010;32(1):97-102.

178. Bakerly ND, Roberts JA, Thomson AR, Dyer M. The effect of COPD health forecasting on hospitalisation and health care utilisation in patients with mild-to-moderate COPD. *Chron Respir Dis* 2011;8(1):5-9.

179. Cooper R, O'Hara R. Patients' and staffs' experiences of an automated telephone weather forecasting service *J Health Serv Res Policy* 2010;15 Suppl 2:41-6.

180. Marno P, Chalder M, Laing-Morton T, Levy M, Sachon P, Halpin D. Can a health forecasting service offer COPD patients a novel way to manage their condition? *J Health Serv Res Policy* 2010;15(3):150-5.

181. Karlowski TR, Chalmers TC, Frenkel LD, Kapikian AZ, Lewis TL, Lynch JM. Ascorbic acid for the common cold. A prophylactic and therapeutic trial. *Jama* 1975;231(10):1038-42.

182. Gilbertson J, Stevens M, Stiell B, Thorogood N. Home is where the hearth is: Grant recipients' views of England's Home Energy Efficiency Scheme (Warm Front). *Soc Sci Med* 2006;63(4):946-56.

183. Barnett AG, Lucas M, Platts D, Whiting E, Fraser JF. The benefits of thermal clothing during winter in patients with heart failure: a pilot randomised controlled trial. *BMJ Open* 2013;3(4).

184. Parkin L, Williams SM, Priest P. Preventing winter falls: a randomised controlled trial of a novel intervention. *N Z Med J* 2009;122(1298):31-8.

185. McKiernan FE. A simple gait-stabilizing device reduces outdoor falls and nonserious injurious falls in fall-prone older people during the winter. *J Am Geriatr Soc* 2005;53(6):943-7.

186. Abeysekera J, Gao C. The identification of factors in the systematic evaluation of slip prevention on icy surfaces. *Int J Ind Ergonom* 2001;28(5):303-13.

187. Berggard G, Johansson C. Pedestrians in wintertime-effects of using anti-slip devices. *Accid Anal Prev* 2010;42(4):1199-204.

188. Laaksi IT, Ruohola JPS, Ylikomi TJ, Auvinen A, Haataja RI, Pihlajamaki HK, et al. Vitamin D fortification as public health policy: significant improvement in vitamin D status in young Finnish men. *Eur J Clin Nutr* 2006;60(8):1035-8.

189. Manios Y, Moschonis G, Lyritis GP. Seasonal variations of vitamin D status in Greek postmenopausal women receiving enriched dairy products for 30 months: the Postmenopausal Health Study. *Eur J Clin Nutr* 2011;65(3):412-4.

190. Dumville JC, Miles JNV, Porthouse J, Cockayne S, Saxon L, King C. Can vitamin D supplementation prevent winter-time blues? A randomised trial among older women. *J Nutr Health Aging* 2006;10(2):151-3.

191. Partonen T, Leppamaki S, Hurme J, Lonnqvist J. Randomized trial of physical exercise alone or combined with bright light on mood and health-related quality of life. *Psychol Med* 1998;28(6):1359-64.

192. Liddell C, Guiney C. Living in a cold and damp home: frameworks for understanding impacts on mental well-being. *Public Health* 2015;129(3):191-9.

193. Barton A, Basham B, Foy C, Buckingham K, Somerville M. The Watcombe Housing Study: the short term effect of improving housing conditions on the health of residents. *J Epidemiol Community Health* 2007;61:771-777.

194. Platt S, Mitchell R, Walker J, Hopton J. *The Scottish Executive Central Heating Programme: Assessing Impacts on Health*. 2007: http://www.gov.scot/Resource/Doc/166025/0045176.pdf Accessed 22 July 2016

195. Bond L, Kearns A, Mason P, Tannahill C, Egan M, Whiteley E. Exploring the relationships between housing, neighbourhoods and mental wellbeing for residents of deprived areas. *BMC Public Health* 2012;**12**:48

196. Shortt N, Rugkasa J. "The walls were so damp and cold" fuel poverty and ill health in Northern Ireland: results from a housing intervention. *Health Place* 2007;13(1):99-110.

197. Braubach M, Heinen D, Dame J. *Preliminary results of the WHO Frankfurt housing intervention project*. 2008:

http://www.euro.who.int/__data/assets/pdf_file/0011/98696/E91699.pdf Accessed 22 July 2016.

198.   Bullen C, Kearns RA, Clinton J, Liang P, Mahoney F, McDuff I. Bringing health home: Householder and provider perspectives on the healthy housing programme in Auckland, New Zealand. *Soc Sci Med* 2008;66(5):1185-96.

199.   Free S, Howden-Chapman P, Pierse N, Viggers H, Housing H, Health Study Research T. More effective home heating reduces school absences for children with asthma. *J Epidemiol Community Health* 2010;64(5):379-86.

200.   Green G, Gilbertson, J. . Housing, poverty and health: the impact of housing investment on the health and quality of life of low income residents. *Open House Int* 1999;24(1):41-53.

201.   Heyman B, Harrington B, Heyman A, Natl Energy Action Res G. A Randomised Controlled Trial of an Energy Efficiency Intervention for Families Living in Fuel Poverty. *Housing Studies* 2011;26(1):117-32.

202.   Hong SH, Gilbertson J, Oreszczyn T, Green C, Ridley I, Warm Front Study G. A field study of thermal comfort in low-income dwellings in England before and after energy efficient refurbishment. *Building and Environment* 2009;44(6):1228-36.

203.   Clinch JP, Healy JD. Valuing improvements in comfort from domestic energy-efficiency retrofits using a trade-off simulation model. *Energy Economics* 2003;25(5):565-83.

204.   Mawle A. *A cost-benefit analysis of affordable warmth interventions in greater Manchester*. 2011: http://www.kwillt.org/files/Healthy%20Housing%20Healthy%20People%20Angela%20Mawle.pdf Accessed 01 March 2016

205.   National Institute for Health and Care Excellence. *Glossary*. 2016: https://www.nice.org.uk/glossary?letter=q Accessed 20 January 2016

206.   Preval N, Chapman R, Pierse N, Howden-Chapman P. Evaluating energy, health and carbon co-benefits from improved domestic space heating: A randomised community trial. *Energy Policy* 2010;38(8):3965-72.

207.   Grimes A, Denne T, Howden-Chapman P, Arnold R, Telfar Barnard L, Preval N, et al. *Cost Benefit Analysis of the Warm Up New Zealand: Heat Smart Programme*. Wellington, New Zealand: Report to the Ministry of Economic Development; 2012.

208.   Jensen H, Keogh-Brown M, Smith R, Chalabi Z, Dangour A, Davies M, et al. The importance of health co-benefits in macroeconomic assessments of UK Greenhouse Gas emission reduction strategies. *Climatic Change* 2013;121(2):223-37.

209.   Liddell C. *Kirklees Warm Zone The project and its impacts on wellbeing*. 2011: http://uir.ulster.ac.uk/19116/1/KIRKLEES_PROJECT_and_COST_BENEFIT_REPO RT.pdf Accessed 01 March 2016

210.   Liddell C. *Estimating the health impacts of Northern Ireland's Warm Homes Scheme 2000-2008*. 2013: http://uir.ulster.ac.uk/26173/ Accessed 01 March 2016

211.   Davidson M, Nichol S, Roys M, Beaumont, A. *The cost of poor housing in Wales*. Watford: Building Research Establishment Trust; 2011.

212.   Levy J, Nishioka Y, Spengler J. The public health benefits of insulation retrofits in existing housing in the United States. *Environ Health* 2003;2(1):4.

213.   Stockton S. Valuable to the vulnerable: consumer perspectives on the winter fuel payment, report from a qualitative investigation. Newcastle-upon-Tyne: National Energy Action; 2011.

214.   Easterbrook PJ, Berlin JA, Gopalan R, Matthews DR. Publication bias in clinical research. *Lancet* 1991;337(8746):867-72.

215.   Jackson LA, Jackson ML, Nelson JC, Neuzil KM, Weiss NS. Evidence of bias in estimates of influenza vaccine effectiveness in seniors. *Int J Epidemiol* 2006;35(2):337-44.

216.   Meechan B. *Save your Breath*. Modern Methods of Construction. 2012 Nov.:12.

217.   Pearce N. Epidemiology as a population science. *Int J Epidemiol* 1999;28(5):S1015-8.

218.   Susser M, Stein Z. Eras in Epidemiology: The Evolution of Ideas. New York: Oxford University Press; 2009.

219.   Blumenthal UJ, Fleisher JM, Esray SA, Peasay A. *Epidemiology: a tool for the assessment of risk*. 2001: http://www.who.int/water_sanitation_health/dwq/iwachap7.pdf Accessed 01 March 2016

220.   World Health Organization. *Chapter 4: Determinants (Risk and protective factors) Indicators*. 2004: http://www.who.int/hiv/pub/me/en/me_prev_ch4.pdf Accessed 01 March 2016

221.   Pearce M. Causality and Interpretation. Lecture presented at Newcastle University; 2014.

222.   Parascandola M, Weed DL. Causation in epidemiology. *J Epidemiol Community Health* 2001;55(12):905-12.

223. Cornfield J, Haenszel W, Hammond EC, Lilienfeld AM, Shimkin MB, Wynder EL. Smoking and lung cancer: recent evidence and a discussion of some questions. *Int J Epidemiol* 2009;38(5):1175-91.

