Use of primary care data to predict those most vulnerable to cold weather

a case-crossover analysis

INTRODUCTION

The phenomenon of excess winter deaths, whereby the death rate is higher during winter months than at other times of the year, is found worldwide, but appears particularly marked for the UK.1–3 It is generally thought that there are two biological mechanisms — increased blood pressure and increased clotting — through which cold might exert its effect.4 The dual environmental issues of cold housing and fuel poverty have been highlighted.5 Wilkinson and associates found associations between excess winter mortality and the age of the property, and poor thermal efficiency ratings.6 Though ecological studies in the UK found no relation of deprivation to increased mortality during cold weather, some evidence was found for age, sex, and medical (chronic) conditions.7–11 In 2015, the National Institute for Health and Care Excellence (NICE) guideline on excess winter deaths12 recommended that primary care team practitioners should help identify people at risk of ill health from living in a cold home, in collaboration with relevant local authority departments, using existing data and professional contacts. Assessing the heating needs of primary care patients once a year should be done during a home visit or through questioning during consultation.13,14 This study aimed to assess whether primary care staff are able to identify people at risk during cold snaps, using a simple algorithm based on information on clinical factors, sociodemographic characteristics, living situation, and location provided in electronic patient records (EPR). As GP home visits are undertaken opportunistically rather than systematically, and cannot reliably identify all those at risk from poorly heated homes, house energy efficiency at lower super output area (LSOA) level was used as a marker of risk. The focus was on patients aged ≥65 years, as these patients are most at risk from temperature-related mortality.6

METHOD

Study design and setting

Data were obtained from the Clinical Practice Research Datalink (CPRD), which contains current data on 4.4 million anonymised patient records (6.9% of the UK population) and are nationally representative for age, sex, and ethnicity.15 The patient’s postcode is recorded at the general practice, and used to assign an LSOA of residence. The CPRD can be linked with Hospital Episode Statistics (HES) and Office for National Statistics (ONS) mortality data in England,16 and patients in CPRD who could be linked by their NHS number to these data in England were investigated. This study tested the association between...
periods of cold absolute temperatures over a short period and risk of death by making use of a case-crossover design as cold temperature was expected to be intermittent, and to have an immediate and transient effect. In a case-crossover design each participant serves as their own control, which eliminates potential influence of between-participant variation. Within this study two control times are supplied by each of the cases themselves, using symmetric bidirectional sampling, that is, past and future controls, to adjust for possible calendar time trends. There was a particular aim to identify subgroups for whom the relationship between temperature and death was strongest, because these subgroups would contain those most vulnerable.

Measuring temperature and lag periods

Daily temperature data from the Met Office was used. It was ensured that data were collated between weather stations within each of the 10 English Strategic Health Authorities (SHAs), so that, for any given day, only one value of the relevant weather variable was assigned to every practice and patient within each authority. The station with the overall highest correlation with all other stations within the same SHA was chosen. These temperature data were used to calculate the average daily temperature over a lag period. There is no agreement about the lag period of mortality following cold periods, ranging from a few days to 23 days, though a recent systematic review concluded that lags of up to 9 days in exposure to cold temperature intervals were substantially associated with all-cause mortality. In this study, the focus was on the impact of the temperature for the date of death and 3 days previously (3-days lag period), assuming that a more immediate impact of temperature is bigger and therefore it may allow for quicker interventions by GPs. This 3-day lag period for both temperature measures for the 28th day before and the 28th day after the date of death (control dates). The 28th day was chosen to adjust for the longer-term, seasonal-related effects of temperature so that the effect of the 3-day mean represents a short-term effect only. In a sensitivity analysis the focus was on the impact of the temperature based on a 13-days lag period, as suggested by Wilkinson et al. The mean and median of the temperature measures are presented in Table 1, demonstrating that temperatures were lower on dates of death than on control dates.

Effect modifiers

This study investigated whether any of the following modified the effect of 3-day temperature: age (categorised as 65–74, 75–84, or ≥85 years), living in an institution (coded according to whether the patient’s family ID number appeared more than twice in the study CPRD patient file) — the prevalence of this rises with age, quintiles of the 2015 English Indices of Multiple Deprivation (IMD2015) score, calculated at LSOA residence level, house energy efficiency at LSOA level (using percentage of properties at LSOA level with ratings of E, F, or G, indicating efficiency lower than 55%), urbanicity (categorised as conurbation, urban, or rural), and north/south of England location (south defined as located in the South West, South Central, London, East of England, or South East of England SHAs).
addition, from the CPRD immunisation file patients who had undergone their winter flu vaccination were identified (Appendix 1). Data from linked Hospital Episode Statistics determined whether an emergency hospital admission occurred 2 years before death to indicate previous health status. This study also determined who was diagnosed with one or more of the following seven chronic conditions: chronic renal disease, cancer, asthma, stroke, coronary heart disease, diabetes, and chronic obstructive pulmonary disease (COPD). Published clinical code lists were used, as collected in the Manchester Clinical Codes repository.

