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Excess winter deaths in 30 European countries 1980–2013: a critical review of methods

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ABSTRACT

Background Extreme temperatures (both excess heat and excess cold) are associated with elevated mortality risk.

Methods and Results This article reviews historical data on cold-related deaths in Europe (1980–2013). It outlines the classic 'excess winter deaths' methodology used to estimate cold-related mortality and explores the inaccuracies that are associated with this generic estimation method: it yields relatively accurate estimates of the actual public health impacts of cold temperatures in only 2 of 30 European countries. This is an issue of concern, given the prominent role of excess winter deaths monitoring in public health policymaking and research. An alternative estimation method is proposed, based on heating degree days, which could yield more accurate estimations of the public health implications of cold weather in Europe, and how these vary across different countries.

Conclusions Further research is needed to scrutinize core assumptions underlying excess winter death methodology, particularly as to whether it has equal validity for estimating public health impacts across the widely diverse climatic conditions that prevail across Europe. In the meantime, given data on heating degree days are freely available for European countries, it is recommended that this approach replaces the conventional methodology.

Keywords excess winter mortality, heating degree days, temperature-related deaths

Introduction

The association between outdoor temperature and health risk has been noted since at least the fifth century. Herodotus (ca. 440 BC), in commenting on the good health of the Egyptians and Libyans, attributed such favourable health status to the absence of changes in the climate, for 'change, and especially change in the weather, is the prime cause of disease'.[1] Thucydides (411–404 BC), describing the fate of Athenian prisoners in Sicily, observed that '. . .the cold autumnal nights, and the change in temperature brought disease among them'.[2] While Hippocrates (ca. 460–377 BC) recommended that 'Whoever wishes to investigate medicine properly, should proceed thus: in the first place to consider the seasons of the year, and what effects each of them produces for they are not all alike'.[3] He believed that hot wet summers were likely to result in fevers and dysentery, and mild winters to result in a healthy year. Strokes in the elderly, Hippocrates conjectured, were likely in a cold spring.[4]

Scientific investigations of the association between cold weather and health risks began when precise meteorological and medical data started to accumulate. Farr first demonstrated an association between respiratory illness and cold weather in 1885.[5] While, in 1924, Young examined mortality in English children, demonstrating perhaps the earliest evidence of time lags between cold weather and health effects: the impact of cold temperatures seemed to emerge a week later.[6] The association between weather and coronary events was first noted in 1938 by Bean and Mills,[7] and in 1961, the first study combining data on coronary and respiratory events was published by Holland *et al.*[8] West *et al.*[9] reported that

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deaths from ischaemic heart disease in England and Wales were more strongly related to temperature than socio-economic group. Rogot and Padgett[10] explored the separate contributions of temperature and snowfall to mortality from coronary events and strokes in the USA, finding temperature the more significant contributor. As Holland[5] remarks, many of these studies were noteworthy '. . .because the methods of analysis were able to disentangle the effect of individual meteorological factors from seasonal effects' (p. 1273). Disentangling effects remain a principal concern to the present day, with many issues still unresolved.

More is understood about the mechanisms by which cold temperatures become associated with adverse events.[11] A link between cold and blood pressure was first noted in 1921 by Hopman and Remen.[12] Blood vessels close to the skin constrict to reduce heat loss when people are exposed to cold, with a concomitant rise in blood pressure, which can be measured within 3 min of temperatures changing.[13] Elevated blood pressure is associated with increased risk for cardiovascular events such as myocardial infarctions because of an increased workload on the heart. In addition, blood viscosity and fibrinogen levels become elevated in cold temperatures, increasing the risk of thrombosis and strokes.[14]

Excess winter deaths and public health research/policy

Excess winter mortality has enjoyed prominent status in many aspects of public policy and research. For example, England's Cold Weather Plan,[15] the UK's Fuel Poverty Strategy[16] as well as the winter fuel payment schemes implemented by several European Member States[17] all have rationales underpinned by the health impacts of cold temperatures. For all three of these areas of policy and action, changes in the number of excess winter deaths (EWDs) over time are deemed to be a valuable metric for monitoring the implementation and cost-effectiveness of policy.[18] EWDs also feature in papers and policymaking related to climate change, where it is commonly agreed that temperature-related deaths are likely to increase over time, not only through an increase in heat-related deaths, but a stubborn persistence of cold-related deaths too.[19] In the past 18 months, >150 publications concerned with EWDs have appeared in peer-reviewed scientific journals concerned with public health, deriving from disciplines as varied as epidemiology, physiology, nursing and health economics, and culminating perhaps in the publication of NICE's 2015 Guidance on EWDs and morbidity and the health risks associated with cold homes.[20]

