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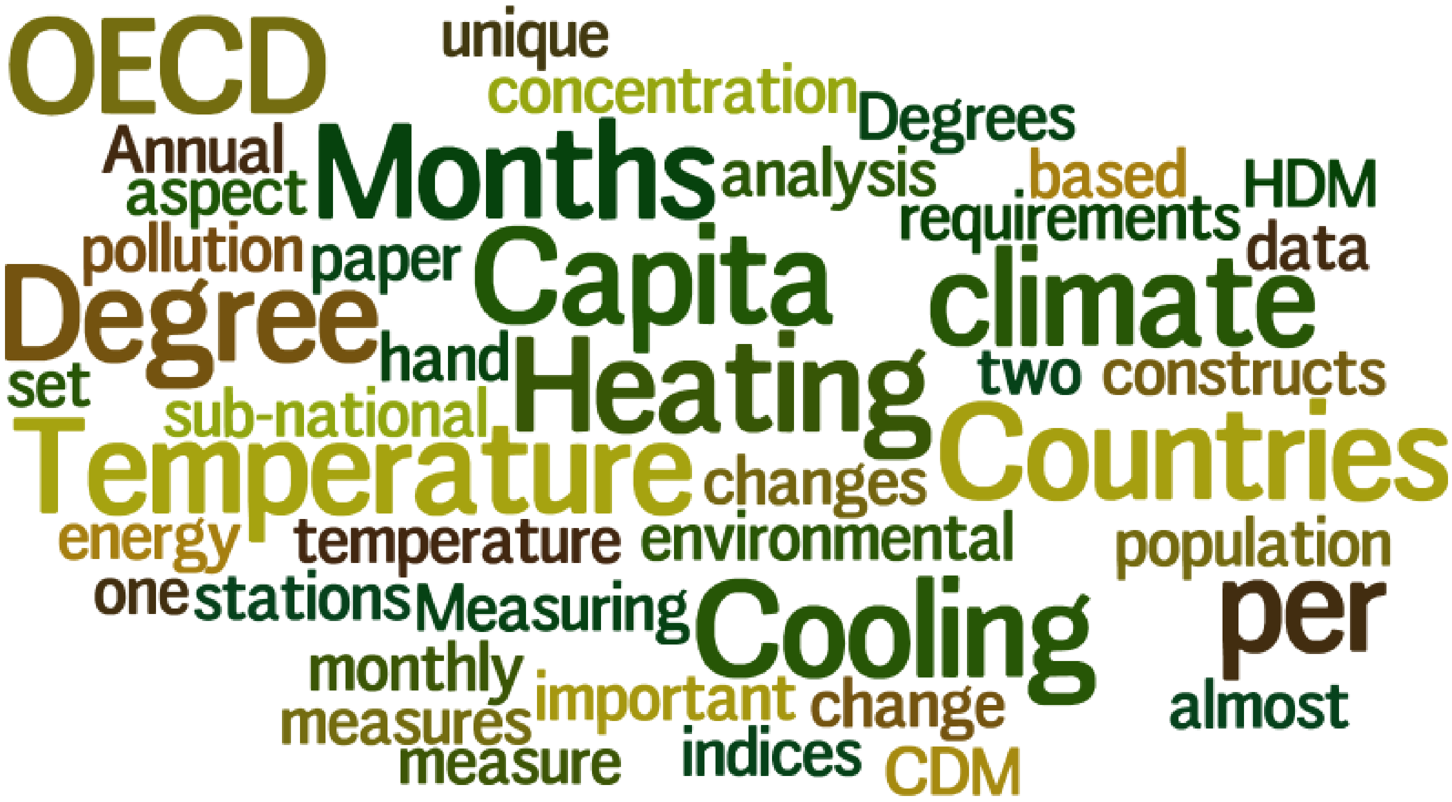

Detlef Jahn

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"Temperature per Capita": Measuring Annual Heating and Cooling Degrees in 21 OECD Countries from 1960 to 2005[1]

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Abstract

"Temperature per Capita" is an important aspect in the analysis of climate change, environmental pollution and energy requirements. This paper constructs two indices which measure the Heating Degree Months (HDM) on the one hand and Cooling Degree Months (CDM) on the other for 21 OECD Countries from 1960 to 2005. This unique data set is based on monthly temperature measures from almost 100 climate stations and the changes in sub-national population concentration. The data can be downloaded from: http://comparativepolitics.uni-greifswald.de/.

Keywords: climate change, environmental pollution, temperature measures

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[1] The results obtained for this paper stem from the research project "Environmental Pollution as a Global Phenomenon" sponsored by the German Research Foundation (DFG). I wish to thank Christoph Oberst, Lena Masch, Katja Stack, Kati Kuitto, and Thomas Behm for help with the data collection, as well as Douglas Voigt for suggestions and editing. The paper was presented at the 8th International Summer Academy of the Institute of Climate Protection, Energy, and Mobility (IKEM) in Guildford, UK, June 23-29, 2011. I also thank Roger Karapin at Hunter College and the CUNY Graduate Center who gave many helpful suggestions. A shorter version of this paper just concentrating on HDMs and its impact on atmospheric emissions has been published in *Weather, Climate, and Society*, a journal of the American Metrological Society (Jahn 2013).

Content

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1 Introduction

The average “Temperature per Capita” is important to know when estimating the impact of climate on climate change, environmental pollution and energy use. The largest tradition of data collection in this respect has come from the U.S. Department of Commerce. However, its major purpose in developing such an index has been to estimate fuel requirements. In environmental analysis, the impact of climate on pollution has been neglected, despite demonstrable evidence that climate has a significant impact on pollution levels (Jahn 2013). The average “Temperature per Capita” is an index which estimates the annual temperature of a country in relation to the concentration of the population. For instance, in a country such as Australia, where most of the population is concentrated along the coasts, the temperature in the coastal regions is clearly more relevant than central Australia for the purpose of estimating the effects of climate on atmospheric emissions and pollution, as well as energy requirements. The most comprehensive comparative study on this issue has been conducted by the European Commission (2007) for the 25 EU member states from 1980 to 2004. However, the European Commission only utilizes an index of Heating Degree Days (HDD). Although the U.S. Department of Commerce has developed an index of Heating Degree Days and Cooling Degree Days (CDD) for the United States, there is no index that enables comparison of the most industrialized countries over a long time period. To develop such an index is the aim of this paper.