### Table 2. Characteristics of 34 752 patients who died and used in case-crossover analysis

| Patient characteristic | Patients who died between 1 April 2012 and 31 March 2014, N(%) | Patients who died in winter months (December to March), N(%) | Patients who died in other seasons and/or due to other diseases, N(%) |
|------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| **Sex**                |                                                               |                                                               |                                                               |
| Male                   | 16 043 (46.2)                                                | 3337 (43.3)                                                   | 12 704 (47.0)                                                 |
| Female                 | 18 709 (53.8)                                                | 4373 (56.7)                                                   | 14 336 (53.0)                                                 |
| **Age at death, years**|                                                           |                                                               |                                                               |
| 65–74                  | 6442 (18.5)                                                  | 920 (11.9)                                                    | 5522 (20.4)                                                   |
| 75–84                  | 11 516 (33.1)                                                | 2400 (31.1)                                                   | 9116 (33.7)                                                   |
| ≥85                    | 16 794 (48.3)                                                | 4390 (57.0)                                                   | 12 404 (45.9)                                                 |
| **Living situation**   |                                                               |                                                               |                                                               |
| Community              | 31 671 (91.1)                                                | 6833 (88.6)                                                   | 24 838 (91.9)                                                 |
| Institution            | 3081 (8.9)                                                   | 877 (11.4)                                                    | 2204 (8.1)                                                   |
| **Location**           |                                                               |                                                               |                                                               |
| Urban conurbation       | 10 583 (30.5)                                                | 2339 (30.3)                                                   | 8244 (30.5)                                                   |
| Cities and towns        | 20 198 (58.1)                                                | 4496 (58.3)                                                   | 15 702 (58.1)                                                 |
| Rural                  | 3971 (11.4)                                                  | 875 (11.4)                                                    | 3096 (11.4)                                                   |
| **Deprivation level (IMD)** |                                                        |                                                               |                                                               |
| Q1 (least deprived)    | 7217 (20.8)                                                  | 1555 (20.2)                                                   | 5662 (20.9)                                                   |
| Q2                     | 8051 (23.2)                                                  | 1756 (22.8)                                                   | 6285 (23.3)                                                   |
| Q3                     | 7470 (21.5)                                                  | 1704 (22.1)                                                   | 5769 (21.3)                                                   |
| Q4                     | 6362 (18.3)                                                  | 1435 (18.6)                                                   | 4927 (18.2)                                                   |
| Q5 (most deprived)     | 5649 (16.3)                                                  | 1260 (16.3)                                                   | 4389 (16.2)                                                   |
| **House energy efficiency** |                                                        |                                                               |                                                               |
| Q1 (lowest inefficiency)| 5206 (15.0)                                                  | 1173 (15.2)                                                   | 4033 (14.9)                                                   |
| Q2                     | 8115 (23.4)                                                  | 1813 (23.5)                                                   | 6302 (23.3)                                                   |
| Q3                     | 8216 (23.6)                                                  | 1821 (23.6)                                                   | 6395 (23.7)                                                   |
| Q4                     | 7845 (22.6)                                                  | 1731 (22.5)                                                   | 6114 (22.6)                                                   |
| Q5 (highest inefficiency)| 5370 (15.5)                                                  | 1172 (15.2)                                                   | 4198 (15.5)                                                   |
| **Emergency hospital admission within 2 years of death** |                                                        |                                                               |                                                               |
| No                     | 6881 (17.5)                                                  | 1575 (20.4)                                                   | 4956 (16.7)                                                   |
| Yes                    | 28 671 (82.5)                                                | 6135 (79.6)                                                   | 22 536 (83.3)                                                 |
| **Chronic condition[s]** |                                                        |                                                               |                                                               |
| No                     | 21 259 (61.2)                                                | 5601 (72.7)                                                   | 15 658 (57.9)                                                 |
| Yes                    | 13 493 (38.8)                                                | 2107 (27.3)                                                   | 11 384 (42.1)                                                 |
| **Region**             |                                                               |                                                               |                                                               |
| South                  | 11 593 (33.4)                                                | 2593 (32.6)                                                   | 9000 (33.3)                                                   |
| North                  | 23 159 (66.6)                                                | 5117 (66.4)                                                   | 18 042 (66.7)                                                 |
| **Total**              | 34 752 (100.0)                                               | 7710 (100.0)                                                  | 27 042 (100.0)                                                |

*Patients who died in winter months (December to March) between 1 April 2012 and 31 March 2014 due to diseases of the circulatory system, respiratory system, nervous system, or mental and behavioural disorders. †Diagnosed with one or more of the following seven chronic conditions: chronic renal disease, cancer, asthma, stroke, coronary heart disease, diabetes, or COPD. COPD = chronic obstructive pulmonary disease.