224. NHS Choices. *Heart attack – Causes*. 2015: http://www.nhs.uk/conditions/heart-attack/Pages/Causes.aspx Accessed 28 February 2015

225. Stern S, Behar S, Gottlieb S. Aging and Diseases of the Heart. *Circulation* 2003;108(14):e99-e101.

226. Jepsen P, Johnsen SP, Gillman MW, Sørensen HT. Interpretation of observational studies. *Heart* 2004;90(8):956-60.

227. Antonisamy B, Soloman C, Prasanna SP. Biostatistics: Principles and Practice. New Delhi: Tata McGraw Hill; 2010.

228. Hulley SB, Cummings SR, Browner SW, Grady DG, Newman TB. Designing Clinical Research. 3rd ed. Philadelphia: Lippincott, Williams and Wilkins; 2007.

229. Maiväli U. Interpreting Biomedical Science: Experiment, Evidence, and Belief. London: Academic Press; 2015.

230. Bowling A, Ebrahim S. Handbook Of Health Research Methods: Investigation, Measurement And Analysis. England: Open University Press; 2005.

231. Koul L. Methodology Of Educational Research. New Delhi: Vikas Publishing House; 2009.

232. Pearce M. Bias and Confounding. 2014. Lecture presented at Newcastle University; 2014.

233. Greenhalgh T, Howick J, Maskrey N. Evidence based medicine: a movement in crisis? *BMJ* 2014;348.

234. Chung KC, Ram AN. Evidence-Based Medicine: The Fourth Revolution in American Medicine? *Plast Reconstr Surg* 2009;123(1):389-98.

235. Suresh KP. An overview of randomization techniques: An unbiased assessment of outcome in clinical research. *J Hum Reprod Sci* 2011;4(1):8-11.

236. Kendall JM. Designing a research project: randomised controlled trials and their principles. *Emerg Med J* 2003;20(2):164-8.

237. Levin KA. Study design VII. Randomised controlled trials. *Evid Based Dent* 2007;8(1):22-3.

238. Ho PM, Peterson PN, Masoudi FA. Evaluating the Evidence: Is There a Rigid Hierarchy? *Circulation* 2008;118(16):1675-84.

239. London Knowledge and Intelligence Team. *Introduction to epidemiology*. 2014: http://www.lho.org.uk/Training/HealthIntelligenceTraining.aspx#Day7.

240.   Song JW, Chung KC. Observational Studies: Cohort and Case-Control Studies. *Plast Reconstr Surg* 2010;126(6):2234-42.

241.   theBMJ. *6. Ecological studies*. 2015: http://www.bmj.com/about-bmj/resources-readers/publications/epidemiology-uninitiated/6-ecological-studies Accessed 01 March 2016

242.   Paradies Y, Stevens M. Conceptual diagrams in public health research. *J Epidemiol Community Health* 2005;59(12):1012-3.

243.   Earp JA, Ennett ST. Conceptual models for health education research and practice. *Health ed res* 1991;6(2):163-71.

244.   Adams J. Socio-economic differences in health: the role of biological ageing. PhD [dissertation]. Newcastle-upon-Tyne: Newcastle University; 2004.

245.   Kuhn TS. The structure of scientific revolutions. Chicago: Chicago University Press; 1970.

246.   Susser M, Susser E. Choosing a future for epidemiology: I. Eras and paradigms. *Am J Public Health* 1996;86:668-73.

247.   Susser M, Susser E. Choosing a future for epidemiology: II. From black box to Chinese boxes and eco-epidemiology. *Am J Public Health* 1996;86(5):674-7.

248.   Bhopal R. Paradigms in epidemiology textbooks: in the footsteps of Thomas Kuhn. *Am J Public Health* 1999;89(8):1162-5.

249.   March D, Susser E. The eco- in eco-epidemiology. *Int J Epidemiol* 2006;35 (6):1379-83.

250.   Bain LE, Awah PK. Eco-epidemiology: challenges and opportunities for tomorrow's epidemiologists. *The Pan African Medical Journal* 2014;17:317

251.   Brown G, Fearn V, Wells C. Exploratory analysis of seasonal mortality in England and Wales, 1998 to 2007. *Health statistics quarterly* 2010(48):58-80.

252.   Liddell C. Expert paper 1: Alzheimer's, dementia and excess winter mortality. National Institute for Health and Care Excellence; 2014.

253.   Probert LJ. *Fuel poverty eradication in the UK: A model for the EU?* 2012: http://fuelpoverty.eu/2012/05/08/ukmodelfortheeu/ Accessed 20 March 2015

254.   Burns PB, Rohrich RJ, Chung KC. The Levels of Evidence and their role in Evidence-Based Medicine. *Plast Reconstr Surg* 2011;128(1):305-10.

255.   Edina. *Digimap*. 2015: http://digimap.edina.ac.uk/digimap/home# Accessed 01 March 2016

256.   BBC. *GCSE Bitesize. Geography. Climate.* 2014.
http://www.bbc.co.uk/schools/gcsebitesize/geography/weather_climate/climate_rev4.s
html Accessed 22 July 2016

257.   Encyclopaedia Britannica. *Orographic Precipitation*. 2016.
https://www.britannica.com/science/orographic-precipitation Accessed 22 July 2016

258.   Fearne V. *Excess Winter Mortality in England and Wales, 2010/11 (provisional)
and 2009/10 (final)*. 2011:
http://webarchive.nationalarchives.gov.uk/20160105160709/http://www.ons.gov.uk/o
ns/rel/subnational-health2/excess-winter-mortality-in-england-and-wales/2010-11--
provisional--and-2009-10--final-/stb-ewm-2010-11.html Accessed 01 March 2016

259.   Met Office. *What is the jet stream?* 2015:
http://www.metoffice.gov.uk/learning/wind/what-is-the-jet-stream Accessed 20 March
2015

260.   National Oceanic and Atmospheric Administration. *The Jet Stream*. 2015:
http://www.srh.noaa.gov/jetstream/global/jet.htm Accessed 2 March 2016

261.   Southampton weather. *Jet streams explained*. 2015:
http://www.southamptonweather.co.uk/jetstreams.php Accessed 2 March 2016

262.   University of Reading. *Winds of Change*. 2010:
http://www.met.reading.ac.uk/~swr01tjw/pubs/win10-winds.pdf Accessed 2 March
2016

263.   Met.Office. *Advances in long range winter forecasts*. 2014:
http://www.metoffice.gov.uk/news/releases/archive/2014/long-range-advances
Accessed 02 March 2016

264.   Pearce F. *Why is it so cold? Simple... it's the North Atlantic Oscillation - and it's
got a bit stuck*. Daily Mail [online newspaper]. 2010:
http://www.dailymail.co.uk/sciencetech/article-1341618/Why-cold-Simple--North-
Atlantic-Oscillation--got-bit-stuck.html Accessed 2 March 2016

265.   Met Office. *What is causing the extreme cold over North America?* 2015:
http://blog.metoffice.gov.uk/2014/01/07/what-is-causing-the-extreme-cold-over-north-
america/ Accessed 2 March 2016

266.   Met Office. *Why was the start to spring 2013 so cold?* 2015:
http://www.metoffice.gov.uk/research/news/cold-spring-2013 Accessed 20 March
2015

267.   Fowler HJ, Kilsby CG. Precipitation and the North Atlantic Oscillation: a study of
climatic variability in northern England. *Int J Climatol* 2002;22(7):843-66.

268.   Croudace T. Latent Class Analysis. Workshop presented at ESRC AQM National Student Conference; Sheffield, UK; 2014.

269.   Wookey R, Bone A, Carmichael C, Crossley A. *Minimum home temperature thresholds for health in winter – A systematic literature review*. Public Health England; 2014.

270.   Hajat S. *Evaluation of Health-Related Impacts of the Cold-weather plan for England*. 2013: http://ehp.niehs.nih.gov/isee/o-3-33-03/ Accessed 02 March 2016

271.   Thomas M. Biological pathways for Excess Winter Mortality. E-mail to Louise Tanner (l.tanner@ncl.ac.uk) 22 May 2014.

272.   The World Health Organization. *Influenza (seasonal)*. 2014: http://www.who.int/mediacentre/factsheets/fs211/en/ Accessed 24 October 2014.

273.   Fisman D. Seasonality of viral infections: mechanisms and unknowns. *Clin microbial infec* 2012;18(10):946-54.

274.   Dilaveris P, Synetos A, Giannopoulos G, Gialafos E, Pantazis A, Stefanadis C. CLimate Impacts on Myocardial infarction deaths in the Athens TErritory: the CLIMATE study. *Heart* 2006;92(12):1747-51.

275.   Abrignani MG, Corrao S, Biondo GB, Renda N, Braschi A, Novo G, et al. Influence of climatic variables on acute myocardial infarction hospital admissions. *Int J Cardiol* 2009;137(2):123-9.

276.   World Health Organization. *Air pollution*. 2015: http://www.who.int/topics/air_pollution/en/ Accessed 20th March 2015

277.   Peng RD, Dominici F, Pastor-Barriuso R, Zeger SL, Samet JM. Seasonal analyses of air pollution and mortality in 100 US cities. *Am J Epidemiol* 2005;161(6):585-94.

278.   Ayres JG. Cardiovascular Disease and Air Pollution: A report by the Committee on the Medical Effects of Air Pollutants. Department of Health; 2006.

279.   Ostro B. Outdoor air pollution: assessing the environmental burden of disease at national and local levels. World Health Organization; 2004.

280.   Department for Environment Food and Rural Affairs. *Public Health Impacts and Local Actions*. 2015: http://laqm.defra.gov.uk/public-health/public-health.html Accessed 02 March 2016

281.   Department for Environment Food and Rural Affairs. *Public Health: Sources and Effects of PM2.5*. 2016: http://laqm.defra.gov.uk/public-health/pm25.html Accessed 09 February 2016

282.   World Health Organization. *Health effects of particulate matter*. 2013: http://www.euro.who.int/__data/assets/pdf_file/0006/189051/Health-effects-of-particulate-matter-final-Eng.pdf Accessed 09 February 2016

283.   NHS. *Coronary heart disease – causes*. 2015: http://www.nhs.uk/Conditions/Coronary-heart-disease/Pages/Causes.aspx 20 April 2015

284.   Florez-Duquet M, McDonald RB. Cold-induced thermoregulation and biological aging. *Physiol Rev* 1998;78(2):339-58.