For highly industrialized countries, such an index is particularly important because these countries often set targets for the reduction of atmospheric emissions. An index of temperature per capita allows for controlling if changes in atmospheric emissions are achieved by political or technological initiatives or simply are a function of changes in annual temperatures. Climate and weather conditions might not only contribute to the explanation of atmospheric emissions, other pollutants may also depend on weather conditions. For instance, besides cold winters, hot summers may also be important. Hot summers increase energy production by the use of air conditioners, as well as increasing the concentration of pollution in rivers and lakes because of low water levels.

This paper constructs an index of Heating Degree Months (HDM) and Cooling Degree Months (CDM) for the 21 established OECD countries from 1960 to 2005. In order to construct such indices, it relies on sub-national temperature data from around 100 climate stations which supply monthly data continuously. Sub-national population data are also important because they reflect the changes in population concentrations within a country over time.

The first part of the paper outlines the index construction of Heating Degree Months and Cooling Degree Months. The second part shows how to calculate the indices and shows results for 21 OECD countries over a time period from 1960 to 2005.The final part concludes and speculates about future directions in the analysis of the impact of climate on environmental degradation.

2 Towards an Index of the Heating and Cooling Degrees for 21 OECD countries from 1960-2005

There have been some attempts of measuring the "Annual National Temperature Per Capita" (ANTPC). In particular, the U.S. Department of Commerce and the European Commission (2007) developed highly sophisticated indices of heating and cooling degree days. The United States has the most developed index available. The U.S. Department of Commerce has published the heating and cooling degree days since 1931/32 on an annual basis.[2] The major reason for this tradition lies in the prediction of heating fuel demand. Heating degree days (HDD) are quantitative indices designed to reflect the demand for the energy needed to heat a home or business. These indices are derived from daily temperature observations, and the heating requirements for a given building at a specific location. A similar index, cooling degree days (CDD), reflects the amount of energy used to cool a home or business.

HDD are defined relative to a base temperature - the outside temperature above which a building needs no heating. The most appropriate base temperature for any particular building depends on the temperature that the building is heated to, and the nature of the building, including the heat-generating occupants and equipment within it. However, for historical reasons HDD are often made available with base temperatures of 65°F (U.S. Department of Commerce) or 15°C (European Commission) base temperatures that are approximately appropriate for a good proportion of buildings. Since the cut-off temperature 65°F or 15°C are rather arbitrary, I refer to the research of thermal comfort models (for a recent overview, see Orosa 2009). I use the established ASHRAE Standard 55 recommendation.[3] This recommendation builds on research on thermoregulation and heat balance theory (Fanger 1973). The resulting equation describes thermal comfort as the discrepancy between actual heat flow from the body in a given thermal environment and the heat flow required for optimal comfort for a given activity. In the final equation, optimal temperature can be obtained by considering activity and clothing. Activity is the estimated metabolic rate (met), which is the amount of energy emitted by an individual as a function of the level of muscle activity. Clothing is estimated as cloth insulation (clo). The scale is such that a naked person has a value of 0,0 clo. Typical street attire has a clo of 1. Clo values that correspond to different garments are outlined in the IS0 7730 (ISO 2005). In fact, the thermal condition of an interior environment is not the temperature but rather the losses of the human body to the environment. This is dependent on air temperature, average temperature radiant, air velocity, and the absolute humidity of the air. The operative temperature in winter is 22°C and in summer 24.5°C with a range between 20-23°C in winter and 23-26°C in summer. However, the minimal accepted value is 15°C. Therefore, I use as cut-off point for Heating Degrees Month the 15°C cut-off point of the European Commission. For summer temperature, I follow the recommendation of the U.S. Department of Commerce and use an 18°C threshold for Cooling Degree Months. I

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[2] See http://lwf.ncdc.noaa.gov/oa/documentlibrary/hcs/hcs.html; accessed April 2011.

[3] ASHRAE stands for **A**merican **S**ociety of **H**eating, **R**efrigerating and **A**ir-Conditioning **E**ngineers. The ASHRAE Standard 55-2004 is the Thermal Environmental Conditions for Human Occupancy (ASHRAE 2004).

present data for the human operative point of 26°C in the data base as well. A lower value of 18°C is more appropriate for this paper because warmer temperatures do not affect only human well-being but also changes in the eco-system such as lower water levels and increasing growth of plants and bacteria.[4]

In order to obtain a single value for a state, or the whole of the USA, the US Department of Commerce HDD and CDD weighted the local temperature with the population living under specific climatic conditions. In order to do so, the USA was divided into nine census regions as defined by the Census Bureau. Their weights were obtained by the population of the States. The temperature was also calculated according to the average state temperature. The average HDD for the USA in 2008 was 4,330. The same was done with the CDD which was 1,277 in the same year. However, such a detailed measure is only available for the United States. Nevertheless, there are some efforts to construct similar measures for various countries or regions.

Referring only to HDD, the European Commission (2007) introduced a similar index which reaches back to 1980. Daily temperature was measured at around 300 climate stations in all the EU member states. To each of these stations, population figures were added from the NUTS (Nomenclature of Territorial Units for Statistics). Regions and climate stations were unevenly distributed. There were 40 stations for Germany, 22 for France, and 18 for Spain. Estonia had only one. The HDD are summarized for each country and for the whole EU. However, in this study, the cut-off temperature is 15°C. According to the European Commission there were 3,386 HDDs in the EU in the long-term average from 1980-2004. The different cut-off points for the HDD in the United States and the EU make it difficult to compare the HDD in both areas. Furthermore, since we are interested in 21 OECD countries we need a measure which is also applicable to the remaining countries.

Since it is not possible to obtain HDD and CDD for all 21 OECD countries for a longer time period, the data was collected independently by our research team. In order to do so, we need to identify (a) the various climatic zones in each country. Second, we need to identify climate stations with a long record of monthly data reporting the monthly mean temperature (b).[5] Third, we need time-variant information about the number of people living in each climate zone (c). This final requirement was quite demanding since various countries changed the size of their administrative units over the last 50 years. Finally we needed to identify a cut-off point from where we calculate the heating or cooling degree (d).