### Statistical methods

Conditional logistic regression models may be applied to these case-crossover data to estimate the odds of exposure to the temperature on the date of death, relative to the odds of exposure to the temperature on the ‘control’ dates. This is equivalent to the odds of death given the temperature on the date of death, compared with that on the control dates. This study thus estimated not only the odds ratio (OR) of
death associated with 3-day temperature but also interactions between temperature and sociodemographic characteristics, clinical factors, and house energy efficiency characteristics; these interactions were expressed as relative odds ratios (RORs). Because certain causes of death are documented as being responsible for the vast majority of excess winter deaths, 21 the second analysis focused on patients who died in winter of diseases of the circulatory system, respiratory system, nervous system, and mental and behavioural disorders, using the International Classification of Diseases (ICD)-10 classification. Among the 34,777 patients in our study those conditions showed higher death rates in winter than in other seasons (Appendix 2).

RESULTS

There were 537,623 patients within 322 English general practices who were eligible in the CPRD source population for linkage to HES and ONS mortality data and aged ≥65 years during at least a part of the observation period 1 April 2012 to 31 March 2014. Linkage of ONS mortality data to the study population revealed 34,777 patients aged ≥65 years who died between 1 April 2012 and 31 March 2014: 6645 (18.5%) died aged 65–74 years, 11,525 (33.1%) aged 75–84 years, and 16,807 (48.3%) aged ≥85 years. This was similar to percentages for all deaths ≥65 years of age in England and Wales in 2012–2014, being 19.3%, 34.7%, and 46.0% for the three age groups. After excluding 25 individuals with missing data on deprivation, the total number of deaths used in the analyses was 34,752, of whom 7710 died during winter months of causes most related to winter mortality (Appendix 2). These patients are described in Table 2; χ² tests show that those who died in winter due to those causes were more likely to be female, aged >85 years, live in institutions, and less likely to have experienced an emergency hospital admission 2 years prior to death or to suffer chronic conditions.

Lower 3-day temperature was associated with higher risk of death (OR 1.011 per 1°C; 95% CI = 1.007 to 1.015; P < 0.001) (Table 3). No interactions were found between temperature measures and age, sex, living in an institution, living in urban/rural areas, living in northern or southern part of England, deprivation level, or house energy efficiency in either unadjusted analyses — containing only the absolute temperature and their interaction with a specific covariate — or adjusted analyses, which allowed for interactions between temperature and all covariates simultaneously (Table 4).

The authors further examined the effect for winter flu vaccination undertaken yearly between September and October, and found that 57% of the patients in this analysis had taken their flu vaccination. Flu vaccination made no impact on protection from cold temperature.

When using mean temperature over 13 days prior to the date of death (or equivalent control dates), a similar association was found for absolute temperature (Table 3: OR 1.013 per 1°C; 95% CI = 1.008 to 1.018; P < 0.001). Nearly all interactions between temperature measures and sociodemographic measures were non-significant in both unadjusted and adjusted analysis (Appendix 3). Both the unadjusted and the adjusted analysis showed evidence for a stronger effect of low 13-day temperature for patients living in the northern part of England (unadjusted ROR northern England: 1.009 per 1°C, 95% CI = 0.999 to 1.019; P = 0.084; adjusted ROR 1.010, 95% CI = 0.999 to 1.020, P = 0.078, see Appendix 3).

When focusing on patients who died in winter of diseases related to the circulatory system, respiratory system, nervous system, or mental and behavioural disorders, bivariable analyses showed lower 3-day temperature was associated with higher risk of death (OR 1.079 per 1°C; 95% CI = 1.067 to 1.091; P < 0.001) (Table 3). There was little evidence of interactions between temperature measures and sociodemographic variables (Table 5), although there was weak evidence for a reduced effect of lower temperature for female patients (adjusted ROR per 1°C for females: 0.980, 95% CI = 0.959 to 1.002, P = 0.082), suggesting more impact of 3-day temperature for male patients. Furthermore, there was some evidence of a stronger effect of lower absolute temperatures for patients living in northern