However, as noted by EuroMOMO (European Monitoring of Excess Mortality for Public Health Action), 'Mortality monitoring methodology is complex and there is a risk of European countries sharing incompatible information if different methodologies are used'. The lack of an agreed common methodology to assess mortality during a major health crisis affecting several European states limits use of this potentially very powerful information source. Thus, a timely mapping of the impact of health threats on mortality across different countries greatly benefit from a uniform approach.[21] While this comment refers more broadly to monitoring of deaths in general, it is no less apt for monitoring cold-related deaths in particular.

Calculating cold-related deaths by country

A standard methodology is used to allow comparison of cold-related death rates in different countries. As recently described by Fowler *et al.*,[22] the EWD index (EWDi) is calculated by comparing the number of deaths that occur in:

- the 4 months of winter (these are pre-designated as December–March in the Northern hemisphere);
- the four autumn months preceding that winter (August–November)
- the four spring months following on from that winter (April–July)

using the formula:

$$\text{EWDi}\ (\%) = \left\{\frac{\text{Winter deaths (Dec}-\text{Mar)} - 0.5\ \text{Non-winter deaths (Aug}-\text{Nov, Apr}-\text{Jul)}}{0.5\ \text{Non-winter deaths (Aug}-\text{Nov, Apr}-\text{Jul)}}\right\} \times 100.$$

EWDi's for European countries (1980–2013) are provided in Table 1, based on death rates published in the United Nations Monthly Bulletin of Statistics.[23] They confirm a wide variety in EWDi's from 8 to 29%.

Almost perversely, the highest EWDi's are consistently found in areas with milder winters, for example Malta (29.4), Portugal (28), Cyprus (23.6) and Spain (20.6). This has long been known as the 'excess winter mortality paradox'[24] in which people are more likely to die during cold spells if they live in more southerly areas of Europe, where climates are temperate and winters are cool, than if they live in more northerly countries like Finland (9.5) or Iceland (8.4) where winters are severe. Many factors appear to contribute to this effect. Spending proportionally more of income on heating costs is an obvious protective factor, which in the coldest winter regions is virtually non-negotiable for survival; in Denmark, for example, the lowest income quartile spends 8% on energy, compared with 4% in Spain and the UK.[25] Other

Table 1 Excess winter death indices in descending order: 30 European countries (1980–2013)

Country	*EWDi*	*Country*	*EWDi*
Malta	29.4	Slovenia	13.2
Portugal	28.0	Hungary	12.3
Cyprus	23.6	Denmark	12.2
Spain	20.6	Norway	12.1
Ireland	19.7	The Netherlands	11.8
UK	18.6	Germany	11.7
Greece	17.9	Poland	11.7
Bulgaria	17.8	Latvia	11.5
Romania	17.5	Lithuania	11.5
Italy	16.0	Luxembourg	11.2
Switzerland	14.2	Estonia	10.9
France	13.8	Czech Republic	10.8
Belgium	13.6	Finland	9.5
Sweden	13.3	Iceland	8.4
Austria	13.2	Slovakia	8.2

protective factors include housing quality (especially insulation and energy efficiency of building fabric), lifestyle adjustments to cold such as wearing adequate protective clothing and altering activity patterns when temperatures are low.[26]

Problems with the standard methodology for calculating EWDs

To date, there has been little public debate about the methodology for calculating cold-related deaths, especially the reliance on an arbitrary and unilateral delineation of the winter months. Europe spans a wide range of latitudes; winters are variable in both duration and prevailing temperatures; variation is further exacerbated by differences between European countries in average altitude and distance from the moderating thermal effects of seas and oceans. In short, Europe is a large and climactically very diverse land mass.