(a) Identifying Climate Zones: In order to identify the climate zones in each country, I use climatic maps referring to Wladimir Köppen's climate regions. Köppen (1900; 1918; 1936) developed his classification system at the turn of the 20th century. Among all other classification systems, Köppen's classification prevailed (Sanderson 1999; Essenwanger 2001). Köppen oriented his classification system

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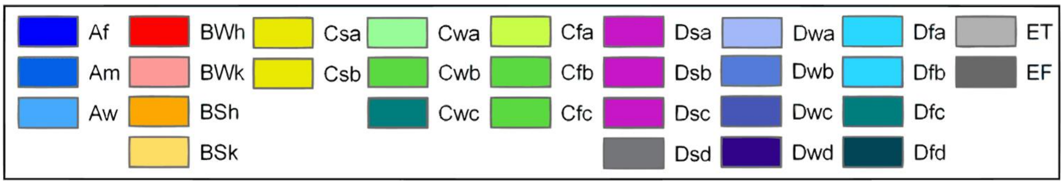
[4] Aside there are also methodological reasons to decide for 18°C. Using a cut-off point of 26°C leads to a very unbalanced distribution because only very few countries have average monthly summer temperature of 26°C and above. A cut-off point of 18°C leads to a less disturbed distribution.

[5] Of course we would have preferred to obtain daily data in order to construct an index of HDD. However, this was out of the question but the analysis could be conducted on a monthly basis from 1960 to 2005.

around the global vegetation map of Grisebach (1866) and developed a classification system based on temperature and precipitation. Köppen distinguishes five major climates (tropical, arid, temperate, cold, and polar) with 22 subgroups. This classification system has been used recently for estimating global warming and greenhouse scenarios (Barnett et al. 2005). In this context, it has been concluded that in comparison to other typologies "... the Köppen classification is easier to apply and is still a useful tool for estimating the ability of climate models to reproduce the present climate as well as indicate the impact of climate changes on the biosphere." (Lohmann et al. 1993: 191) However, over the years, the empirical classification has been further developed through introducing a growing number of climate stations (Kottek et al. 2006). The research in this paper relies on the newest comprehensive system developed by Peel and colleagues (2007). They base their classification on more than 4,000 locations of daily data over several decades. Peel et al. (2007) use the following climate classifications also applied in this study:

Figure 1: Climate Classifications for the Following Maps



1st	*2nd*	*3rd*	*Description*	*Criteria**
A			Tropical	$T_{cold} \geq 18$
	f		- Rainforest	$P_{dry} \geq 60$
	m		- Monsoon	Not (Af) & $P_{dry} \geq 100-MAP/25$
	w		- Savannah	Not (Af) & $P_{dry} < 100-MAP/25$
B			Arid	$MAP < 10 \times P_{threshold}$
	W		- Desert	$MAP < 5 \times P_{threshold}$
	S		- Steppe	$MAP \geq 5 \times P_{threshold}$
		h	- Hot	$MAT \geq 18$
		k	- Cold	$MAT < 18$
C			Temperate	$T_{hot} > 10$ & $0 < T_{cold} < 18$
	s		- Dry Sommer	$P_{sdry} < 40$ & $P_{sdry} < P_{wwet}/3$
	w		- Dry Winter	$P_{wdry} < P_{swet}/10$
	f		- Without dry season	Not (Cs) or (Cw)
		a	- Hot Summer	$T_{hot} \geq 22$
		b	- Warm Summer	Not (a) & $T_{mon10} \geq 4$
		c	- Cold Summer	Not (a or b) & $1 \leq T_{mon10} < 4$
D			Cold	$T_{hot} > 10$ & $T_{cold} \leq 0$
	s		- Dry Summer	$P_{sdry} < 40$ & $P_{sdry} < P_{wwet}/3$
	w		- Dry Winter	$P_{wdry} < P_{swet}/10$
	f		- Without dry season	Not (Ds) or (Dw)
		a	- Hot Summer	$T_{hot} \geq 22$
		b	- Warm Summer	Not (a) & $T_{mon10} \geq 4$
		c	- Cold Summer	Not (a,b or d)
		d	- Very Cold Winter	Not (a or b) & $T_{cold} < -38$
E			Polar	$T_{hot} < 10$
	T		- Tundra	$T_{hot} > 0$
	F		- Frost	$T_{hot} \leq 0$

*MAP = mean annual precipitation, MAT = mean annual temperature, Thot = temperature of the hottest month, Tcold = temperature of the coldest month, Tmon10 = number of months where the temperature is above 10, Pdry = precipitation of the driest month, Psdry = precipitation of the driest month in summer, Pwdry = precipitation of the driest month in winter, Pswet = precipitation of the wettest month in summer, Pwwet = precipitation of the wettest month in winter, Pthreshold = varies according to the following rules (if 70% of MAP occurs in winter then Pthreshold = 2 x MAT, if 70% of MAP occurs in summer then Pthreshold = 2 x MAT + 28, otherwise Pthreshold = 2 x MAT + 14). Summer (winter) is defined as the warmer (cooler) six month period of ONDJFM and AMJJAS.

(b) Identifying Climate Stations: Once the major climate zones in a country with a significant population were specified, I collected monthly temperature data from 1960 to 2005. In order to collect the temperature data, I rely on various data sources such as CISL (2009); Deutscher Wetterdienst (2009); EDI (2009); Meteored (2009), and NASA (2009). From these data sources I was able to collect data from 91 climate stations. These were the climate stations which had a relatively uninterrupted monthly report of mean temperature and which were representative for a national region with long-term population data available.