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**Table 3. Main effects from a univariable analysis of relationship between 1°C fall in average temperature in °C (3-days lag period) and death (odds ratios [P-value]), using 28th day before and after date of death as control days**

|          | 3-days lag |          | 13-days lag |
|----------|------------|----------|-------------|
| OR       | 95% CI     | P         | OR          | 95% CI      | P           |
| Overall  | 1.011      | 1.007 to 1.015 | <0.001   | 1.013      | 1.008 to 1.018 | <0.001   |
| Winter time | 1.079      | 1.067 to 1.091 | <0.001   | 1.138      | 1.121 to 1.155 | <0.001   |

*Based on temperatures of date of death and 3 days previous (case day), and 28th day before date of death and 3 days previous and 28th day after date of death and 3 days previous (control days). Those who died in the months December to March of diseases of the circulatory system, respiratory system, nervous system, or mental and behavioural disorders.
parts of England in the unadjusted analysis (ROR per 1°C for north England: 1.037, 95% CI = 1.013 to 1.063; \( P = 0.002 \)), and in the adjusted analysis (ROR 1.040 per 1°C, 95% CI = 1.013 to 1.066, \( P = 0.002 \)).

Similar associations were found when using mean temperature over 13 days prior to the date of death (or equivalent control dates) (Appendix 4).

DISCUSSION

Summary

This analysis of routine medical records held over >300 general practices in England has confirmed that lower temperatures over 3- and 13-day periods were associated with increased risk of death in people aged ≥65 years. These effects were particularly marked for deaths occurring in the winter months, for the circulatory and respiratory causes typically associated with excess winter mortality. However, though this study found some evidence that patients living in northern parts of England and males were more vulnerable to cold weather, it was not possible to demonstrate changes in effects when comparing characteristics such as age, living situation and location, presence of chronic diseases, and average local housing energy efficiency.

Strengths and limitations

This was a large study, including 537 623 patients from 322 practices across England, which are considered broadly representative of all English practices.15 More than 34,000 deaths were included, making this analysis particularly powerful for investigating interactions, compared with the authors’ previous work.4 The authors
employed a case-crossover analysis, which is particularly powerful for investigating the effect of short-term exposures such as low temperature on discrete outcomes, and is free of confounding effects of between-person variables.17,18 Any interactions detected however would not carry this advantage. The study used a wide range of covariates, including sociodemographic and geographic characteristics, clinical factors, and house energy efficiency characteristics, though marital status could not be included due to many missing data in CPRD. This study focused on recent winters of 2012/2013 and 2013/2014, but the winter 2013/2014 showed the lowest number of excess winter deaths since records began in 1950/1951,27 making it harder to detect associations.

It is possible that reasons for winter deaths may lie outside purely medical explanations. In particular, improvements to housing through insulation or servicing of boilers, more suitable clothing or heating in cold weather, and property characteristics such as construction and age28 may carry more influence. This study included a measure of energy efficiency in homes in the patient’s LSOA — this however was of limited value because it could not be attributed to an individual patient’s home condition. Furthermore, energy performance data only exist for properties when constructed, sold, or let, in particular those that have been on the property market since 2010; relevant data may therefore be particularly lacking for people aged >65, and explain the lack of association with temperature-related mortality in this study’s analysis.