Hence, the classic method by which EWDi's are calculated may underestimate the number of cold-related deaths that occur in some countries, while overestimating them in others, by virtue of how many days of cold weather actually occur in the designated 4 months of winter. The following seasonal scenarios can be considered:

- if winter temperatures are low, and virtually all cold days occur between December and March (few or none in autumn or spring), then the classic EWDi method is likely to be fit for purpose;
- if the cold season lasts a great deal longer, then many cold-related deaths will be occurring in the non-winter periods leading up to, and out of, the winter months, i.e. in the preceding autumn and following spring. In this case, the EWDi may significantly underestimate the actual number of cold temperature-related deaths, because many of these will be counted in the death rates for the non-winter periods;
- if a country becomes very hot in summer, then there are likely to be a large number of excess heat-related deaths; in this way, hot summers cause the ratio of winter : non-winter deaths to fall for reasons that have little to do with cold temperatures *per se*. In other words, high rates of excess heat-related deaths may mask the impact of cold temperatures on mortality.

Heating degree days: an alternative methodology

Heating degree days (HDDs) quantify the amount of heating that buildings need in order that inhabitants can maintain health, well-being and thermal comfort.[27] An indoor comfort threshold is set, and from that HDDs can be calculated depending on the average outdoor temperature. One HDD means that the average temperature outside was below the thermal comfort level by 1°C for 1 day. Thus, heat was needed inside the building to maintain thermal comfort, but at 1 HDD, the demand for heating was small. In other words, the number of HDDs reflect the extent of temperature shortfall in a building, were it not to be heated. This shortfall varies depending on temperatures prevailing outside. Eurostat publishes degree day data for European Member States, setting the thermal comfort level for the Member States at 18°C.[28] Degree day data are available at smaller within-country regional level, although EWDs data are less commonly reported at similar levels of granularity; as a result, comparison across 30 European countries necessitates examining data at Member State level, acknowledging that homogenized HDD data assigned to a country may incur considerable inaccuracies, particularly in countries where topography is mixed.[29]

HDDs give an indication of the combined effect of duration of shortfall (measured rather than assumed) and intensity of indoor heat requirements. Intensity should not be underestimated as a major contributor to HDD burdens in Europe since (for example) average January temperatures in Athens tend to fall between 7 and 14°C, while in Helsinki, they move between -2 and -8°C.[30]

As already mentioned, periods of temperature shortfall may precede and/or extend beyond the traditional 4 months of winter stipulated by EWDi methodology. In New Zealand, for example, hospitalization rates for respiratory illness have a peak that extends beyond the conventional 4 months of

Table 2 Annual heating degree days by month for 30 European countries (1980–2013)

Country	*HDDs*	*% HDDs in winter* *December–March*	*% HDDs in colder months* *November–April*
Cyprus	761	87	99
Malta	534	86	99
Greece	1635	75	94
Portugal	1272	71	90
Bulgaria	2658	70	90
Italy	2028	69	90
Hungary	2885	68	89
Romania	3096	68	88
Spain	1826	67	88
Slovenia	3016	65	87
Slovakia	3417	64	85
France	2456	62	84
Austria	3538	61	82
Poland	3585	61	82
Czech	3538	61	82
Germany	3204	60	82
Lithuania	4070	60	81
Belgium	2831	59	81
The Netherlands	2860	59	80
Latvia	4246	59	80
Luxembourg	3163	59	80
Switzerland	3460	58	80
Estonia	4422	58	79
Denmark	3451	56	78
Finland	5795	54	75
Sweden	5403	53	73
UK	3085	51	72
Ireland	2877	50	70
Norway	5609	50	70
Iceland	4831	43	62

winter (in their case June–September), beginning 10 days before 'winter' and continuing 11 days after it,[31] suggesting that the 'winter period' could reasonably be extended by ~20% to suit their climatic conditions.

In Northern Ireland, even summer indoor temperatures seldom rise above the 15.5°C threshold; between 1980 and 2006, only 27 of 318 months (9%) had an average temperature exceeding 15.5°C.[32] During that period, almost half of Northern Ireland's HDDs fell outside of the winter period; to attain WHO standards of health and safety, indoor temperatures in Northern Ireland would need to have been raised by an average of 10°C each day in winter, 6°C in spring, 7°C in autumn and 2°C in summer.