285.   Donaldson GCD, Rintamaki H, Nayha S. Outdoor clothing: its relationship to geography, climate, behaviour and cold-related mortality in Europe. *Int J Biometeorol* 2001;45(1):45-51.

286.   Tod AM, Lusambili A, Homer C, Abbott J, Cooke JM, Stocks AJ, et al. Understanding factors influencing vulnerable older people keeping warm and well in winter: a qualitative study using social marketing techniques. *BMJ Open* 2012;2(4).

287.   Institute for Fiscal Studies. *Cash by any other name? Evidence on labelling from the UK Winter Fuel Payment*. 2011: http://www.ifs.org.uk/wps/wp1110.pdf Accessed 10 April 2014

288.   Office for National Statistics. *What are the top causes of death by age and gender?* 2013: http://www.ons.gov.uk/ons/rel/vsob1/mortality-statistics--deaths-registered-in-england-and-wales--series-dr-/2012/sty-causes-of-death.html Accessed 10 April 2016

289.   Woodside JV, Yarnell JW, Patterson CC, Arveiler D, Amouyel P, Ferrieres J, et al. Do lifestyle behaviours explain socioeconomic differences in all-cause mortality, and fatal and non-fatal cardiovascular events? Evidence from middle aged men in France and Northern Ireland in the PRIME Study. *Preventive medicine* 2012;54(3-4):247-53.

290.   Ward MM, Guthrie LC, Butler SC. Time perspective and socioeconomic status: a link to socioeconomic disparities in health? *Soc Sci Med* 2009;68(12):2145-51.

291.   Phillips D, Barker GE, Brewer KM. Christmas and New Year as risk factors for death. *Soc Sci Med* 2010;71(8):1463-71.

292.   National Institute for Health and Care Excellence. *Smoking: harm reduction*. 2015: https://www.nice.org.uk/guidance/ph45 Accessed 02 March 2016

293.   Law MR, Morris JK, Wald NJ. Environmental tobacco smoke exposure and ischaemic heart disease: an evaluation of the evidence. *BMJ* 1997;315:973-80.

294. Morita H, Ikeda H, Haramaki N, Eguchi H, Imaizumi T. Only two-week smoking cessation improves platelet aggregability and intraplatelet redox imbalance of long-term smokers. *J Am Coll Cardiol* 2005;45(4):589-94.

295. Lin H, Wang H, Wu W, Lang L, Wang Q, Tian L. The effects of smoke-free legislation on acute myocardial infarction: a systematic review and meta-analysis. *BMC Public Health* 2013;13(1):529.

296. Costa D. The Impact of Obesity on Pulmonary Function in Adult Women. *Clinics* 2008;63:719–24.

297. Saito K, Sano H, Furuta Y, Fukuzaki H. Effect of oral calcium on blood pressure response in salt-loaded borderline hypertensive patients. *Hypertension* 1989;13(3):219-26.

298. World Health Organization. *Damp and mould: health risks, prevention and remedical action*. 2009: http://www.euro.who.int/__data/assets/pdf_file/0003/78636/Damp_Mould_Brochure.pdf Accessed 27 March 2015

299. Which? *Cavity wall insulation: damp problems*. 2015: http://www.which.co.uk/energy/creating-an-energy-saving-home/guides/cavity-wall-insulation/cavity-wall-insulation-damp-problems/ Accessed 27 March 2015.

300. Blain AP, Thomas MF, Shirley MD, Simmister C, Elemraid MA, Gorton R, et al. Spatial variation in the risk of hospitalization with childhood pneumonia and empyema in the North of England. *Epidemiol infect* 2014;142(2):388-98.

301. Healy J. Do fuel-poor households exhibit higher risk factors associated with poor health? *Int J Health Promot Educ* 2003;41(1):14-20.

302. Boslaugh S. Secondary Data Sources for Public Health: A Practical Guide (Practical Guides to Biostatistics and Epidemiology). Cambridge, UK: Cambridge University Press; 2007.

303. Local Government Group. *Local Government Structure Overview*. 2010: http://www.local.gov.uk/c/document_library/get_file?uuid=2cb6b1c0-0bf0-48f2-a677-9592c1533c5d&groupId=10180 Accessed 08 April 2015

304. Office for National Statistics. *Local authority districts (2011) to counties (2011) Eng lookup*. 2015: https://geoportal.statistics.gov.uk/geoportal/catalog/search/resource/details.page?uuid=%7BB6DF78CC-8FED-49D8-A071-05C9FED8D931%7D Accessed 08 April 2015

305. GOV.UK. *Neighbourhood Statistics Geography Glossary*. 2014: http://neighbourhood.statistics.gov.uk/HTMLDocs/nessgeography/neighbourhoodstati

sticsgeographyglossary/neighbourhood-statistics-geography-glossary.htm Accessed 08
April 2015

306.   Office for National Statistics. *Local government restructuring*. 2015:
http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-
guide/administrative/our-changing-geography/local-government-
restructuring/index.html Accessed 08 April 2015

307.   Office for National Statistics. *Release: Population Estimates for England and
Wales, Mid-2011 (2011 Census-based)*. 2012:
http://www.ons.gov.uk/ons/publications/re-reference-tables.html?edition=tcm%3A77-
262039 Accessed 08 April 2015

308.   Office for National Statistics. *Electoral wards/divisions*. 2015:
http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-
guide/administrative/england/electoral-wards-divisions/index.html Accessed 08 April
2015

309.   Office for National Statistics. *Super Output Areas (SOA)*. 2015:
http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/census/super-
output-areas--soas-/index.html Accessed 08 April 2015

310.   Heath S. *Local authorities' public health responsibilities (England)*. 2014
http://researchbriefings.files.parliament.uk/documents/SN06844/SN06844.pdf
Accessed 12 Feb 2016

311.   National Institute for Health and Care Excellence. *NICE guidance and public
health outcomes*. 2012: https://www.nice.org.uk/advice/lgb5/chapter/introduction
Accessed 08 April 2015

312.   Kohler M. Supporting older people: cold, poor and baffled. *Br J Community Nurs*
2006;11(5):202-4.

313.   Lawlor DA. The health consequences of fuel poverty: what should the role of
primary care be? *Br J Gen Pract* 2001;51(467):435-6.

314.   Department of Health. *Cold Weather Plan for England-Protecting health and
reducing harm from severe cold weather London, England*. 2010:
http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/documents/digitalass
et/dh_130926.pdf Accessed 09 April 2015

315.   Office for National Statistics. FOI request: *Coronary heart disease statistics*.
2013: Available from: http://www.ons.gov.uk/ons/about-ons/business-
transparency/freedom-of-information/what-can-i-request/previous-foi-requests/health-

and-social-care/coronary-heart-disease-statistics/index.html?format=contrast Accessed
01 December 2014

316.   Health and Social Care Information Centre. *Hospital Episode Statistics*. 2015:
http://www.hscic.gov.uk/hes Accessed 01 December 2014

317.   NHS. *Your records*. 2015:
http://www.nhs.uk/NHSEngland/thenhs/records/healthrecords/Pages/care-data.aspx
Accessed 2nd April 2015

318.   Partridge SN. *Review of data releases by the NHS Information Centre*. 2014:
https://www.gov.uk/government/publications/review-of-data-releases-made-by-the-
nhs-information-centre Accessed 2nd April 2015

319.   Health and Social Care Information Centre. *HSCIC learns lessons of the past with
immediate programme for change*. 2014:
http://www.hscic.gov.uk/article/4780/HSCIC-learns-lessons-of-the-past-with-
immediate-programme-for-change Accessed 09 December 2014

320.   Gorton R. Sources of influenza data. E-mail to Louise Tanner
(l.tanner@ncl.ac.uk) 10 October 2014.

321.   Health Protection Agency. *Sources of UK flu data Influenza Surveillance in the
United Kingdom*. 2014:
http://194.74.226.162/web/HPAweb&HPAwebStandard/HPAweb_C/1195733821514
Accessed 02 December 2014

322.   Public Health England. *Sources of UK flu data: influenza surveillance in the UK*.
2014: https://www.gov.uk/sources-of-uk-flu-data-influenza-surveillance-in-the-uk
Accessed 02 March 2016

323.   Public Health England. *Sources of UK flu data Influenza Surveillance in the
United Kingdom*. 2014:
http://webarchive.nationalarchives.gov.uk/20140626151846/http://hpa.org.uk/Topics/I
nfectiousDiseases/InfectionsAZ/SeasonalInfluenza/EpidemiologicalData/30influsSour
cesofUKfludata/ Accessed 02 April 2015

324.   Harcourt SE, Edwards DE, Fleming DM, Smith RL, Smith GE. How
representative is the population covered by the RCGP spotter practice scheme? Using
Geographical Information Systems to assess. *Journal of public health* 2004;26(1):88-
94.

325.   QSurveillance®. *QSurveillance*. 2011:
http://www.qsurveillance.org/QSurveillance/Home_Page.html Accessed 02 March
2016

326.   Influenzanet. *FluSurvey*. 2014: http://flusurvey.org.uk/ Accessed 22 December 2014

327.   Madjid M, Aboshady I, Awan I, Litovsky S, Casscells SW. Influenza and Cardiovascular Disease: Is There a Causal Relationship? *Tex Heart Inst J* 2004;31(1):4-13.