### Table 5. Unadjusted and adjusted interaction effects with average temperature fall per 1°C (3-days lag period)

| Unadjusted | Adjusted |
|------------|----------|
|            | ORb      | RORc  | 95% CI  | P-value | ROR  | 95% CI  | P-value |
| Temperature* sex (ref=male) | 1.090 | 1.070 | 0.982 | 0.962 to 1.003 | 0.091 | 0.980 | 0.959 to 1.002 | 0.082 |
| Female      | 1.079 | 1.004 | 0.969 | 1.041 | 0.820 | 1.006 | 0.971 to 1.044 | 0.729 |
| Temperature*age died (ref=65–74), years | 1.075 | 1.079 | 1.004 | 0.972 to 1.038 | 0.795 | 1.012 | 0.978 to 1.048 | 0.488 |
| ≥85         | 1.079 | 1.004 | 0.969 | 1.041 | 0.820 | 1.006 | 0.971 to 1.044 | 0.729 |
| Temperature*community [ref] or institution | 1.080 | 1.067 | 0.987 | 0.955 to 1.019 | 0.431 | 0.989 | 0.956 to 1.022 | 0.516 |
| Institution | 1.076 | 1.048 | 0.975 | 0.951 to 0.998 | 0.036 | 0.984 | 0.959 to 1.010 | 0.227 |
| Cities and towns | 1.088 | 1.046 | 0.993 | 0.963 to 1.031 | 0.700 | 0.989 | 0.950 to 1.030 | 0.592 |
| Rural       | 1.079 | 1.074 | 0.994 | 0.962 to 1.028 | 0.740 | 0.997 | 0.964 to 1.030 | 0.820 |
| Temperature*IMD [ref=Q1] | 1.080 | 1.092 | 1.011 | 0.979 to 1.045 | 0.493 | 1.012 | 0.979 to 1.044 | 0.488 |
| Q2          | 1.074 | 1.077 | 0.987 | 0.933 to 1.021 | 0.448 | 0.989 | 0.953 to 1.024 | 0.497 |
| Q3          | 1.079 | 1.066 | 0.999 | 0.963 to 1.035 | 0.956 | 0.992 | 0.952 to 1.031 | 0.685 |
| Q4          | 1.079 | 1.079 | 1.010 | 0.975 to 1.046 | 0.598 | 1.013 | 0.977 to 1.052 | 0.486 |
| Q5 (most deprived) | 1.079 | 1.079 | 1.029 | 0.989 to 1.068 | 0.167 | 1.027 | 0.984 to 1.071 | 0.215 |
| Temperature*house energy efficiency [ref=Q1] | 1.069 | 1.076 | 1.006 | 0.972 to 1.043 | 0.718 | 1.012 | 0.978 to 1.049 | 0.494 |
| Q2          | 1.074 | 1.074 | 1.004 | 0.969 to 1.041 | 0.608 | 1.008 | 0.973 to 1.044 | 0.645 |
| Q3          | 1.079 | 1.079 | 1.010 | 0.975 to 1.046 | 0.598 | 1.013 | 0.977 to 1.052 | 0.486 |
| Q4          | 1.079 | 1.079 | 1.029 | 0.989 to 1.068 | 0.167 | 1.027 | 0.984 to 1.071 | 0.215 |
| Q5 (highest inefficiency) | 1.093 | 1.093 | 1.027 | 0.999 to 1.010 | 0.221 | 0.979 | 0.953 to 1.006 | 0.132 |
| Temperature*emergency admission [ref=no] | 1.075 | 1.075 | 0.980 | 0.959 to 1.010 | 0.894 | 0.999 | 0.975 to 1.024 | 0.917 |
| Yes         | 1.079 | 1.077 | 0.998 | 0.975 to 1.022 | 0.894 | 0.999 | 0.975 to 1.024 | 0.917 |
| Temperature*chronic conditions [ref=no] | 1.067 | 1.108 | 1.038 | 1.013 to 1.063 | 0.002 | 1.040 | 1.013 to 1.066 | 0.002 |

*aBased on temperatures of date of death and 3 days previous (case day), and 28th day before date of death and 3 days previous and 28th day after date of death and 3 days previous (control days). bOdds ratio per 1°C fall in temperature. cRelative odds ratio to indicate modifying effect of factor to temperature, for example, for sex: odds ratio for females divided by odds ratio for males: ROR female = 1.070/1.090 = 0.982. dDiagnosed with one or more of the following seven chronic conditions: chronic renal disease, cancer, asthma, stroke, coronary heart disease, diabetes, or COPD. * = interaction. COPD = chronic obstructive pulmonary disease. OR = odds ratio. ref = reference. ROR = relative odds ratio.
relative risk between subgroups of patients, but in the absence of differences in relative risk, it is still likely that those individuals who are constantly at high risk (such as people aged >85 years) will show the greatest increase in absolute risk during periods of cold weather.

Comparison with existing literature
Some ecological studies in Great Britain investigated the relationship between excess winter mortality and deprivation, and found a weak or no association,8–11 in line with this study’s results. Aylin et al concluded from an ecological study that lack of central heating was significantly associated with dying in winter,11 though Wilkinson et al found no association between difficulties in keeping the house warm and vulnerability to winter mortality in their cohort study,7 in line with this current study’s results using an average house energy efficiency measure. Furthermore, Wilkinson et al found little evidence for differences between regions, age groups, and markers for illness such as shortness of breath, depression, or taking more than five medications, but found some evidence of increased vulnerability for females and patients with pre-existing respiratory illness.2 Similar to Wilkinson et al this current study’s results showed no differences between age groups. However, this current study found some evidence of less impact of low temperature for females in winter for causes typically associated with excess winter mortality, but the authors did not find associations for patients with previous emergency admission[s] and patients with chronic conditions. Hajat et al observed little modification of the cold effect by sex in their ecological study, but did find that people in nursing and care homes were more vulnerable to both hot and cold weather.2 The current study did not find an association between living in institutions and risk of death related to cold weather.

Implications for research and practice
The authors have not found evidence to support the use of existing data in medical records to identify those at increased risk of death during cold periods, leaving GPs without the necessary tools to implement NICE recommendations. Alternatively, GPs or general practices might identify vulnerable patients by communication with other medical staff to increase knowledge about patients, so-called team-based continuity of care, or by improving access and use of comprehensive information about a patient’s previous healthcare encounters for providers caring for a patient, so-called informational continuity.