(c) Regional Population Data: The population data were mainly taken from Lahmeyer (1999/2006) with the exception of Australia, Japan and the United States for which I could use more detailed annual national data. Lahmeyer reports regional population data from national censuses and official estimates from sub-national administrative districts. Over the period of 1960 to 2005, a few countries altered or merged their administrative districts. Whenever possible, I calculated the population of these changes myself to obtain a long time-series. However, as a consequence, I lost many sub-national regions since I could only rely on the highest aggregated data. For small countries with minor climatic variation, I used just one climate station (the capital city or one close to it). This was possible for Belgium, Denmark, Greece, Ireland and the Netherlands. Italy, New Zealand, Norway, Sweden, and Finland are countries with a wide North/South spread which had to be taken into account by including climate stations from different parts of the country. Other countries have specific climate zones which were considered in our study. Besides the USA, Japan, Spain, and Switzerland were particularly challenging. Therefore, I present some further details about the operationalization for each of the countries included in the study. Apart from information from national sources, I also used the regional HDD-data from the European Commission (2007: CD information) in order to identify relevant regions and to test our index against the European Commission's.

(d) *Setting Temperature Thresholds*: In order to identify HDM I had to set a threshold from which point heating is necessary. As mentioned above, I follow the guide of the European Commission and use 15°C as the threshold. For CDM I use 18°C and 26°C.

Table 1 shows all the climate stations used in this study for each country and the regions which have been aligned to these stations. In some countries, I could be very detailed while in others, only a very rough indicator could be obtained. For the United Kingdom and New Zealand, various regional reforms during the last 50 years have made it only possible to use very few regions (for New Zealand, only the North and the South Island and for the UK only England, Scotland, Wales and Northern Ireland could be used). To be consistent, I needed relatively complete temperature data for identical climate stations from 1960 to 2005, as well as a relatively complete data set for the population in identical regions over the same time period.[6] Often enough, climate stations stopped reporting and regions were restructured.

Table 1: Climate Stations and Aligned Regions of 20 OECD Countries

Country	*Climate Stations*	*Regions*
Australia	Townsville	Northern Territory
	Brisbane	Queensland
	Adelaide	Southern Australia
	Perth	Western Australia
	Sydney	New South Wales
	Melbourne	Victoria, Tasmania
Austria	Vienna	Burgenland, Niederösterreich, Oberösterreich, Steiermark, Wien
	Innsbruck	Kärnten, Tirol, Vorarlberg, Salzburg
Belgium	Brussels (= Uccle)	whole country
Canada	Edmonton	Alberta
	Vancouver	British Columbia
	Winnipeg	Manitoba, Saskatchewan
	Toronto	New Brunswick, Nova Scotia, Ontario, Prince Edward Island
	Montreal	Newfoundland, Québec
Denmark	Copenhagen	whole country
Finland	Helsinki	Etelä-Suomi, Länsi-Suomi, Ahvenanmaa
	Jyväskylä	Itä-Suomi
	Kajaani	Oulu, Lappi
France	Paris	Alsace, Auvergne, Bourgogne, Centre, Champagne-Ardenne, Franche-Comté, Île-de-France, Limousin, Lorraine, Nord-Pas-de-Calais, Basse-Normandie, Haute-Normandie, Picardie, Rhône-Alpes
	Bordeaux	Aquitaine, Bretagne, Pays de la Loire, Midi-Pyrénées, Poitou-Charentes
	Marseilles	Corse, Languedoc-Roussillon, Provence-Alpes-Côte d'Azur
Germany	Hamburg	Bremen, Hamburg, Mecklenburg-Vorpommern, Niedersachsen, Sachsen-Anhalt, Schleswig-Holstein
	Berlin	Berlin, Brandenburg, Sachsen, Thüringen
	Essen	Nordrhein-Westfalen
	Frankfurt	Hessen, Rheinland-Pfalz, Saarland
	München	Baden-Württemberg, Bayern
Greece	Athens	whole country
Switzerland	Basel	Solothurn, Basel-Stadt, Basel-Landschaft, Schaffhausen, Aargau, Jura
	Zürich	Zürich, Luzern, Uri, Schwyz, Nidwalden, Glarus, Zug, Appenzell Ausser Rhoden, Appenzell Inner Rhoden, Sankt Gallen, Graubünden, Thurgau
	Geneva	Vaud, Neuchâtel, Genève
	Lugano	Ticino
	Bern	Bern, Obwalden, Fribourg
	Sion	Valais
Ireland	Dublin	whole country
Italy	Milan	Emilia-Romagna, Friuli-Venezia Giulia, Liguria, Lombardia, Piemonte, Toscana, Trentino-Alto Adige, Umbria, Valle d'Aosta, Veneto
	Rome	Abruzzo, Campania, Lazio, Marche, Molise, Puglia, Sardegna
	Messina	Basilicata, Calabria, Sicilia

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[6] Regional population data are dependent on a census or official estimations. These data points were not available annually. Therefore I imputed the data by linear imputation from one observation to the other.

Country	*Climate Stations*	*Regions*
Japan	Sapporo	Hokkaidô
	Tokyo	Chiba, Fukushima, Ibaraki, Iwate, Kanagawa, Miyagi, Saitama, Tochigi, Tôkyô, Aichi, Shizuoka, Yamanashi
	Fukuoka	Fukuoka, Kagawa, Kagoshima, Kôchi, Kumamoto, Miyazaki, Nagasaki, Okinawa, Saga, Tokushima
	Osaka	Ehime, Hiroshima, Hyôgo, Kyôto, Mie, Nara, Ôita, Ôsaka, Shimane, Tottori, Wakayama, Yamaguchi
	Matsumoto	Gumma, Nagano, Gifu, Okayama
	Wajima	Niigata, Fukui, Ishikawa, Shiga, Toyama,
	Akita	Akita, Aomori, Yamagata
Netherlands	Amsterdam (= De Bilt)	whole country
New Zealand	New Plymouth	North Island
	Christchurch	South Island
Norway	Tromsø	Finnmark, Troms
	Trondheim	Nordland, Nord-Trøndelag, Sør-Trøndelag
	Bergen	Hordaland, Møre og Romsdal, Sogn og Fjordane
	Oslo	Akershus, Aust-Agder, Buskerud, Hedmark, Oppland, Østfold, Oslo, Telemark, Vestfold
	Stavanger	Rogaland, Vest-Agder
Portugal*	Lisbon	Lisbon, Leiria, Santarém, Setúbal, Beja, Faro, Évora, Portoalegre
	Porto	Castelo Branco, Guarda, Coimbra, Aveiro, Viseu, Bragança, Vila Real, Porto, Braga, Viana do Castelo
Spain	La Coruna	Asturias, Cantabria, Galicia, Navarra, País Vasco
	Barcelona	Catalunya, Murcia, València
	Madrid	Castilla-La Mancha, Madrid, Rioja (La -)
	Sevilla	Andalucía, Extremadura
	Palma de Mallorca	Balears (Illes -)
	Valladolid	Castilla y Léon,
	Santa Cruz de Tenerife	Canarian Islands
	Zaragoza	Aragón
Sweden	Luleå	Jämtland, Norrbotten, Västerbotten, Västernorrland
	Stockholm	Dalarna, Gävleborg, Kristianstad, Örebro, Östergötland, Södermanland, Stockholm [City], Stockholm, Uppsala, Värmland, Västmanland
	Gothenburg	Älvsborg, Göteborg och Bohus, Skaraborg, Västra Götaland
	South Sweden (= Copenhagen)	Blekinge, Gotland, Halland, Jönköping, Kalmar, Kronoberg, Malmöhus, Skåne
United Kingdom	London	England
	Edinburgh	Scotland
	Dublin	Wales and Northern Ireland