328.   Tanner L. Socio-economic and behavioural risk factors for adverse winter health and social outcomes in economically developed countries: a systematic review of quantitative observational research (2001 – 2011): MSc [dissertation]. Newcastle-upon-Tyne: Newcastle University; 2012.

329.   Archie JP. Mathematic coupling of data: a common source of error. *Ann Surg* 1981;193(3):296-303.

330.   Lofgren E, Fefferman NH, Naumov YN, Gorski J, Naumova EN. Influenza seasonality: underlying causes and modeling theories. *Journal of virology* 2007;81(11):5429-36.

331.   National Weather Service Climate Prediction Center. *North Atlantic Oscillation (NAO)*. 2012: http://www.cpc.ncep.noaa.gov/data/teledoc/nao.shtml Accessed 08 February 2016

332.   Met Office. *UKCP09: Gridded observation data sets*. 2015: http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/ Accessed 02 March 2015

333.   The R foundation. *The R project for statistical computing*. 2013: http://www.R-project.org/ Accessed 02 March 2016

334.   GOV.UK. *English indices of deprivation 2010*. 2011: https://www.gov.uk/government/statistics/english-indices-of-deprivation-2010 Accessed 09 March 2016

335.   Sofianopoulou E. Spatio-temporal analysis: respiratory prescribing in relation to air pollution and deprivation, in primary health care: PhD [dissertation]. Newcastle-upon-Tyne: Newcastle University; 2011.

336.   Bancroft P, Emerson A. A, B, C and M: Road Numbering Revealed. England; Capital Transport Publishing; 2007.

337.   Department for Transport. *Traffic counts*. 2015: http://www.dft.gov.uk/traffic-counts/ Accessed 02 April 2015

338.   Department for environment food and rural affairs. *Data archive*. 2015: http://uk-air.defra.gov.uk/data/ Accessed 02 March 2016

339. Harrison D. Air pollution data measurements. E-mail to Louise Tanner (l.tanner@ncl.ac.uk) 21 April 2015.

340. Hajat S. Air Pollution data sources. E-mail to Louise Tanner (l.tanner@ncl.ac.uk) 25 February 2014.

341. Health and Social Care Information Centre. *Health Survey for England; Health, social care and lifestyles*. 2014: http://www.hscic.gov.uk/article/3741/Health-Survey-for-England-Health-social-care-and-lifestyles Accessed 15 August 2014

342. UK Data Archive. *The UK's largest collection of digital research data in the social sciences and humanities*. 2015: http://www.data-archive.ac.uk/ Accessed 14th April 2015.

343. Holgate ST, Mavroleon G. Molecular Biology Series The molecular and cell biology of allergy. *J Laryngol Otol* 1998;112:1126-37.

344. Public Health England. *Measures of central adiposity*. 2009: http://www.noo.org.uk/uploads/doc/vid_5187_MEASURESOFCENTRALADIPOSIT YAugust%2009_updated%20Feb%202010.pdf Accessed 02 April 2015

345. Public Health England. *Data Sources*. 2015: http://www.noo.org.uk/data_sources Accessed 02 April 2015

346. Mindell J, Biddulph JP, Hirani V, Stamatakis E, Craig R, Nunn S, et al. Cohort Profile: The Health Survey for England. *Int J Epidemiol* 2012;41(6):1585-93.

347. Public Health England. *Welcome to Local Health*. 2014: http://www.localhealth.org.uk/#v=map8;i=t2.obese_adults;l=en Accessed 14 April 2015

348. Public Health England. *Adult Obesity: Model-based estimates using HSE*. 2015: http://www.noo.org.uk/data_sources/adult/model_based_estimates Accessed 15 April 2015

349. Public Health England. *Active People Survey (APS) excess weight data for the Public Health Outcomes Framework*. 2015: http://www.noo.org.uk/data_sources/physical_activity/activepeople Accessed 15 April 2015

350. UK Data Archive. *Active People Survey 5-7 Technical Report Updated to include APS6 (July 2013)*. 2013: http://doc.ukdataservice.ac.uk/doc/7369/mrdoc/pdf/7369_aps_6_technical_report.pdf Accessed 02 March 2016

351. Office for National Statistics. *Discussion of options for Taking Part and Active People Survey Integration*. 2012:

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/73024/ Discussion_of_options_for_Taking_Part_and_Active_People_Survey_Integration.pdf Assessed 15 April 2015

352.   Fadnes L, Taube A, Tylleskär T. How to identify information bias due to self-reporting in epidemiological research. *The Internet Journal of Epidemiology* 2009;7.

353.   Health and Social Care Information Centre. *National Child Measurement Programme*. 2015: http://www.hscic.gov.uk/ncmp Accessed 02 April 2015

354.   Health and Social Care Information Centre. *National Child Measurement Programme: England, 2012/13 school year*. 2013: http://www.hscic.gov.uk/catalogue/PUB13115/nati-chil-meas-prog-eng-2012-2013-rep.pdf Accessed 02 April 2015

355.   Office for National Statistics. *Statistical bulletin: Excess Winter Mortality in England and Wales, 2013/14 (Provisional) and 2012/13 (Final)*. 2014: http://www.ons.gov.uk/ons/rel/subnational-health2/excess-winter-mortality-in-england-and-wales/2013-14--provisional--and-2012-13--final-/stb.html Accessed 02 April 2015

356.   Office for National Statistics. *Super Output Area mid-year population estimates for England and Wales (experimental)*. 2013: http://www.ons.gov.uk/ons/rel/sape/soa-mid-year-pop-est-engl-wales-exp/index.html Accessed 02 April 2015

357.   Office for National Statistics. *Population Estimates: A Short Guide to Population Estimates*. 2016: http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ve d=0CCQQFjAA&url=http%3A%2F%2Fwww.ons.gov.uk%2Fons%2Fguide-method%2Fmethod-quality%2Fspecific%2Fpopulation-and-migration%2Fpop-ests%2Fpopulation-estimates-methodology-archive%2Fa-short-guide-to-population-estimates---superseded-12-11-04.pdf&ei=ocowVf7tOIL0aObFgNgF&usg=AFQjCNHF8YZDElT6dwt69rY54W5h9 ueAJg&bvm=bv.91071109,d.ZWU Accessed 02 March 2016

358.   ONS. Statistical bulletin: 2011 Census: Population and Household Estimates for Wales, March 2011. 2011: http://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/popu lationestimates/bulletins/2011censuspopulationandhouseholdestimatesforwales/2012-07-16 Accessed 12 March 2016

359.   UK Data Service. *INFUSE*. 2015: http://infuse.mimas.ac.uk/ Accessed 17 April 2015

360.   Office for National Statistics. *Response Rates in the 2011 Census*. 2012:
http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=2&ve
d=0CCcQFjAB&url=http%3A%2F%2Fwww.ons.gov.uk%2Fons%2Fguide-
method%2Fcensus%2F2011%2Fcensus-data%2F2011-census-data%2F2011-first-
release%2Ffirst-release--quality-assurance-and-methodology-papers%2Fresponse-
rates-in-the-2011-
census.pdf&ei=4ckwVbTtFcnPaMaSgfAL&usg=AFQjCNHTYDBOCMW2cZpK4T6
N1wzcpibzmw&bvm=bv.91071109,d.ZWU Accessed 17 April 2015

361.   Office for National Statistics. *Overcrowding and under-occupation in England
and Wales*. 2014: http://www.ons.gov.uk/ons/dcp171776_360082.pdf Accessed 02
April 2015

362.   UK Data Service. *INFUSE 2001*. 2015. Available from:
http://infuse.mimas.ac.uk/infusewiz.aspx?cookie=openaccess Accessed 17 April 2015

363.   Office for National Statistics. *Census 1911-2001*. 2014:
http://www.ons.gov.uk/ons/guide-method/census/2011/how-our-census-works/about-
censuses/census-history/200-years-of-the-census/census-1911-2001/index.html
Accessed 29 December 2014

364.   Department for environment communities and local government. The English
Indices of Deprivation 2010 - Frequently Asked Questions. E-mail to Louise Tanner
(l.tanner@ncl.ac.uk) 10 October 2014.

365.   Department for environment food and rural affairs. *2011 Rural-Urban
Classification of Local Authority Districts in England: User Guide*. 2014:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/389780
/RUCLAD2011_User_Guide.pdf Accessed 02 March 2016

366.   Office for National Statistics. *UK Standard Area Measurements (SAM)*. 2015:
http://www.ons.gov.uk/ons/guide-method/geography/products/other/uk-standard-area-
measurements--sam-/index.html Accessed 06 February 2016

367.   Department of Energy and Climate Change. *Fuel poverty sub-regional statistics*.
2013: https://www.gov.uk/government/collections/fuel-poverty-sub-regional-statistics
Accessed 05 May 2015

368.   GOV.UK. *Standard Assessment Procedure*. 2014: https://www.gov.uk/standard-
assessment-procedure Accessed 02 April 2015

369.   The poverty site. *English Housing Survey - Stock Data (formerly called the
English House Condition Survey)*. http://www.poverty.org.uk/technical/ehcs.shtml
Accessed 02 March 2016

370. Stockton H. *Internal temperature data*. E-mail to Louise Tanner (l.tanner@ncl.ac.uk) 10 October 2013.

371. Department of Energy and Climate Change. *Private Rented Sector Energy Efficiency Regulations*. 2014: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/346767/Domestic_PRS_Regulations_Consultation_Draft__v1_6__No_tracks_final_version.pdf Accessed 02 April 2016

372. National Obesity Observatory. *Physical Activity Surveillance in England what is measured and where are the gaps?* 2009: http://www.noo.org.uk/uploads/doc/vid_3953_noo_PhysicalActivity1_210909.pdf Accessed 02 March 2016

373. Holtgraves T. Social desirability and self-reports: testing models of socially desirable responding. *Pers Soc Psychol Bull* 2004;30(2):161-72.