HDD data (expressed as monthly totals) are available for 30 EU Member States in the Eurostat data archive,[28] and as far back as 1980. Table 2 presents details, outlining the proportion of HDDs that fall within the classic 4 months of winter, and comparing this with the proportion that fall within the colder half of the year using the following categorization:

- Countries where >85% of DDs fall in the conventional 4 months of winter could be reasonably classified as having fairly accurate EWDi's, always provided that EWDi gives a reasonable measure of cold-related deaths, despite the omission of the effect of cold intensity.
- Countries where between 60 and 85% of DDs fall in the conventional 4 months of winter are likely to have EWDi's that underestimate the actual number of cold-related deaths that occur each year.
- For countries where <60% of HDDs fall in the conventional 4 months of winter, EWDi's may be severely underestimated.

These results are based on relatively long time periods, which is important because of the wide variability in HDDs across successive winters. In Denmark, for example, the 4 months of winter 2006–07 required 2800 HDDs; 3 years later, HDD demand was almost a third higher (3600).[25]

From Table 2, the following conclusions can be drawn:

- Conventional calculation of EWDi using a 4-month winter adequately reflects the spread of DDs for only 2 of 30 European countries;
- For all other countries, the EWDi based on 4 months of winter may underestimate cold-related deaths;
- In almost half of these ($n = 14$), the underestimate may be very considerable;
- Using a 6-month cold season as a metric instead of the conventional 4-month metric removes all countries from a range in which an EWDi may have severely underestimated cold-related deaths, but leaves 20 countries with some degree of underestimation;
- For some of these (e.g. Norway and Iceland), the cold season would need to stretch to 8 months of the year to capture cold-related deaths more accurately.

While colder countries such as Norway and Sweden have long been thought exemplars of good practice in preventing winter deaths, the outcome of a HDDs analysis raises the possibility that their low EWDi's may reflect, at least in part, the fact that many cold days in these countries are also occurring in periods conventionally categorized as 'non-winter'. As such, cold-related deaths in Norway and Sweden may be somewhat more common than hitherto thought.

Among warmer countries that have high EWDi's, those cited for Greece, Cyprus, Portugal and Spain may return a close estimate of real impacts based on temperatures (Table 2 indicating that most of their cold days do occur in the winter months used to calculate EWDi).

Overall, therefore, a continuous metric based on actual HDDs seems a more valid measure by which excess cold-related deaths can be calculated and compared across the different Member States. Such a metric would dispose of the rather arbitrary division of time into months that are either winter or non-winter, relying instead on prevailing temperatures throughout the year, and the HDD demand arising from these temperatures. This in turn would require a change of terminology, from 'EWDs' to 'excess cold weather deaths', i.e. excess deaths that are associated with cold outdoor temperatures, regardless of whether these occur in the designated months of winter or not.

Distinguishing cold temperatures from other causes of death that are more common in colder months

Cold temperatures are not the only contributors to excess deaths in the cooler months of the year. Deaths from influenza are more common in these months, as are deaths associated with higher levels of atmospheric pollution. Both of these are known contributors to excess deaths in colder seasons and hence contribute to EWDi's, but influenza epidemics and smog-forming atmospheric conditions, though cold-related, have their own effects on EWD rates, which are independent of the more direct effects of outside temperatures on human physiology.

A HDD methodology can be used to provide a much more specific and robust index measure of those EWDs that are most likely to be attributable to cold temperatures *per se*. Table 3 tabulates EWDi's as calculated using the 4-month methodology (which includes EWDs that may have been caused by factors other than cold temperatures) and an index derived from HDDs (which excludes deaths from these extraneous causes). The index derived from HDDs (IHDD) is calculated via this formula:

$$\text{IHDD} = \frac{\%\,\text{of degree days falling in winter months}}{0.5 \times (\%\,\text{of degree days falling outside of winter})}.$$

The percentage term is the average for all those years where data are available, rather than the percentage of all HDDs observed, thus avoiding giving greater weight to cold years in assessing the annual seasonal pattern.

Using Ireland's data in Table 2 as an example, there are an average of 2877 degree days in Ireland; 50% of these fall in the winter months ($n = 1439$) and hence the same for degree days falling in non-winter months ($n = 1439$). There are 4 winter months, but 8 non-winter months, hence the 0.5 multiplier in the equation: $1439/(1439/2) = 2$.