* For Portugal we excluded Madeira and the Azores. The percentage has been calculated on the districts mentioned in the table.

Because the United States is the most complex country with various climate zones over a huge territory, I use 22 climate stations alone for the US (see table 2). For the identification of climate zones in the USA, I relied on the definition of the National Oceanic and Atmospheric Administration (NOAA), which are regions within a state that are as climatically homogeneous as possible. Each NOAA climate division is placed into one of five zones based on its 30-year average heating degree-days (HDD) and cooling degree-days (CDD) for the period of 1971 through 2000.

For each climate station, I aligned specific states. I divided California into North and South California using San Francisco for Northern California and San Diego for Southern California and aligned specific counties to both cities. Texas is the largest state in the contiguous United States and is split into three areas but just one climate zone. Since population is concentrated in Houston, Dallas and San Antonio, I use climate stations from these three cities, where Houston and Dallas are weighted equal with 1 and San Antonio with 0.5. Other cities were taken as representative for a combination of states such as Atlanta, New York, Boston, Chicago, Salt Lake City, Minneapolis, and St. Louis.

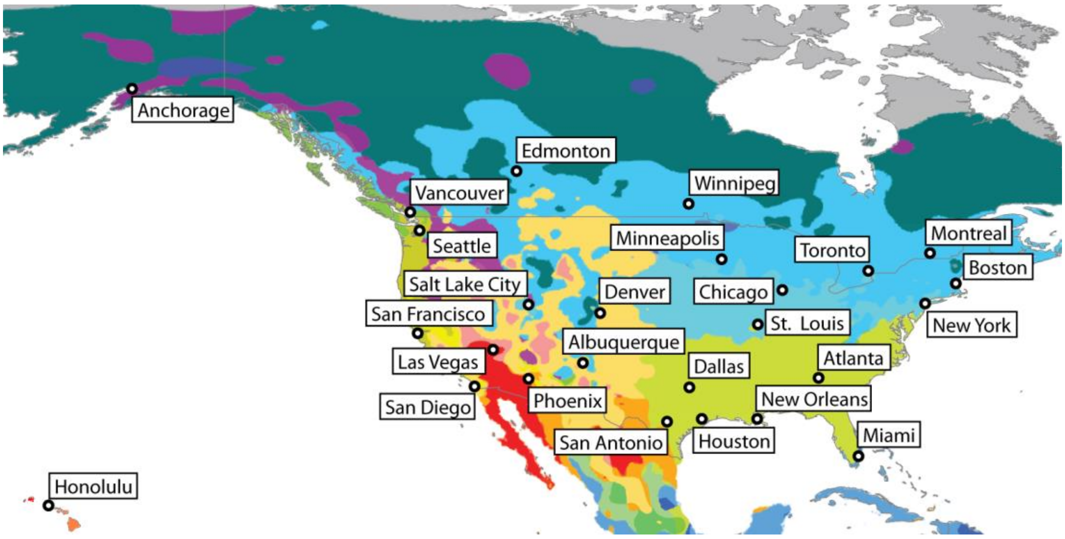
Table 2: Climate Stations and States in the USA

Climate Station	*States*
Anchorage	Alaska
Miami	Florida
Atlanta	Alabama, Delaware, District of Columbia, Georgia, Louisiana, North Carolina, South Carolina, Tennessee, Virginia
New Orleans	Mississippi
Houston; San Antonio; Dallas	Texas = (2*Houston, 2*Dallas, 1* San Antonio) / 5
Dallas	Arkansas, Oklahoma
Phoenix	Arizona
San Diego*	South California
San Fransisco*	North California
Las Vegas	Nevada
Denver	Colorado
New York	Connecticut, Maryland, New Jersey, New York, Pennsylvania
Boston	Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
Chicago	Illinois, Indiana, Iowa, Michigan, Ohio, Wisconsin
Salt Lake City	Idaho, Nebraska, Utah, Wyoming
Minneapolis	Minnesota, Montana, North Dakota, South Dakota
Seattle	Oregon, Washington
Albuquerque	New Mexico
St. Louis	Kansas, Missouri, Kentucky, West Virginia
Honolulu	Hawaii

* California has been divided into Southern (Imperial, Kern, Los Angeles, Orange, Riverside, San Bernardino, San Diego, San Luis Obispo, Santa Barbara, Ventura) and Northern (all other counties) California.

In order to illustrate the location of selected climate stations within the specific climatic zones, I included maps with the climate zones and the name of the city where the climate station is located. Figure 2 shows the climate zones of Canada and the USA.

Figure 2: Climate Zones and Selected Climate Stations in Canada and the USA



Source: Map from Peel et al. (2007), cities for the selected climate stations are added to the map by the author.

In Canada, all our climate stations are in the cold climate zones with the exception of Vancouver, which is in the temperate climate zone. However, considerable variation of temperature exists in the cold climate zones, so I included four climate stations within the same climate zone. For instance, in the year 2000, the average winter temperature was -10.7°C for Edmonton, -16.07°C for Winnipeg, -5.37°C for Toronto, and -8.7°C for Montreal.