374. Public Health England. *National Diet and Nutrition Survey*. 2015: http://www.noo.org.uk/data_sources/Nutrition/NDNS Accessed 02 April 2015

375. UK Data Service. *Living Costs and Food Survey (Expenditure and Food Survey)*. 2015: http://discover.ukdataservice.ac.uk/series/?sn=2000028 Accessed 02 April 2015

376. Office for National Statistics. *Integrated Household Survey*. 2016: http://webarchive.nationalarchives.gov.uk/20160105160709/http://www.ons.gov.uk/ons/guide-method/method-quality/specific/social-and-welfare-methodology/integrated-household-survey/index.html Accessed 02 March 2016

377. Food Standards Agency. *Low income diet and nutrition survey*. 2011: http://tna.europarchive.org/20110116113217/http://www.food.gov.uk/science/dietarysurveys/lidnsbranch/ Accessed 02 March 2016

378. Public Health England. *Low Income Diet and Nutrition Survey*. 2015: http://www.noo.org.uk/data_sources/Nutrition/LIDNS Accessed 02 March 2016

379. DATA.GOV.UK. *General Lifestyle Survey _survey*. 2011: http://data.gov.uk/dataset/general_lifestyle Accessed 02 March 2016

380. Jephson D. MSOA level smoking data. E-mail to Louise Tanner (l.tanner@ncl.ac.uk) 09 December 2013.

381. NHS CHOICES. *Find Services*. 2016: http://www.nhs.uk/service-search Accessed 12 March 2016

382. Microsoft Office Excel. 2013: http://microsoft-excel.en.softonic.com/.

383.   Office for National Statistics. Open Geography Portal. 2015: https://geoportal.statistics.gov.uk/geoportal/catalog/main/home.page Accessed 05 May 2015

384.   RStudio Team. 2015: RStudio: http://www.rstudio.com/ Accessed 09 March 2016

385.   Office for National Statistics. *Published Ad hoc Data: Health, Requests During June 2014*. 2014: http://www.ons.gov.uk/ons/about-ons/business-transparency/freedom-of-information/what-can-i-request/published-ad-hoc-data/health/june-2014/index.html Accessed 02 December 2014

386.   National Oceanic and Atmospheric Administration. *North Atlantic Oscillation*. 2005: http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao.shtml Accessed 05 May 2015

387.   Office for National Statistics. *You searched for "'Mid-year population estimates'"* 2015: http://www.ons.gov.uk/ons/search/index.html?content-type=Reference+table&pubdateRangeType=allDates&newquery='Mid-year+population+estimates'&pageSize=50&applyFilters=true Accessed 05 May 2015

388.   Office for National Statistics. *Datasets and reference tables*. 2015: http://www.ons.gov.uk/ons/datasets-and-tables/index.html?pageSize=50&sortBy=none&sortDirection=none&newquery=overcrowding Accessed 02 March 2016

389.   Office for National Statistics. *Tenure of household (2001 Census)*. 2015: http://data.gov.uk/dataset/tenure_of_household_2001_census Accessed 05 May 2015

390.   Public Health England. *Public Health Outcomes Framework*. 2015: http://www.phoutcomes.info/ Accessed 06 May 2015

391.   Sport England. *Who plays sport?* 2015: https://www.sportengland.org/research/who-plays-sport/ Accessed 06 May 2015

392.   Elliot P. Spatial Epidemiology: Current Approaches and Future Challenges. *Environ Health Persp* 2004;112:998-1006.

393.   theguardian [online newspaper]. *John Snow's data journalism: the cholera map that changed the world*. 2013: http://www.theguardian.com/news/datablog/2013/mar/15/john-snow-cholera-map Accessed 06 May 2015

394.   Public Health England. *Excess Winter Deaths (EWD) in England*. 2013: http://www.wmpho.org.uk/excesswinterdeathsinEnglandatlas/ Accessed 06 May 2015

395.   Duff C. Durham's Warm and Healthy Homes scheme. Creating Healthy Places in the North East: the Role of Housing. Workshop presented at FUSE housing and health inequalities event; Teesside University; 2015

396.   Blangiardo M, Cameletti M. Spatial and spatiotemporal Bayesian models with R-INLA. United Kingdom: Wiley; 2015.

397.   Brunsdon C, Corcoran J, Higgs G. *Visualising crime in space and time*. 2004: https://www.ucl.ac.uk/jdi/events/mapping-conf/conf-2004/conf2004-downloads/c-brunsdon.pdf Accessed 06 February 2016

398.   G'omes-Rubio V, Best N, Richardson G. *Bayesian Statistics for Small Area Estimation*. http://eprints.ncrm.ac.uk/1686/1/BayesianSAE.pdf Accessed 06 May 2015

399.   Rezaeian M, Dunn G, St Leger S, Appleby L. Geographical epidemiology, spatial analysis and geographical information systems: a multidisciplinary glossary. *J Epidemiol Community Health* 2007;61(2):98-102.

400.   Legendre P. Spatial Autocorrelation: Trouble or New Paradigm? *Ecology* 1993;74(6):1659-73.

401.   Norwegian Institute of Science and Technology. *Spatial modelling with INLA: the first spatial models*. 2014: http://www.math.ntnu.no/~daniesi/INLA/StAndrews/slides/day%201/ Accessed 06 February 2016

402.   Office for National Statistics. *Quality and methodology information*. 2015: http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&ved=0ahU KEwiooYexmaLLAhXHOBQKHdMjBxYQFgg0MAQ&url=http%3A%2F%2Fwww. ons.gov.uk%2Fons%2Fguide-method%2Fmethod-quality%2Fquality%2Fquality-information%2Fhealth-and-social-care%2Fquality-and-methodology-information-for-excess-winter-mortality-in-england-and-wales.pdf&usg=AFQjCNGB9gH2sio4GMDWd2Odlkge0skhAg&bvm=bv.115339255 ,d.ZWU Accessed 02 March 2016

403.   The Pennsylvania State University. *Lesson 9: Poisson Regression*. 2016: https://onlinecourses.science.psu.edu/stat504/node/165 Accessed 06 February 2016

404.   Blangiardo M, Cameletti M, Baio G, Rue H. Spatial and spatio-temporal models with R-INLA. *Spatial and spatio-temporal epidemiology* 2013;4:33-49.

405.   The R project. *Latent models*. 2015: http://www.r-inla.org/models/latent-models Accessed 07 February 2016

406.   Congdon P. Bayesian Statistical Modelling. 2nd edition. Wiley; 2006.

407. Tu YK, Kellett M, Clerehugh V, Gilthorpe MS. Problems of correlations between explanatory variables in multiple regression analyses in the dental literature. *Br Dent J* 2005;199(7):457-61.

408. Public Health England. *Longer Lives*. http://fingertips.phe.org.uk/topic/mortality/#ati/101/gid/1000001/pat/101 Accessed 22 July 2016

409. Unal B, Capewell S, Critchley, JA. Coronary heart disease models: a systematic review. *BMC Public Health* 2006 18;6:213.

410. Lowen AC, Steel J. Roles of Humidity and Temperature in Shaping Influenza Seasonality. *J Virol* 2014;88 (14): 7692-95.

411. Soebiyanto RP, Clara W, Jara J, Castillo L, Sorto OR, Marinero S, et al. The Role of Temperature and Humidity on Seasonal Influenza in Tropical Areas: Guatemala, El Salvador and Panama, 2008–2013. *PLoS ONE* 2014;9(6): e100659.

412. Gasparrini A, Armstrong B. *Time series regression analysis*. 2016: http://csm.lshtm.ac.uk/themes/time-series-regression-analysis/ Accessed 06 February 2016

413. Bernard S. Lonliness and social isolation among older people in North Yorkshire. The University of York; 2013.

414. Middlemiss L, Gillard R. Fuel poverty from the bottom-up: Characterising household energy vulnerability through the lived experience of the fuel poor. *Energy Research and Social Science* 2015;6:146–154.

415. Yang J, Yin P, Zhou M, Ou CQ, Guo Y, Gasparrini A et al. Cardiovascular mortality risk attributable to ambient temperature in China. *Heart* 2015;101(24):1966-72.

416. Chung Y, Lim YH, Honda Y, Guo YL, Hashizume M, Bell ML et al. Mortality related to extreme temperature for 15 cities in northeast Asia. *Epidemiology* 2015;26(2):255-62.

417. Lacroix E, Chaton C. Fuel poverty as a major determinant of perceived health: the case of France. *Public Health* 2015 May;129(5):517-24.

418. Díaz J, Carmona R, Mirón IJ, Ortiz C, Linares C. Comparison of the effects of extreme temperatures on daily mortality in Madrid (Spain), by age group: The need for a cold wave prevention plan. *Environ Res* 2015;143(Pt A):186-91

419. Rehill N, Armstrong B, Wilkinson P. Clarifying life lost due to cold and heat: a new approach using annual time series. *BMJ Open* 2015;5(4):e005640.

420.   Gray B, Allison S, Thomas B, Morris C, Liddell, C. Excess winter deaths among people living with Alzheimer's Disease or related dementias. Chesshire Lehmann Fund;2015.