At its simplest, if winter deaths were mostly attributable to cold temperatures, then EWDi and IHDD would show a correlation approximating 1.00. The poorer the correlation, the

Table 3 EWDi : IHDD ratios for European countries

Country	*EWDi*	*IHDD*	*EWDi : IHDD ratio*	*Country*	*EWDi*	*IHDD*	*EWDi : IHDD ratio*
Ireland	19.7	2.0	9.9	Latvia	11.5	2.9	4.0
UK	18.6	2.1	8.9	Estonia	10.9	2.8	3.9
Norway	12.1	2.0	6.1	Germany	11.7	3.0	3.9
Sweden	13.3	2.3	5.9	Luxembourg	11.2	2.9	3.9
Portugal	28	4.9	5.7	Lithuania	11.5	3.0	3.8
Iceland	8.4	1.5	5.6	Bulgaria	17.8	4.7	3.8
Switzerland	14.2	2.8	5.1	Poland	11.7	3.1	3.7
Spain	20.6	4.1	5.1	Italy	16	4.5	3.6
Denmark	12.2	2.5	4.8	Slovenia	13.2	3.7	3.6
Belgium	13.6	2.9	4.7	Czech Republic	10.8	3.1	3.5
France	13.8	3.3	4.2	Greece	17.9	6.0	3.0
Austria	13.2	3.1	4.2	Hungary	12.3	4.3	2.9
Romania	17.5	4.3	4.1	Malta	29.4	12.3	2.4
The Netherlands	11.8	2.9	4.1	Slovakia	8.2	3.6	2.3
Finland	9.5	2.3	4.0	Cyprus	23.6	13.4	1.8

more other winter causes of death, such as influenza, are at contributing to the EWDi.

The correlation between the conventional EWDi and the IHDD ($n = 30$ countries) is 0.70, which, though statistically a strong correlation, reflects the extent to which the EWDi is measuring factors over and above cold temperatures in winter. This is illustrated by interpreting the EWDi : IHDD ratios in Table 3. The smaller the ratio for any one country, the more likely it is that EWDs in that country are likely to be directly attributable to cold temperatures; where ratios are small, the classic EWDi metric probably returns values that closely resemble cold-related deaths in the winter months. As indicated in Table 3, these are Cyprus, Slovakia, Malta, Hungary and Greece, with ratios of 1.8–3.0.

But for countries like Ireland and the UK, the EWDi is least likely to be an accurate reflection of cold-related deaths *per se* in winter, since ratios here are estimated to be 9.9 and 8.9, respectively. For these countries, factors additional to cold temperatures contribute more strongly to higher rates of death in winter than at other times of year, especially when compared with countries such as Cyprus and Greece.

Further refinements enabled via degree day methodology

Within most Member States, HDDs are available at smaller scale regional levels. This is particularly useful for understanding patterns of cold-related deaths in countries where there are wide variations in climate (because of differences in altitude between lowland and mountainous areas, for example). Regional variations are greater in some countries than in others. For example, Denmark and Northern Ireland are located at approximately the same latitude (55.7°N and 54.6°N, respectively), are close neighbours and are both maritime landmasses. However, Denmark has relatively little regional variation in winter temperatures between its different regions (having not exceeded a regional variation of 1.3°C in the past 5 years),[25] whereas in Northern Ireland, winter temperatures show a regional variation of twice that order (2.6°C)[32] despite the region being a third of the size of Denmark. In recognition of such regional variations, some Member States provide heating subsidies to households that vary by climate zone. In Italy, for example, 2011 subsidies for households in the warmest regions were set at €70, while for the coldest regions, they were three times higher at €183; this closely matched the differences in monthly expenditure on gas in the warm and cold regions (€27 and €75, respectively).[33]

There are opportunities for comparing cold-related deaths across these smaller regions, possibly through the development of a classification system based on the number and monthly distribution of HDDs. In Scotland, for example, it is more sensible to compare EWDs in the southerly lowland farming areas of Dumfries and Galloway and the Scottish Borders, and separately the northerly agricultural areas of Aberdeenshire with Perth and Kinross[34,35] (see Table 4).

On the same basis, mountainous regions of Switzerland, France, Austria, Slovenia, Spain, etc. could be a distinct comparison group, as could coastal and maritime regions of the UK, Ireland, Finland, Iceland and Denmark. Achieving an evidence-based consensus on areas that could be meaningfully compared would not be difficult to develop.