Japan is another challenging case for constructing an index of HDM and CDM since it stretches more than 3,000 kilometers from north to south. Were Japan put into North America or Europe, it would reach from Toronto in Canada to Georgia in the USA or from Milan in Italy to Gadamis in Libya, which is on the level of Cairo (excluding the southern islands which stretch another 400 kilometer to the south). Japan is divided into six principal climatic zones: (1) Belonging to the cool temperate zone, Hokkaidō, the northern part of Japan, has long, cold winters and cool summers. The climate station here is Sapporo. (2) The population at the Sea of Japan, in the northwest of Japan experiences seasonal wind in winter which gives heavy snowfalls. In summer, it is cooler than the Pacific coast but sometimes experiences extremely high temperatures. I selected Akita from the north of this climate zone and Wajima from the more southerly part as climate stations for this region. (3) The Central Highland has a typical inland climate, having large temperature differences between summers and winters and between days and nights. Matsumoto is the climate station here. The Seto Inland Sea is surrounded by the mountains in the Chūgoku and Shikoku regions which block the seasonal winds and bring mild climate and many fine days throughout the year. Osaka is the climate station here. (5) The Pacific Ocean region is characterized by cold winters with little snowfall, and summers are hot and humid due to the southeast seasonal wind. Tokyo is the climate station in this region. (6) The Southwest Islands have a subtropical climate with warm winters and hot summers. Precipitation is very high, and is especially affected by the rainy season and typhoons. Since this region is not densely populated, I included it into the southern climate zone of the main island. I collected Fukuoka as a representative climate station for this part of Japan. Figure 3 uses the map of climate zones as presented by Peel et al. (2007). I indicated the climate stations used on this map as well.

Figure 3: Climate Zones and Selected Climate Stations in Japan

Source: Map from Peel et al. (2007), cities for the selected climate stations are added to the map by the author.

As shown in table 1, I assigned the population of various prefectures (*ken*) to the above mentioned climate stations in order to calculate the HDM and CDM for Japan.

Europe has several distinct climate zones and most countries have various weather conditions within their borders. In particular, the Nordic countries of Norway, Sweden, and Finland stretch from north to south for a considerable distance. However, the population is concentrated in the southern parts of these three countries. Nevertheless, I collected data from various climate stations. For Sweden and Norway, there are climate stations in the south and north. In the south, I collected data from climate stations on the west (Bergen and Stavanger for Norway and Göteborg for Sweden) and east coasts (Oslo and Stockholm) due to high population concentrations. For the north, I selected Luleå (Sweden) and Tromsø (Norway). For Norway, I also included the climate station at Trondheim because mid-Norway has another concentration of population. In Finland, I collected data for Helsinki representing the relatively densely populated regions in the south and southwest. Jyväskylä covers the central eastern region with a relative concentration of population. Kajaani covers the northern part of Finland.

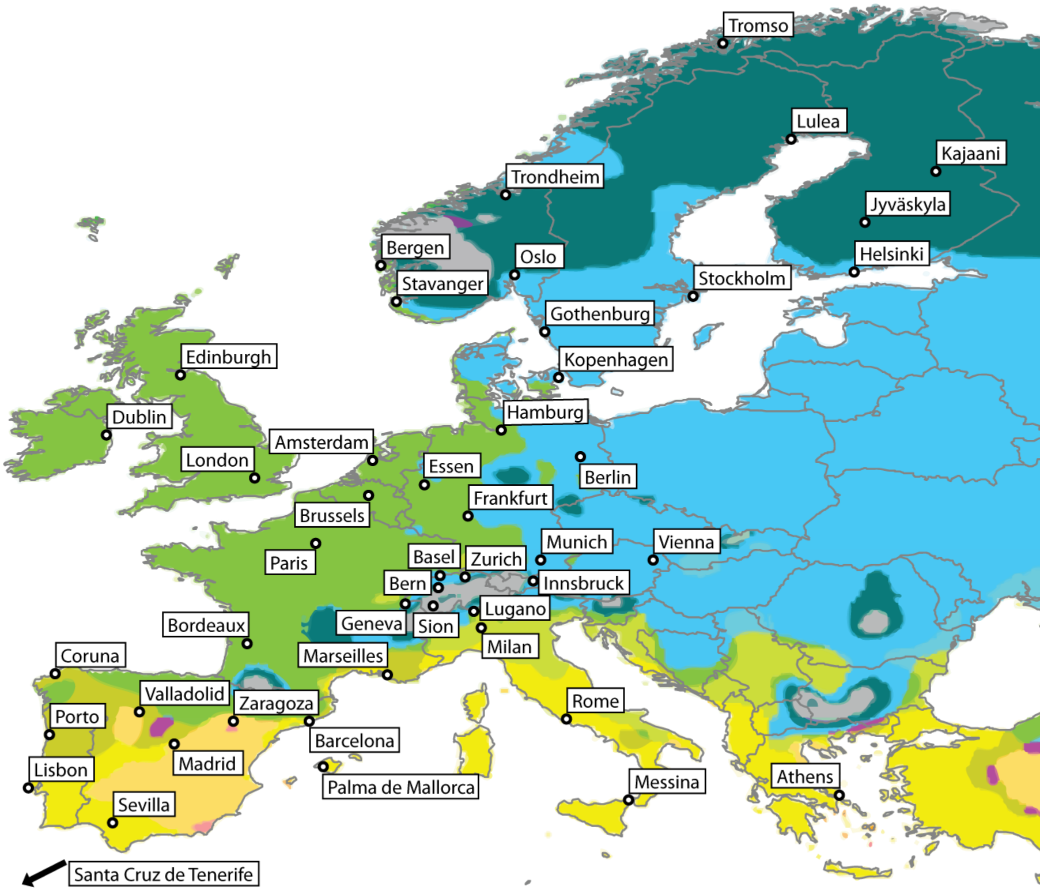
For Ireland, Belgium, the Netherlands and Denmark, I used only one climate station, close to the capital since all four countries are small with uniform climate zones. Germany, the United Kingdom and France also have a low number of climate zones. However, because of their size, I selected climate stations from different areas. This practice was also necessary since the population is spread over the whole territory aside for concentrations in London (UK) and Paris (France). Since the UK conducted several administrative reforms in the post-War period, the information for regional population data was scarce, limiting the data to three regions.