421.   Public Health England. *Public Health Outcomes Framework.* http://www.phoutcomes.info/search/social%20isolation#pat/6/ati/102/par/E12000004 Accessed 22 July 2016

422.   Whitley E, Gunnell D, Dorling D, Davey Smith G. Ecological study of social fragmentation, poverty, and suicide. *BMJ* 1999; 319(7216): 1034–1037

Eleven. Appendices

Appendix A: electronic search strategies for the systematic review presented in chapters two-three

Ovid MEDLINE(R) (1946 to October Week 3 2012) and PsychInfo (1806 to October Week 3 2012)
Search 1: Winter **OR** Seaso* **OR** Cold **AND** Socio-economic **OR** Socioeconomic **OR** Deprivation **OR** Housing/ **OR** Lifestyle/ **AND** Mortality/ **OR** Morbidity/ **OR** Hospita* **OR** Health **OR** Excess Limit to (English language and humans)
Search 2: "Fuel Poverty"
Search 3: Cloth* OR smoking OR tobacco OR diet OR physical activity OR excur* OR cold exposure OR alcohol AND intervention OR initiative OR programme OR campaign OR scheme OR awareness OR prevention strategies OR health promotion OR prevention OR strategy OR policy AND Winter OR Seaso* OR Cold AND Mortality/ OR Morbidity/ OR Hospita* OR Health OR Excess Limit to (English language and humans)

Scopus
Search 1: TITLE-ABS-KEY-AUTH(winter AND socio-economic OR socioeconomic OR deprivation OR behav* OR housing AND mortalit* OR morbidit* OR health OR hospita* OR excess) AND (LIMIT-TO(SUBJAREA, "MEDI") OR LIMIT-TO(SUBJAREA, "SOCI") OR LIMIT-TO(SUBJAREA, "ENER")) AND (LIMIT-TO(LANGUAGE, "English"))
Search 2: "Fuel Poverty" (no search restrictions).

PubMed
Search 1: ((((((((((socioeconomic[Title/Abstract]) OR socio-economic[Title/Abstract]) OR deprivation[Title/Abstract]) OR "housing"[MeSH Terms])) OR "behav*"[Title/Abstract])) AND ((((((excess[Title/Abstract]) OR mortalit*[Title/Abstract]) OR morbidit*[Title/Abstract]) OR health[Title/Abstract]) OR hospita*[Title/Abstract])) AND (((winter[Title/Abstract]) OR cold[Title/Abstract]) OR seaso*[Title/Abstract]) AND (Humans[Mesh] AND English[lang])
Search 2: "Fuel Poverty"
Web of Science
Search term: "Fuel Poverty"

Appendix B: inclusion and exclusion criteria for the systematic review presented in chapters two-three

Titles and abstracts (where available) of located references were screened against the review inclusion criteria (see below). The full texts of any references considered potentially eligible for inclusion were obtained in full. Unobtainable references were excluded.

Studies were included either in the review of vulnerability studies or the review of intervention evaluation studies if they met the following inclusion criteria:

The following factors were considered relevant exposures or interventions*, based on previous, extensive reading of the literature:

 i. Cold exposure, assessed using direct measures of personal cold-exposure, data on meteorological factors considered to characterise 'cold-weather' (e.g. measure of temperature, precipitation and sunshine duration) or temporal indicators, including month(s) of assessment being during the winter period.

  And

 ii. Socioeconomic factors, including any individual or composite measures that were deemed appropriate by the reviewer.

  Or

 iii. Measure of housing conditions relating to low indoor temperature, house location (rural-urban status), occupancy level and tenure.

  Or

 iv. Measure of fuel poverty.

  Or

 v. Lifestyle-related factors, including active or passive smoking, alcohol intake and consumption of prescription or non-prescription drugs; measures of diet and nutrition, influenza vaccination status, clothing protection, personal cold-exposure, physical activity and indoor energy behaviour.

  Or

 vi. * Interventions which addressed the exposures specified in sections i and ii-v.

Outcomes included measures of physical health, mental health and wellbeing; biological factors known to be involved in disease pathways; nutritional status; measures of quality of life and social function; impact on everyday activities; slips and falls; measures of healthcare utilisation; educational attainment; school and work attendance; economic impacts and quality-adjusted life years.

The following studies were excluded from the review of vulnerability and intervention evaluation studies:

i. Non-primary studies

ii. Studies which measured only environmental outcomes (e.g. carbon dioxide emissions associated with thermally inefficient housing).

iii. Studies which identified only risk factors relating to winter sporting or recreational activities (e.g. sledding and snowboarding).

iv. Risk factors of not considered to be of contemporary relevance to the UK.

v. Studies not presenting evidence of the synergistic effects of exposure to cold and any of the other exposures outlined in the inclusion criteria (sections ii-v).

Exclusion reasons were recorded during the second screen, of full texts.

Included studies were separated into those which identified vulnerability factors associated with cold-related adverse health or social outcomes and those evaluating the effects of interventions on these outcomes. These two categories of evidence were synthesized separately in the review presented in chapters two-three.

Appendix C: screen shot of the Excel file used to link LAD-level data

Appendix D: correlations between explanatory variables for the period January-March 2011

	Resp.Med	Cardiology	A&E	Ad_overwe	Incomedep	Smok%	Crowded%	Activ%	Y6_overwe	RUC score	Fpov%	PrivRent%	Age≥65yrs%	Min	Mea	Max	Win	Hum	Sun	Fro	PM2.5	N02	Popdens
Min	0.4	0.4	0.4	-0.5	0.1	0.0	0.6	0.1	0.2	0.4	-0.4	0.5	0.3	1.0	0.0	0.0	-0.1	0.1	0.0	0.0	0.7	0.6	0.6
PM2.5	0.5	0.5	0.5	-0.5	0.1	0.0	0.8	0.2	0.2	0.6	-0.3	0.5	0.4	0.7	-0.1	-0.1	0.0	0.1	0.0	0.0	1.0	0.9	0.7
Crowded%	0.6	0.7	0.6	-0.6	0.4	0.1	1.0	0.1	0.5	0.6	-0.2	0.8	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.9
Popdens	0.7	0.6	0.7	-0.6	0.5	0.2	0.9	0.1	0.5	0.6	-0.1	0.7	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.8	1.0
N02	0.6	0.6	0.5	-0.4	0.4	0.2	0.8	0.1	0.5	0.8	-0.1	0.6	0.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.0	0.8
PrivRent%	0.5	0.6	0.6	-0.6	0.4	0.2	0.8	0.1	0.3	0.4	0.0	1.0	0.5	0.5	0.0	-0.1	0.0	-0.1	0.0	0.0	0.5	0.6	0.7
Cardiology	0.7	1.0	0.7	-0.4	0.2	0.1	0.7	0.1	0.3	0.4	-0.2	0.6	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.6	0.6
RUC score	0.4	0.4	0.4	-0.3	0.4	0.3	0.6	0.1	0.4	1.0	0.0	0.4	0.4	0.4	0.0	0.0	0.0	-0.1	0.0	0.0	0.6	0.8	0.6
Resp. Med	1.0	0.7	0.9	-0.4	0.3	0.1	0.6	0.1	0.3	0.4	0.0	0.5	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.6	0.7
A&E	0.9	0.7	1.0	-0.5	0.3	0.1	0.6	0.1	0.3	0.4	0.0	0.6	0.5	0.4	0.0	0.0	0.0	0.0	0.1	0.0	0.5	0.5	0.7
Age≥65yrs%	0.4	0.3	0.5	-0.4	0.3	0.2	0.6	0.1	0.3	0.4	-0.1	0.5	1.0	0.3	0.1	0.1	0.0	-0.1	0.0	0.0	0.4	0.4	0.6
Y6_overwe	0.3	0.3	0.3	0.1	0.6	0.4	0.5	-0.4	1.0	0.4	0.2	0.3	0.3	0.2	0.1	0.1	0.1	-0.2	0.1	0.0	0.2	0.5	0.5
Activ%	0.1	0.1	0.1	-0.4	-0.3	-0.4	0.1	1.0	-0.4	0.1	-0.2	0.1	0.1	0.1	0.0	0.0	-0.1	0.2	-0.1	0.0	0.2	0.1	0.1
Hum	0.0	0.0	0.0	-0.1	-0.2	-0.2	0.0	0.2	-0.2	-0.1	-0.1	-0.1	-0.1	0.1	-0.1	-0.1	0.0	1.0	0.0	0.1	0.1	0.0	0.0
Incomedep	0.3	0.2	0.3	0.0	1.0	0.6	0.4	-0.3	0.6	0.4	0.3	0.4	0.3	0.1	0.1	0.1	0.1	-0.2	0.1	0.1	0.1	0.4	0.5
Sun	0.0	0.0	0.1	0.0	0.1	0.1	0.0	-0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.1	0.0	1.0	0.5	0.0	0.0	0.0
Fro	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	-0.3	-0.1	0.2	0.1	0.5	1.0	0.0	0.0	0.0
Mea	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	1.0	0.9	-0.1	-0.1	0.1	-0.3	-0.1	0.0	0.0
Max	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.1	-0.1	0.1	0.0	0.9	1.0	-0.1	-0.1	0.3	-0.1	-0.1	0.0	0.0
Smok%	0.1	0.1	0.1	0.2	0.6	1.0	0.1	-0.4	0.4	0.3	0.3	0.2	0.2	0.0	0.0	0.1	0.1	-0.2	0.1	0.1	0.0	0.2	0.2
Win	0.0	0.0	0.0	0.0	0.1	0.1	0.0	-0.1	0.1	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.1	1.0	0.0	0.1	0.2	0.0	0.0	0.0
Fpov%	0.0	-0.2	0.0	0.1	0.3	0.3	-0.2	-0.2	0.2	0.0	1.0	0.0	-0.1	-0.4	0.0	0.1	0.0	-0.1	0.0	0.1	-0.3	-0.1	-0.1
Ad_overwe	-0.4	-0.4	-0.5	1.0	0.0	0.2	-0.6	-0.4	0.1	-0.3	0.1	-0.6	-0.4	-0.5	0.1	0.1	0.0	-0.1	0.0	0.0	-0.5	-0.4	-0.6