Table 4 Percentage of excess winter deaths: Scottish regions[34,35]

Year	*Dumfries and Galloway*	*Scottish Borders*	*Perth and Kinross*	*Aberdeenshire*	*All Scotland*
Latitude	55.06°N	55.36°N	56.42	57.15°N	55°N −61°N
HDDs	3, 195	3, 356	3, 432	3, 490	
2003–04	5	9	18	20	16
2004–05	12	15	10	17	15
2005–06	10	14	3	4	10
2006–07	10	15	23	33	16
2007–08	16	19	14	16	12
2008–09	25	24	14	13	21
2009–10	18	12	21	17	16
2010–11	8	19	32	13	14
2011–12	3	9	15	10	8
2012–13	7	16	7	11	11

Discussion

What was already known about this topic?

Cold-related deaths have been noted for centuries. Data derived from the classic EWDi are often used as evidence underpinning both public health policymaking and outcomes monitoring. It contributes particularly to areas of public health that are concerned with people living in cold conditions.

Main finding of this study

We demonstrate that conventional calculation of cold-related deaths (i.e. EWDi using a 4-month winter) adequately reflects the spread of HDDs for only 2 of 30 European countries, which questions the validity of using EWDi to assess cold-related deaths.

What this study adds?

European EWDi estimates are almost all likely to underestimate the severity of cold temperature-related mortality. In almost half of these countries, the underestimate may be very considerable; moving from the least severe underestimate to the most, these countries are Belgium, the Netherlands, Latvia, Luxembourg, Switzerland, Estonia, Denmark, Finland, Sweden, UK, Ireland, Norway and Iceland.

At a bare minimum, using a 6-month cold season as a metric instead removes all countries from a range in which an EWDi may severely underestimate cold-related deaths, but leaves 20 countries with some degree of underestimation. Iceland remains problematic, since >40% of its HDDs remain outside of the six coldest months.

A continuous metric, based on actual HDDs, could perhaps be a more valid way of monitoring cold-related deaths; it can be more meaningfully compared across different parts of Europe. Since HDD data are readily available for all Member States, with an extensive archive from previous years, there seems little impediment to testing this alternative methodology more rigorously in the future.

HDDs data are also available for smaller regions within countries, which gives ample scope for beginning to establish ‘degree day zones’ that can be much more meaningfully compared—for example enabling comparison of all montane regions (e.g. Switzerland and Slovakia), or maritime regions, in a manner that reduces the confounding effects of wider scale differences between the land masses of different Member States. On the basis of the IHDD estimates cited here, three broad areas are already identifiable at country level:

- In Scandinavia and the British Isles, IHDD estimates range from 1.5 (Iceland) to 2.5 (Denmark); this zone also includes Ireland and Finland;
- South of that, a band extends from the South Baltic to the Pyrenees and Alps, with IHDD estimates ranging from 2.8 (Switzerland) to 3.7 (Slovenia); this zone also includes Estonia, Latvia, Lithuania, Poland, Czech Republic, Slovakia, Germany, the Netherlands, Belgium, Luxembourg, France and Austria.
- The final area is the Mediterranean and the Balkans, where IHDD estimates ranging from 4.1 (Spain) to 13.4 (Cyprus); it also includes Romania, Hungary, Italy, Bulgaria, Portugal, Greece and Malta.

These are of course national figures. In countries such as Spain, Italy and Greece, the climatic variation from Galicia to Grenada, Trentino to Sicily and Macedonia to Crete is quite radical, and the national figure is an average of very different conditions.

There is strong justification for replacing the tradition of comparing the 4 months of ‘winter’ with the rest of the year in terms of death rates related to cold. In place of this methodology, one in which regional data within degree day zones are compared will help us compare parts of Europe on a more meaningful basis, giving us a better understanding of trends and help us identify regions where interventions are most needed.

The same approach can of course extend to cooling degree days, as a means of standardizing the approach to calculating excess deaths related to the warmer months of the year. Taken together, this will help resolve the difficulties associated with high indices of heat-related deaths in some parts of Europe masking the effects of cold on mortality (and vice versa).