Italy also stretches a considerable distance from north to south over varying climate zones. In the Italian case, it was particularly difficult to identify climate stations over the whole period of analysis. Fortunately, I could obtain data from three stations which are representative for distinct climate zones in Italy (Milan, Rome, and Messina) and correspond to high population concentrations.

Spain is probably the European country with most climate zones. The weather conditions vary from the cool and wet area on the Atlantic coast, the hot and dry zones in the south, and the moderate zone of the highland surrounding Madrid. Catalonia and the Balearic Islands also have a distinct climate as well as the Canary Islands. In addition, there are also substantial differences within climate zones which led to the inclusion of additional climate stations. In sum, I ended up using eight climate stations for Spain.

Portugal has two distinct climate zones which are represented by Lisbon and Porto in my study. There might be other climate zones in the mountains in the east of the country. However, I could not identify a climate station with longitudinal data there. In addition, the bulk of the population in Portugal lives close to the sea.

Figure 4: Climate Zones and Selected Climate Stations in Europe



Source: Map from Peel et al. (2007), cities for the selected climate stations are added to the map by the author.

Because of its alpine character, Switzerland – although a relatively small country – has seven climate zones. Except for the high mountain area, which is not populated and therefore not relevant for the calculation of our index, I collected data for six climate zones.[7] I align the respective cantons to the six selected climate stations as documented in table 1. The climate zones north of the Alps are cold with warm summers. In the west and northwest, the influence of the temperate Atlantic climate is felt more strongly, in the east, the influence of the continental climate (Zürich) is more prevalent. The southern regions of the Alps are warm. For this region, I included the climate station of Lugano. However, due to their complex structure, the Alps additionally generate several different climate regions on their own. This is why I selected the three climate stations of Geneva, Bern and Basel north of the Alps. Furthermore, these cities are together with Zürich – which is in the center of the most populated area in Switzerland – the largest cities in Switzerland. Furthermore, the valleys in the central Alps have their own distinct climate, because they are shielded against precipitation both from the north and the south, leading to dry conditions. This is clearly the case in the Valais region in Southwestern Switzerland for example. Here I picked Sion as a climate station. However, temperatures depend largely on altitude, with averages 5°C lower for each additional 300 meters of elevation. This fact could not be considered in this study.

The climate zones for New Zealand are derived from the Department of Building and Housing. More detailed climate zones exist.[8] However, since there have been frequent regional reforms, population data over the whole time period have only been available either for the North and the South islands. Although I would have wished for a more detailed classification of New Zealand's climate zones, I believe that my procedure is sufficient for New Zealand. The North Island has a warm subtropical climate and the South Island a cool temperate one. Most people in New Zealand live either in the moderately cool parts on the coast of the South Island or in the moderately warm parts of the North Island. The following figure shows the climate zones in New Zealand and Australia.

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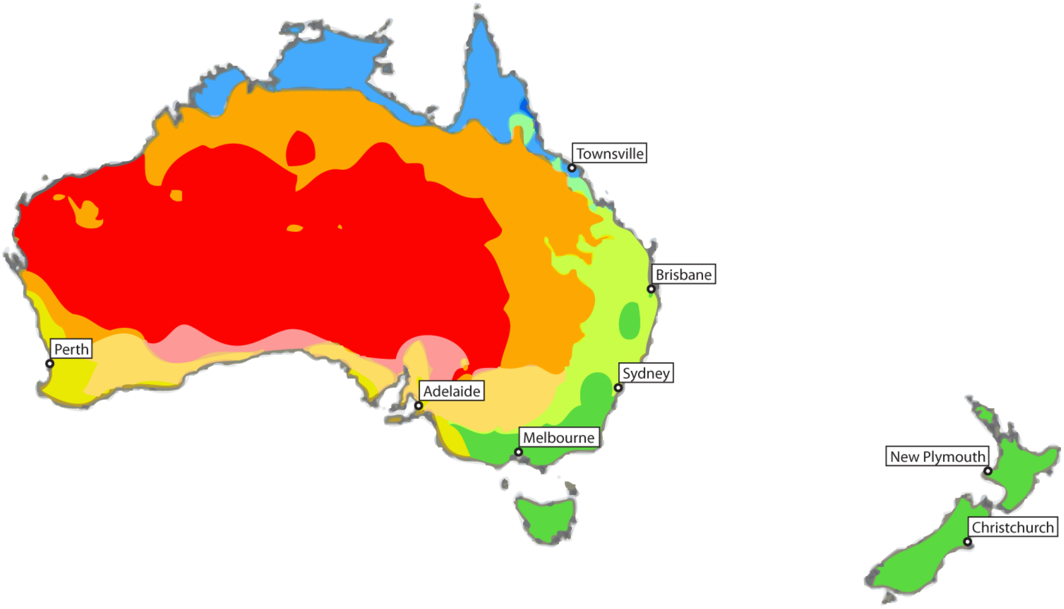
[7] Because of detailed information I collected the Swiss data from national source (http://www.meteoschweiz.admin.ch; accessed April 2009).

[8] See for instance the Institute for Water and Atmospheric Research (http://www.niwa.co.nz/education-and-training/schools/resources/climate/overview, accessed: June 2009).

Figure 5: Climate Zones and Selected Climate Stations in Australia and New Zealand



Source: Map from Peel et al. (2007), cities for the selected climate stations are added to the map by the author.

Although Australia has a sizable territory, people live mainly on the coast. Most people actually live in the area between Melbourne and Sidney which has a relatively moderate climate. This also includes Tasmania. Areas with a substantial amount of people and different climate zones are represented by the climate stations in Adelaide, Perth and Brisbane respectively. Townsville represents the Northern Territory which is much less populated than the southern and the southeastern parts of Australia. Because of the limited population in the center and northwestern part of Australia, I did not include climate station from these areas.