It has been demonstrated that, though individual days that are exceptionally cold carry the highest risk, such days are rare, and that the majority of deaths due to cold weather are attributable to moderate cold rather than severe cold.2 If public health interventions or advice to patients are geared only to self-care on the coldest days, little impact will be made on the burden of excess winter mortality. Population-level interventions that focus on the effects of moderate cold are most likely to decrease burden in the population and the need for emergency medical care. Evaluative studies of innovations in building designs are required, at the same time that such innovations are occurring, or of retrospective improvements of older housing stock.

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Appendix 2. Causes of death according to ICD-10, version 2016 (N = 34,777)

| Category                                                                 | Winter (December–March) | Spring and first part summer (April–July) | Second part summer and autumn (August–November) | Total N |
|--------------------------------------------------------------------------|--------------------------|------------------------------------------|---------------------------------------------|---------|
| Certain infectious and parasitic diseases                                | 37.29                    | 30.23                                    | 32.49                                       | 354     |
| Neoplasms                                                               | 33.78                    | 32.82                                    | 33.4                                        | 9,624   |
| Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism | 30.65                    | 37.1                                     | 32.26                                       | 62      |
| Endocrine, nutritional, and metabolic diseases                          | 35.8                     | 33.41                                    | 30.79                                       | 419     |
| Mental and behavioural disorders                                       | 39.17                    | 30.66                                    | 30.18                                       | 2,913   |
| Diseases of the nervous system                                         | 41.24                    | 27.71                                    | 31.05                                       | 1,901   |
| Diseases of the eye and adnexa                                         | 0                        | 50                                       | 50                                          | 2       |
| Diseases of the ear and mastoid process                                | 100                      | 0                                        | 0                                           | 1       |
| Diseases of the circulatory system                                      | 36.04                    | 32.36                                    | 31.6                                        | 10,033  |
| Diseases of the respiratory system                                      | 41.22                    | 30.12                                    | 28.66                                       | 5,527   |
| Diseases of the digestive system                                        | 35.34                    | 34.16                                    | 30.5                                        | 1,446   |
| Diseases of the skin and subcutaneous tissue                           | 32.06                    | 29.77                                    | 38.17                                       | 131     |
| Diseases of the musculoskeletal system and connective tissue            | 38.33                    | 29.62                                    | 32.06                                       | 287     |
| Diseases of the genitourinary system                                    | 34.98                    | 33.2                                     | 31.82                                       | 729     |
| Pregnancy, childbirth, and the puerperium                               | 0                        | 0                                        | 0                                           | 0       |
| Certain conditions originating in the perinatal period                  | 100                      | 0                                        | 0                                           | 1       |
| Congenital malformations, deformations, and chromosomal abnormalities    | 24                       | 44                                       | 32                                          | 25      |
| Symptoms, signs, and abnormal clinical and laboratory findings, not elsewhere classified | 33.63                    | 31.99                                    | 34.38                                       | 797     |
| Injury, poisoning, and certain other consequences of external causes    | 0                        | 100                                      | 0                                           | 1       |
| External causes of morbidity and mortality                              | 34.59                    | 33.11                                    | 32.3                                        | 743     |
| Factors influencing health status and contact with health services      | 0                        | 0                                        | 0                                           | 0       |
| Codes for special purposes                                              | 54.55                    | 9.09                                     | 36.38                                       | 11      |
| OVERALL                                                                 | 36.59                    | 31.53                                    | 31.88                                       | 34,777  |

ICD-10 = International Classification of Diseases, 10th Revision.
Appendix 3. Unadjusted and adjusted interaction effects with average temperature fall per 1°C (13-days lag period) on death among patients aged ≥65 years who died in the financial years 2012/2013 to 2013/2014 (N = 34,752 deaths)