Limitations of this study

It should be noted that all of these conclusions are subject to the assumption that the relationship of cold to morbidity and mortality is more or less constant across Europe. In the absence of detailed analysis of the trends in individual countries, this assumption remains subject to verification, even though it underpins all of EWD methodology. We have outlined some ways in which an alternative methodology would resolve some but not all of the problems experienced when applying the classic EWD methodology. However, it is not a complete resolution; for example the critique that EWDi is affected by extreme summer temperatures applies in equal measure to our proposed alternative method.

For the purpose of this article, the relationship of ‘experienced cold’ to mortality is assumed to be linear, although the principles explored could be recast for non-linear relationships where appropriate. The article also assumes that there is no relationship between the number of additional deaths and the length of period of a cold spell (i.e. that the number of excess deaths caused by one day of cold at a certain temperature is the same as what is caused by the eighth consecutive day of cold at the same temperature). But both of these are assumptions shared with the classic EWDi methodology.

In this context, it is important to note that EuroMOMO has recently developed a much more complex methodology addressing these and many other drawbacks of older methodologies. The consortium focuses on all excess deaths (not just winter ones) where 'excess' is defined in terms of the baseline weekly death rates in spring and autumn.[36] It is a radically different approach to monitoring excess deaths, with seasonality modelled by a sine curve embedded within an algorithm of great complexity. The data could be readily merged with HDD data. However, since the EuroMOMO approach is only a few years old, it is difficult to ascertain its potential for transforming our understanding.

As matters stand, though data on EWDs are published annually and are gaining increasing attention in both the scientific and public domains, they remain data collected using methods that have seldom been subject to public debate.

Key points

- Cold-related deaths are a long-standing phenomenon across European countries.
- The conventional methodology for estimating and monitoring cold-related deaths may have resulted in poor estimates of their prevalence in most countries.
- An alternative methodology, based on HDDs, is likely to yield more accurate estimates.
- Consequently, a HDD methodology is recommended for Europe-wide measurement and monitoring of EWDs.
- This can be further refined by considering whether regional comparisons, when made, are being made across regions with similar or very different climatic conditions.

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References

1 de Sélincourt A. *The Histories of Herodotus*. London: Penguin, 1954.

2 Sage MM. *Warfare in Ancient Greece*. New York: Routledge, 1996.

3 Hippocrates. Airs, waters and places. An essay on the influence of climate, water supply and situation on health. In: Lloyd GER (ed). *Hippocratic Writings*. London, UK: Penguin, 1978.

4 Jones WHS. *(Trans.) Hippocrates Collected Works*. Cambridge, MA: Harvard University Press, 1868.

5 Holland W. Cold temperature and consultations for respiratory and cardiovascular disease. *Int J Epidemiol* 2002;**31**:1272–4.

6 Young M. The influence of weather conditions on the mortality from bronchitis and pneumonia in children. *J Hyg* 1924;**23(2)**: 151–75.

7 Bean WB, Mills CA. Coronary occlusion, heart failure, and environmental temperatures. *Am Heart J* 1938;**16(6)**:701–13.

8 Holland WW, Spicer CC, Wilson JMG. Influence of weather on respiratory and heart disease. *Lancet* 1961;**2**:334.

9 West RR, Lloyd S, Roberts CJ. Mortality from ischaemic heart disease—association with weather. *BR J Prev Soc Med* 1973;**27(1)**:36–40.

10 Rogot E, Padgett SJ. Associations of coronary and stroke mortality with temperature and snowfall in selected areas of the United States 1962–1966. *Am J Epidemiol* 1976;**103(6)**:565–75.

11 Cheng X, Su H. Effects of climatic temperature stress on cardiovascular diseases. *Eur J Intern Med* 2010;**21**:164–7.

12 Hopman R, Remen L. Jaherszeitliche krankheirsbereitschaft, Blutdruckhohe und Jahreszeiten. *Z Klin Med* 1921;**122**:703–10.

13 Komulainen S, Oja T, Rintämaki H *et al.* Blood pressure and thermal responses to whole body cold exposure in mildly hypertensive subjects. *J Therm Biol* 2004;**29**:851–6.

14 Keatinge WR, Coleshaw SR, Cotter F *et al.* Increases in platelet and red cell counts, blood viscosity, and arterial pressure during mild surface cooling: factors in mortality from coronary and cerebral thrombosis in winter. *BMJ* 1984;**24**:1405–8.