Variable key: A&E: Number of accidents and emergency departments per sq km *1000; **Crowded%:** Proportion of over-crowded households; **Ad_overwe%:** Proportion of overweight or obese adults; **FPov%** Proportion of fuel poor households; **Fro:** Days of air frost; **Hum:** Mean relative humidity; **Incomedep%:** Proportion of income deprived households; **Max:** Mean daily maximum temperature; **Mea** Mean daily air temperature; **Min** Mean minimum daily temperature; **N0$_2$** Annual mean modelled concentration of N0$_2$; **Y6_overwe%** Proportion of overweight or obese children aged 10-11 years; **Age ≥65 years%** Proportion of the population aged ≥65 years; **PM$_{2.5}$** Annual mean modelled concentration of PM$_{2.5}$; **Popdens** Population density, number per sq km; **PrivRent%:** Proportion of privately-rented households; **Cardiology:** Number of organisations providing cardiology services per sq km *1000; **Resp. Med:** Number of organisations providing respiratory medicine per sq km *1000; **Smok%** Adult smoking prevalence; **Activ%** Proportion of adults participating in 30 minutes of moderate intensity physical activity at least four times over the last 28 days; **Sun:** Sunshine duration; **RUC score:** Rural Urban classification score; **Win** Mean wind speed

Appendix E: individual factors associated with spatial variations in circulatory mortality ratios across English LADs during the period January-March 2011

	A	B	C	D	E	F	G	H
1	**Model (variable abbreviation)**	**Model ID**	**DIC value**	**Regression est.**	**RR**		**RR95%BCI**	
2	PM2.5	x20	2625.339	-0.1893	0.827591	0.8089675, 0.8464618	
3	N02	x21	2630.528	-0.1866	0.829848	0.8103963, 0.8495729	
4	Crowded%	x6	2630.715	-0.1853	0.830874	0.8118003, 0.8501967	
5	Popdens	x22	2640.145	-0.1663	0.846846	0.8267162, 0.8672673	
6	Cardiology	x1	2654.112	-0.1359	0.873067	0.8428356, 0.9038447	
7	PrivRent%	x11	2654.662	-0.1179	0.888891	0.8646772, 0.9134993	
8	Ad_overwe%	x3	2655.436	0.119	1.126509	1.096464, 1.157027	
9	Min	x13	2655.721	-0.1087	0.897065	0.8724545, 0.9220844	
10	RUC score	x9	2655.756	-0.1155	0.891027	0.8671132, 0.9153539	
11	Age≥65years%	x12	2657.073	-0.1175	0.889264	0.8650913, 0.9138905	
12	A&E	x2	2658.826	-0.1	0.904942	0.8796141, 0.9307138	
13	Fpov%	x10	2659.925	0.0709	1.073586	1.042478, 1.105336	
14	Activ%	x7	2661.357	-0.0765	0.926485	0.8999886, 0.9534695	
15	Y6_overw%	x8	2662.768	-0.0607	0.941238	0.9137941, 0.9691961	
16	Hum	x17	2663.736	-0.0483	0.952924	0.9256087, 0.9807485	
17	Mea	x14	2664.372	0.0303	1.03093	1.000503, 1.061948	
18	Max	x15	2664.397	0.03	1.030557	1.000139, 1.061565	
19	Incomedep%	x4	2664.675	-0.0428	0.958259	0.9302831, 0.9867886	
20	Null (bym)	0	2664.703				
21	Win	x16	2664.819	-0.0143	0.985887	0.9565148, 1.0157941	
22	Smok%	x5	2665.008	-0.0059	0.9942	0.9645438, 1.0244057	
23	Sun	x18	2665.092	0.0167	1.016941	0.9867527, 1.0476763	
24	Fro	x19	2665.169	0.0002	1.000294	0.9706016, 1.0305499	
25							

Circulatory, Jan-Mar 2011 | Circulatory, Jul-Sep 2011 | Respiratory, Jan-Mar 2011 | Respiratory, Jul-Sep 2011

Appendix F: individual factors associated with spatial variations in circulatory mortality ratios across English LADs during the period July-September 2011

	A	B	C	D	E	F G	H
1	Univariate model (variable abbreviation)	Model ID	DIC value	Regression est.	RR	RR 95% BCI	
2	PM2.5	x20	2556.62	-0.1939	0.82	0.8055925, 0.8422917	
3	N02	x21	2564.42	-0.1931	0.82	0.8056351, 0.8435550	
4	Crowded%	x6	2572.02	-0.18	0.84	0.8157397, 0.8552618	
5	Popdens	x22	2576.90	-0.1672	0.85	0.8259711, 0.8664216	
6	Ad_overwe%	x3	2591.75	0.1275	1.14	1.106136, 1.166448	
7	RUC score	x9	2592.25	-0.1251	0.88	0.8589175, 0.9065070	
8	PrivRent%	x11	2593.52	-0.1209	0.89	0.8621483, 0.9107346	
9	Min	x13	2594.51	-0.1117	0.89	0.8702133, 0.9189294	
10	A&E	x2	2594.93	-0.1135	0.89	0.8681066, 0.9178704	
11	Cardiology	x1	2595.43	-0.1511	0.86	0.8305402, 0.8898552	
12	Activ%	x7	2598.68	-0.0841	0.92	0.8930775, 0.9462816	
13	Age≥65years%	x12	2598.80	-0.106	0.90	0.8746154, 0.9248539	
14	Fpov%	x10	2602.14	0.0576	1.06	1.028119, 1.091394	
15	Y6_overw%	x8	2603.75	-0.0574	0.94	0.9167003, 0.9725829	
16	Mea	x14	2604.86	0.0234	1.02	0.9935948, 1.0546175	
17	Max	x15	2604.91	0.022	1.02	0.9921779, 1.0531709	
18	Incomedep%	x4	2604.97	-0.0415	0.96	0.9314451, 0.9880612	
19	Null (bym)	0	2605.13				
20	Hum	x17	2605.31	-0.0056	0.99	0.9654083, 1.0241789	
21	Sun	x18	2605.31	0.0072	1.01	0.9774326, 1.0377852	
22	Fro	x19	2605.32	-0.0041	1.00	0.9662223, 1.0262858	
23	Smok%	x5	2605.34	-0.0015	1.00	0.9686187, 1.0291104	
24	Win	x16	2605.35	0.0048	1.00	0.9747443, 1.0356656	
25							

Circulatory, Jan-Mar 2011 | Circulatory, Jul-Sep 2011 | Respiratory, Jan-Mar 2011 | Respiratory, Jul-Sep 2011

Appendix G: individual factors associated with spatial variations in respiratory mortality ratios across English LADs during the period January-March 2011

	A	B	C	D	E	F G	H
1	**Univariate model (variable abbreviation)**	**Model ID**	**DIC value**	**Regression est.**	**RR**	**RR 95% BCI**	
2	PM2.5	x20	2388.977	-0.1989	0.819678	0.800185, 0.8395525	
3	Crowded%	x6	2400.007	-0.1847	0.831443	0.8104138, 0.8528101	
4	N02	x21	2408.972	-0.1694	0.844266	0.8211675, 0.8678470	
5	Popdens	x22	2411.43	-0.1545	0.856935	0.8339926, 0.8802494	
6	Ad_overwe%	x3	2417.557	0.1425	1.153235	1.121642, 1.185319	
7	PrivRent%	x11	2422.993	-0.1247	0.882856	0.8572397, 0.9089321	
8	Resp. Med	x1	2424.516	-0.1122	0.893939	0.8669897, 0.9213121	
9	Min	x13	2426.371	-0.1147	0.891741	0.8655332, 0.9184631	
10	A&E	x2	2428.368	-0.0987	0.906141	0.8786957, 0.9340530	
11	Age≥65years%	x12	2431.201	-0.096	0.90855	0.8813523, 0.9363188	
12	Activ%	x7	2432.554	-0.0733	0.929442	0.9006705, 0.9587948	
13	Fpov%	x10	2432.866	0.068	1.070479	1.037206, 1.104432	
14	RUC score	x9	2434.207	-0.0715	0.931106	0.9027004, 0.9601226	
15	Smok%	x5	2435.122	0.0533	1.054902	1.021899, 1.088544	
16	Hum	x17	2435.398	-0.0492	0.952084	0.9233991, 0.9813656	
17	Max	x15	2435.866	0.0333	1.034008	1.001606, 1.067128	
18	Mea	x14	2436.173	0.0315	1.0321	0.9997635, 1.0651278	
19	Sun	x18	2436.469	0.0263	1.026782	0.9946647, 1.0595799	
20	Null (bym)	0	2437.047				
21	Incomedep%	x4	2437.147	0.005	1.005123	0.9738651, 1.0370657	
22	Fro	x19	2437.275	0.0022	1.002298	0.9709483, 1.0343174	
23	Y6_overw%	x8	2437.291	-0.0202	0.980101	0.949155, 1.011728	
24	Win	x16	2437.344	0.0057	1.005817	0.9738531, 1.0384191	
25							

⧎ ◂ ▸ ▸⧎   Circulatory, Jan-Mar 2011   Circulatory, Jul-Sep 2011   **Respiratory, Jan-Mar 2011**   Respiratory, Jul-Sep 2011

Appendix H: individual factors associated with spatial variations in respiratory mortality ratios across English LADs during the period July-September 2011