| Interaction                                                                 | Unadjusted | Adjusted |
|-----------------------------------------------------------------------------|------------|----------|
|                                                                             | ORb       | RORc     | 95% CI  | P-value  | ROR  | 95% CI  | P-value  |
| Temperature*sex (ref = male)                                               | 1.015     | 0.997    | 0.987 to 1.006 | 0.524 | 0.997 | 0.988 to 1.007 | 0.535 |
| Female                                                                      | 1.012     | 0.999    | 0.986 to 1.013 | 0.944 | 1.000 | 0.986 to 1.014 | 0.970 |
| Temperature*age died (ref = 65–74), years                                  | 1.014     | 0.999    | 0.986 to 1.013 | 0.910 | 1.000 | 0.986 to 1.014 | 0.944 |
| 75–84                                                                       | 1.013     | 0.999    | 0.986 to 1.013 | 0.910 | 1.000 | 0.986 to 1.014 | 0.944 |
| ≥85                                                                         | 1.013     | 0.999    | 0.986 to 1.013 | 0.910 | 1.000 | 0.986 to 1.014 | 0.944 |
| Temperature*community (ref or institution)                                  | 1.014     | 0.991    | 0.974 to 1.007 | 0.276 | 0.991 | 0.974 to 1.008 | 0.289 |
| Institution                                                                | 1.005     | 1.000    | 0.989 to 1.010 | 0.947 | 1.003 | 0.991 to 1.014 | 0.623 |
| Cities and towns                                                           | 1.010     | 1.001    | 0.994 to 1.018 | 0.901 | 1.003 | 0.986 to 1.021 | 0.712 |
| Rural                                                                      | 1.014     | 1.005    | 0.991 to 1.019 | 0.488 | 1.005 | 0.990 to 1.019 | 0.528 |
| Temperature*IMD (ref = Q1)                                                 | 1.010     | 1.005    | 0.991 to 1.019 | 0.488 | 1.005 | 0.990 to 1.019 | 0.528 |
| Q2                                                                         | 1.015     | 1.004    | 0.989 to 1.019 | 0.612 | 1.003 | 0.989 to 1.018 | 0.654 |
| Q3                                                                         | 1.014     | 1.004    | 0.989 to 1.019 | 0.612 | 1.003 | 0.989 to 1.018 | 0.654 |
| Q4                                                                         | 1.013     | 1.003    | 0.986 to 1.018 | 0.777 | 1.003 | 0.987 to 1.018 | 0.724 |
| Q5 (most deprived)                                                         | 1.016     | 1.006    | 0.990 to 1.022 | 0.457 | 1.004 | 0.988 to 1.021 | 0.611 |
| Temperature*house energy efficiency (ref = Q1)                             | 1.012     | 1.004    | 0.987 to 1.020 | 0.666 | 1.005 | 0.988 to 1.021 | 0.578 |
| Q2                                                                         | 1.016     | 1.004    | 0.987 to 1.020 | 0.666 | 1.005 | 0.988 to 1.021 | 0.578 |
| Q3                                                                         | 1.012     | 1.000    | 0.984 to 1.016 | 0.992 | 1.001 | 0.985 to 1.017 | 0.906 |
| Q4                                                                         | 1.011     | 0.999    | 0.983 to 1.015 | 0.902 | 1.000 | 0.985 to 1.017 | 0.906 |
| Q5 (highest inefficiency)                                                   | 1.016     | 1.003    | 0.986 to 1.021 | 0.698 | 1.006 | 0.988 to 1.025 | 0.542 |
| Temperature*emergency admission (ref = no)                                 | 1.015     | 1.005    | 0.991 to 1.019 | 0.738 | 0.997 | 0.984 to 1.010 | 0.660 |
| Yes                                                                        | 1.013     | 0.998    | 0.985 to 1.010 | 0.997 | 0.998 | 0.984 to 1.010 | 0.660 |
| Temperature*chronic conditions4 (ref = no)                                 | 1.015     | 1.001    | 0.997 to 1.007 | 0.530 | 0.996 | 0.986 to 1.006 | 0.433 |
| Yes                                                                        | 1.011     | 0.997    | 0.987 to 1.007 | 0.530 | 0.996 | 0.986 to 1.006 | 0.433 |
| Temperature*north/south divide (ref = south)                               | 1.010     | 1.009    | 0.999 to 1.019 | 0.084 | 1.010 | 0.999 to 1.020 | 0.078 |
| North                                                                      | 1.020     | 1.009    | 0.999 to 1.019 | 0.084 | 1.010 | 0.999 to 1.020 | 0.078 |

*Based on temperatures of date of death and 13 days previous (case day), and 28th day before date of death and 13 days previous and 28th day after date of death and 13 days previous (control days). ^Odds ratio per 1°C fall in temperature. Relative odds ratio to indicate modifying effect of factor to temperature, for example, for sex: odds ratio for females divided by odds ratio for males: ROR female = 1.012/1.015 = 0.997. ^Diagnosed with one or more of the following seven chronic conditions: chronic renal disease, cancer, asthma, stroke, coronary heart disease, diabetes, or COPD. * = interaction. COPD = chronic obstructive pulmonary disease. OR = odds ratio. ref = reference. ROR = relative odds ratio.
Appendix 4. Unadjusted and adjusted interaction effects with average temperature fall per 1°C (13-days lag period) on death among patients aged ≥65 years who died in winters of the financial years 2012/2013 to 2013/2014 due to diseases of the circulatory system, respiratory system, nervous system, or mental and behavioural disorders (N = 7710 deaths)