15 Department of Health. Cold Weather Plan for England: Making the Case: Why Cold Weather Planning is Essential to Health and Well-being. 2011. http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/documents/digitalasset/dh_130925.pdf (10 June 2015, date last accessed).

16 Department of Energy and Climate Change. Cutting the Cost of Keeping Warm. A Fuel Poverty Strategy for England. 2015. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/408644/cutting_the_cost_of_keeping_warm.pdf (10 June 2015, date last accessed).

17 Iparraguirre J. Have winter fuel payments reduced excess winter mortality in England and Wales? *J Public Health* 2014;**37**:26–33.

18 Ghosh A, Carmichael C, Elliot AJ *et al.* The Cold Weather Plan evaluation: an example of pragmatic evidence-based policy making? *Public Health* 2014;**128**:619–27.

19 Hajat S, Vardoulakis S, Heaviside C *et al.* Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. *J Epidemiol Community Health* 2014;**68**:641–8.

20 National Institute of Health and Care Excellence. Excess Winter Deaths and Morbidity and the Health Risks Associated With Cold Homes. 2015. http://www.nice.org.uk/guidance/ng6 (10 June 2015, date last accessed).

21 European Monitoring of Excess Mortality for Public Health Action. Rationale. European Monitoring of Excess Mortality for Public Health Action. http://www.euromomo.eu/methods/rationale.html (10 June 2015, date last accessed).

22 Fowler T, Southgate RJ, Waite T *et al.* Excess winter deaths in Europe: a multi-country descriptive analysis. *Eur J Public Health* 2015;**25**: 339–45.

23 UNdata. Monthly Bulletin of Statistics Online. 2015. http://unstats.un.org/unsd/mbs/app/DataSearchSeries.aspx (20 October 2015, date last accessed).

24 Healy JD. Excess winter mortality in Europe: a cross country analysis identifying key risk factors. *J Epidemiol Community Health* 2003;**57**: 784–9.

25 Nierop S. Energy Poverty in Denmark? 2014. Projecketer.aau.dk/Master_Thesis_Energy_Poverty_Sam_Nierop.pdf (28 November 2014, date last accessed).

26 Wilkinson P, Landon M, Armstrong B *et al. Cold Comfort: The Social and Environmental Determinants of Excess Winter Mortality.* Bristol, UK: Policy Press, 2001.

27 Laverge J, Janssens A. Heat recovery ventilation operation traded off against natural and simple exhaust ventilation in Europe by primary energy factor, carbon dioxide emission, household consumer price and energy. *Energ Build* 2012;**50**: 315–23.

28 European Commission. Eurostat Data Archive. http://epp.eurostat.ec.europa.eu/portal/page/portal/product_details/dataset?p_product_code=NRG_ESDGR_M (June 2015, date last accessed).

29 Trewin B. A daily homogenized temperature data set for Australia. *Int J Climatol* 2013;**33(6)**:1510–29.

30 Average January Temperatures for Cities in Europe. http://www.currentresults.com/Weather/Europe/Cities/temperature-january.php (10 June, date last accessed).

31 Telfar Barnard L. Home Truths and Cool Admissions: New Zealand Housing Attributes and Excess Winter Hospitalisation. 2011. http://otago.ourarchive.ac.nz/handle/10523/591 (28 November 2014, date last accessed).

32 Morris C. Fuel Poverty, Climate and Mortality in Northern Ireland 1980–2006. Occasional Paper 25. Belfast: Northern Ireland Statistics and Research Agency, 2007.

33 Miniaci R, Scarpa C, Valbonesi P. Energy affordability and the benefits system in Italy. *Energ Pol* 2014;**75**:289–300.

34 UK Meteorological Office data archive. 2013. http://www.metoffice.gov.uk/climatechange/science/monitoring/ukcp09/available/annual.html (November 2015, date last accessed).

35 General Register Office Scotland. http://www.gro-scotland.gov.uk/statistics/theme/vital-events/deaths/winter-mortality/ (June 2015, date last accessed).

36 Gergonne B, Mazick A, O'Donnell J *et al.* A European Algorithm for a Common Monitoring of Mortality Across Europe. Copenhagen: European Commission, 2011.