	A	B	C	D	E	F G
1	**Univariate model (variable abbreviation)**	**Model ID**	**DIC value**	**Regression est.**	**RR**	**RR 95% BCI**
2	Crowded%	x6	2225.105	-0.1402	0.869256	0.8451334, 0.8937921
3	PM2.5	x20	2225.185	-0.1433	0.866603	0.8426665, 0.8910847
4	Popdens	x22	2231.294	-0.1213	0.88589	0.8611420, 0.9110602
5	Ad_overwe%	x3	2231.84	0.115	1.122013	1.089744, 1.154827
6	N02	x21	2233.989	-0.1169	0.889762	0.8631038, 0.9169859
7	PrivRent%	x11	2237.994	-0.0965	0.90814	0.8809774, 0.9358303
8	Min	x13	2240.696	-0.086	0.917703	0.8907443, 0.9452891
9	Resp.Med	x1	2242.183	-0.0722	0.930426	0.9013313, 0.9599584
10	A&E	x2	2242.469	-0.0729	0.929827	0.9008404, 0.9592888
11	Age≥65years%	x12	2242.59	-0.0786	0.92457	0.8962531, 0.9535124
12	Activ%	x7	2242.753	-0.0591	0.942716	0.9128376, 0.9731821
13	Smok%	x5	2244.538	0.0563	1.058036	1.024171, 1.092537
14	Hum	x17	2246.658	-0.0282	0.972318	0.942638, 1.002691
15	Fpov%	x10	2246.664	0.0338	1.034515	1.001328, 1.068329
16	RUC score	x9	2247.053	-0.036	0.964733	0.9341023, 0.9961244
17	Incomedep%	x4	2247.169	0.0048	1.004968	0.9735042, 1.0371564
18	Win	x16	2247.26	0.0076	1.007812	0.9752646, 1.0410699
19	Null (bym)	0	2247.273			
20	Max	x15	2247.321	-0.0042	0.99593	0.9647933, 1.0277531
21	Mea	x14	2247.338	-0.002	0.998158	0.9670137, 1.0300024
22	Sun	x18	2247.342	0.0002	1.000318	0.9688642, 1.0324078
23	Fro	x19	2247.368	-0.0034	0.996762	0.964651, 1.029434
24	Y6_overw%	x8	2247.535	-0.0073	0.992824	0.9610355, 1.0253835
25						

Circulatory, Jul-Sep 2011 | Respiratory, Jan-Mar 2011 | **Respiratory, Jul-Sep 2011** | Circulatory Jan-Dec

298

Appendix I: individual factors associated with spatiotemporal variations in monthly circulatory mortality ratios across English LADs from January-December 2011

Univariate model (variable abbreviation)	Model ID	DIC value	Regression est.	RR	RR 95% BCI
PM2.5	19	24579.49	-0.1982	0.82026	0.7997690, 0.8410419
N02	20	24579.83	-0.1958	0.822248	0.8009795, 0.8438299
Crowded%	8	24588.7	-0.1908	0.82639	0.8050025, 0.8480931
Cardiology	3	24589.33	-0.1631	0.849644	0.8204368, 0.8793307
PrivRent%	13	24591.57	-0.1234	0.883991	0.8575450, 0.9109006
Popdens	21	24592.73	-0.1784	0.8367	0.8150548, 0.8586869
RUC score	11	24593.04	-0.1374	0.871741	0.8466122, 0.8973134
Ad_overwe%	5	24594.32	0.1183	1.125689	1.092350, 1.159659
Fpov%	12	24594.33	0.0722	1.075027	1.040963, 1.109834
A&E	4	24594.72	-0.1218	0.885415	0.8592787, 0.9120473
Win	25	24595.22	0.0094	1.009488	0.9952964, 1.0238144
Smok%	7	24595.4	-0.0099	0.990154	0.975076, 1.005354
Hum	24	24595.73	-0.0243	0.976082	0.9537247, 0.9988386
Null (ST1)	0	24595.8			
Incomedep%	6	24596.76	0.0189	1.019264	0.9864272, 1.0528067
Sun	23	24597.53	-0.0031	0.996942	0.972460, 1.022127
Min-1	18	24597.92	-0.1007	0.904429	0.8699202, 0.9412465
NAOt-1	15	24598.08	0.0175	1.017851	0.9758045, 1.0615055
NAO	14	24598.53	0.0074	1.007851	0.9552227, 1.0638060
Age≥65years%	16	24598.76	-0.0169	0.983429	0.9516676, 1.0158860
Mea	1	24598.9	-0.0075	0.992833	0.9474313, 1.0439285
Max	2	24599.17	0.0058	1.006011	0.9646658, 1.0492595
Fro	22	24600.66	0.0056	1.005634	0.990592, 1.020809
Activ%	9	24600.69	-0.0117	0.988359	0.9747378, 1.0020969
Y6_overw%	10	24601.15	-0.0194	0.980836	0.9629965, 0.9989292
Min	17	24602.2	-0.0742	0.928589	0.9006593, 0.9585259

Appendix J: individual factors associated with spatiotemporal variations in monthly respiratory mortality ratios across English LADs from January-December 2011

Univariate model (variable abbreviation)	Model ID	DIC value	Regression est.	RR	RR 95% BCI
Fpov%	12	19833.46	0.0988	1.104039	1.059461 1.149853
Incomedep%	6	19833.85	0.0723	1.075237	1.031454 1.120245
Ad_overwe%	5	19833.9	0.1443	1.155416	1.110940 1.201029
Resp. Med.	3	19833.91	-0.1203	0.886818	0.8518487 0.9227026
PM2.5	19	19834.02	-0.2039	0.815705	0.7870136 0.8450812
Age≥65years%	16	19834.21	-0.0141	0.986268	0.9453317 1.0283690
PrivRent%	13	19834.26	-0.1236	0.883903	0.8489539 0.9197806
RUC score	11	19834.31	-0.0792	0.924059	0.8864869 0.9626677
Popdens	21	19834.38	-0.1642	0.848774	0.8169472 0.8813997
Null (ST1)	0	19834.43	0.4753	1.608913	1.542230 1.677341
A&E	4	19834.45	-0.0974	0.907402	0.8709879 0.9448007
N02	20	19834.52	-0.1676	0.845846	0.8135731 0.8789609
Mea	1	19835.37	0.0018	1.001861	0.9825852 1.0221427
Min	17	19835.37	-0.004	0.996027	0.9766344 1.0139957
Sun	23	19835.45	0.0006	1.000671	0.9872926 1.0142368
Hum	24	19835.52	-0.0004	0.999663	0.9835277 1.0159072
Max	2	19835.57	0.0021	1.002154	0.9830564 1.0222635
Mint-1	18	19835.7	-0.0052	0.994904	0.9718967 1.0170821
Y6_overw%	10	19835.84	-0.0052	0.994887	0.9738946 1.0161546
NAOt-1	15	19835.96	0	1.000012	0.9904921 1.0095601
NAO	14	19835.99	0	1.000014	0.9898406 1.0102222
Win	25	19835.99	-0.0001	0.999886	0.9897403 1.0100648
Fro	22	19836	0.0002	1.000176	0.9894824 1.0109159
Smok%	7	19837.43	0.0125	1.012646	0.9943411 1.0311163
Activ%	9	19837.53	-0.0107	0.9894	0.9738721 1.0050707
Crowded%	8	19838.01	-0.1896	0.827448	0.7971081 0.8585365

Appendix K: individual climatic factors associated with spatiotemporal variations in circulatory mortality ratios across English LADs and winter periods from 2001/2 to 2011/12

	A	B	C	D	E	F	G
1	Univariate model (variable abbreviation)	Model ID	DIC value	Regression est.	RR		RR 95% BCI
2	Min	X1	29522.29	-0.0097	0.990376	0.9796555, 1.0010301	
3	Hum	X7	29522.6	-0.0067	0.993349	0.9843603, 1.0023655	
4	Fro	X4	29523.21	-0.0065	0.993561	0.9839062, 1.0031130	
5	Mea	X2	29523.83	0.0065	1.006574	0.991576, 1.022468	
6	STII	Null	29524.01				
7	NAO	X8	29524.06	0.0041	1.004153	0.985445, 1.023155	
8	Sun	X5	29524.29	0.0224	1.022758	1.001430, 1.042882	
9	Max	X3	29524.96	0.0012	1.001238	0.984284, 1.018687	
10	Win	X6	29525.08	0.0029	1.002919	0.9945124, 1.0113808	
11	STI		29870.42				
12	STIII		30063.12				
13	temporal		71631.95				
14							
15							
16							
17							

Appendix L individual climatic factors associated with spatiotemporal variations in respiratory mortality ratios across English LADs and winter periods from 2001/2 to 2011/12

	Univariate model (variable abbreviation)	Model ID	DIC value	Regression est.	RR	RR 95% BCI
1	Univariate model (variable abbreviation)	Model ID	DIC value	Regression est.	RR	RR 95% BCI
2	Max	x3	26942.33	0.0344	1.0351	1.005338, 1.066441
3	Min	x1	26942.67	-0.0174	0.982814	0.9665527, 0.9990808
4	Mea	x2	26943.32	0.028	1.028451	1.003694, 1.054052
5	STintII	Null	26947.75			
6	NAO	x8	26947.81	0.0271	1.027632	0.990909, 1.065141
7	Win	x6	26947.98	0.0073	1.007391	0.9949803, 1.0198924
8	Sun	x5	26948.73	0.005	1.005184	0.9739042, 1.0354490
9	Hum	x7	26949.1	-0.0032	0.996834	0.9844801, 1.0092624
10	Fro	x4	26951.74	-0.0158	0.984392	0.9703167, 0.9985438
11	STintI	0	26964	-0.0074	0.992884	0.9476286, 1.0395246
12	STintIII	0	27184.18			
13	Temporal	0	44486.13			
14						
15						