|                                           | Unadjusted |          |          |          |          |          |          |          |
|-------------------------------------------|------------|----------|----------|----------|----------|----------|----------|----------|
|                                           | ORb       | RORc     | 95% CI   | P-value  | ROR      | 95% CI   | P-value  |
| Temperature*sex (ref = male)              | 1.160      |          |          |          |          |          |          |          |
| Female                                    | 1.123      | 0.968    | 0.940 to 0.997 | 0.031 | 0.971    | 0.942 to 1.001 | 0.058 |
| Temperature*age died (ref = 65–74)        | 1.150      |          |          |          |          |          |          |          |
| 75–84                                      | 1.146      | 0.997    | 0.948 to 1.048 | 0.893 | 0.999    | 0.951 to 1.050 | 0.964 |
| ≥85                                        | 1.132      | 0.984    | 0.940 to 1.031 | 0.506 | 0.995    | 0.949 to 1.044 | 0.958 |
| Temperature*community (ref or institution) | 1.141      |          |          |          |          |          |          |          |
| Institution                               | 1.121      | 0.982    | 0.959 to 1.028 | 0.445 | 0.992    | 0.947 to 1.040 | 0.728 |
| Temperature*urban (ref = urban conurbation) | 1.156      |          |          |          |          |          |          |          |
| Cities and towns                          | 1.124      | 0.973    | 0.942 to 1.005 | 0.094 | 0.986    | 0.953 to 1.022 | 0.455 |
| Rural                                     | 1.167      | 1.009    | 0.958 to 1.064 | 0.721 | 1.012    | 0.956 to 1.071 | 0.681 |
| Temperature*IMD (ref = Q1)                | 1.140      |          |          |          |          |          |          |          |
| Q2                                        | 1.160      | 1.016    | 0.972 to 1.064 | 0.476 | 1.015    | 0.970 to 1.063 | 0.519 |
| Q3                                        | 1.124      | 0.985    | 0.942 to 1.031 | 0.516 | 0.985    | 0.941 to 1.031 | 0.509 |
| Q4                                        | 1.121      | 0.983    | 0.982 to 1.030 | 0.475 | 0.982    | 0.936 to 1.031 | 0.478 |
| Q5 (most deprived)                       | 1.148      | 1.007    | 0.958 to 1.057 | 0.804 | 0.995    | 0.944 to 1.048 | 0.855 |
| Temperature*house energy efficiency (ref = Q1) | 1.138      |          |          |          |          |          |          |          |
| Q2                                        | 1.144      | 1.005    | 0.958 to 1.055 | 0.835 | 1.015    | 0.966 to 1.066 | 0.557 |
| Q3                                        | 1.117      | 0.982    | 0.935 to 1.031 | 0.462 | 0.987    | 0.940 to 1.037 | 0.615 |
| Q4                                        | 1.139      | 1.001    | 0.953 to 1.050 | 0.975 | 1.005    | 0.956 to 1.058 | 0.837 |
| Q5 (highest inefficiency)                | 1.162      | 1.021    | 0.968 to 1.076 | 0.445 | 1.018    | 0.962 to 1.080 | 0.530 |
| Temperature*emergency admission (ref = no) | 1.142      |          |          |          |          |          |          |          |
| Yes                                       | 1.137      | 0.996    | 0.961 to 1.033 | 0.833 | 0.992    | 0.956 to 1.029 | 0.667 |
| Temperature*chronic conditions (ref = no) | 1.136      |          |          |          |          |          |          |          |
| Yes                                       | 1.143      | 1.006    | 0.974 to 1.040 | 0.717 | 1.002    | 0.970 to 1.036 | 0.910 |
| Temperature*north/south divide (ref = south) | 1.122      |          |          |          |          |          |          |          |
| North                                     | 1.177      | 1.049    | 1.015 to 1.083 | 0.004 | 1.048    | 1.013 to 1.086 | 0.007 |

*Based on temperatures of date of death and 13 days previous (case day), and 28th day before date of death and 13 days previous and 28th day after date of death and 13 days previous (control days). bOdds ratio per 1°C fall in temperature. Relative odds ratio to indicate modifying effect of factor to temperature, for example, for sex: odds ratio for females divided by odds ratio for males: ROR female = 1.123/1.160 = 0.968.  bDiagnosed with one or more of the following seven chronic conditions: chronic renal disease, cancer, asthma, stroke, coronary heart disease, diabetes, or COPD. * = interaction. COPD = chronic obstructive pulmonary disease. OR = odds ratio. ref = reference. ROR = relative odds ratio.