3 An Index of Heating and Cooling Degree Months in 21 OECD Countries from 1960 to 2005

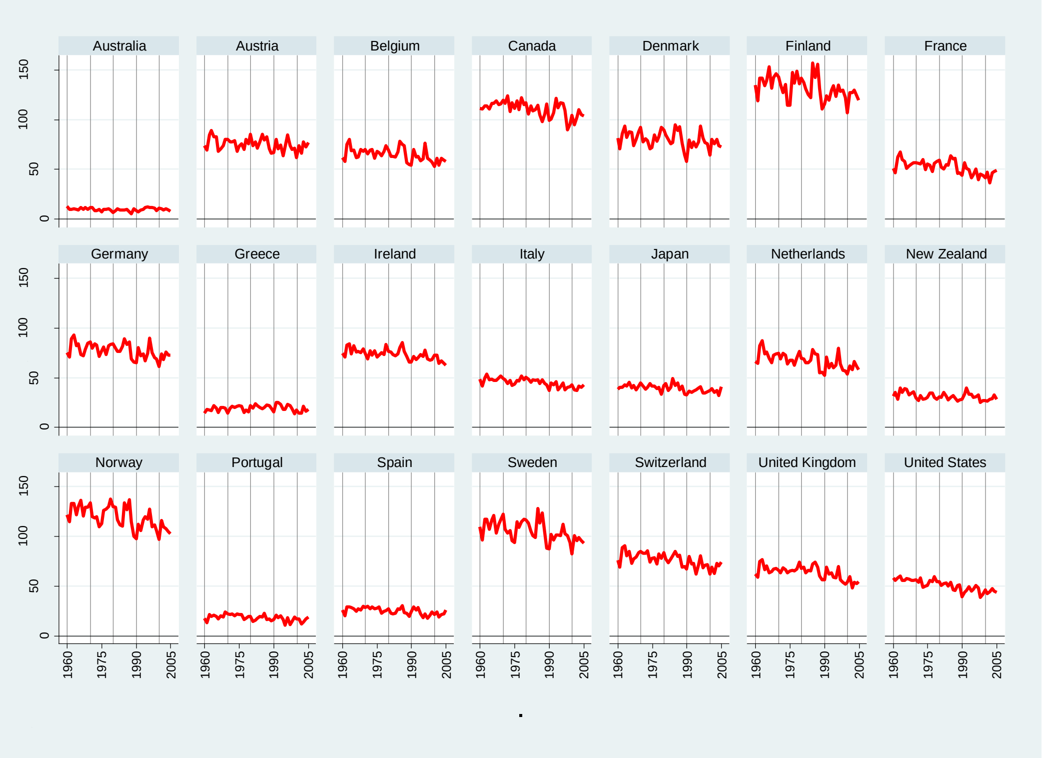
The HDM index is derived from the difference of the base temperature to the actual monthly temperature for each region, weighting it by the regional population in order to obtain the average annual national HDMs. The total index for the HDMs for a country *c* at year *t* is:

$$HDMs_{ct} = \sum_i^n \left(\sum_{m=1}^{12} \left[15°C - \left\{ {T_m, if\ T_m < 15°C \atop 15°C, if\ T_m \geq 15°C} \right. \right] * \sum_i^n \frac{P_i}{P_n} \right)_{c,t} \tag{1}$$

In the equation, *i* stands for the *i*th region of a country *c*, *m* are the months reaching from January (1) to December (12). *Tm* is the mean temperature of a respective month where $T < 15°$ C and when $T \geq 15°$ C, *T* is set to 15 for that month. *Pi* is the population in the *i*th region aligned to the climate station which is representative for the region and *Pn* is the total population. The calculations have been made for all countries *c* in all the years *t* from 1960 to 2005. Taking the example of Canada in the year 2000, Edmonton had 140.52 HDMs, Vancouver 56.76 HDMs, Winnipeg 158.4 HDMs, Toronto 95.88 HDMs, and for Montreal, 114.48. In

2000, 9.83 % of the Canadian population lived in Alberta, where Edmonton is the representative climate station; 13.04 % of the population lived in British Columbia with Vancouver as the climate station; 7.07% of the population lived in Manitoba and Saskatchewan, with Winnipeg as climate station; 43.97% of the population lived in New Brunswick, Nova Scotia, Ontario, and Prince Edward Island, with Toronto as climate station; while Newfoundland and Québec had 26.08 % of the Canadian population with Montreal as the station. Taking the proportional distribution of the population into account, the final HDMs for Canada in 2000 is 104.28. The same calculation was conducted for all 21 OECD countries under investigation for every year from 1960 to 2005. Figure 6 shows the annual HDMs for all 21 OECD countries from 1960 to 2005.

Figure 6: Annual Heating Degree Months in 21 OECD Countries from 1960 to 2005 (> 15°C)



The figure demonstrates considerable variation between the countries. The mean of the HDMs is 63.5 for all 21 OECD countries in the period from 1960 to 2005. The minimum value is 5.24 (for Australia in 1988) and the maximum value is 156.96 (for Finland in 1985). Over time, there is a trend towards fewer HDMs in most but not all countries (e.g. Greece). The average of HDMs over all 21 OECD countries from 1960 to 1987 was always above 60 HDMs, except 1961 (59.6). From 1988 to 2005, less than 60 HDMs was common in 13 of the 18 years. However, implying causal relationships is difficult from the data. Warmer winters may be one causal factor. Another reason may be that a large proportion of people moved from colder to warmer places within a country. A case in point is the migration to Las Vegas in the USA, one of the fastest growing cities during this period.[9] Similar migration trends

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[9] For the State of Nevada, where Las Vegas is located, the population has grown from 285,000 in 1960 to about 2 million in 2000. This means that in 1960, 0.16 % of the US population lived in Nevada and 0.71% in 2000.

are identifiable for California or the move from the north to the south in the Nordic countries.[10]

The standard deviation over all 21 countries from 1960 to 2005 is 34.01 HDMs. The countries with the highest variations of HDMs are Finland (11.71), Norway (11.19), and Sweden (10.43). All these countries are in relatively cold climates. Countries with low changes in winter temperature are Australia (1.53), Greece (3.02), Portugal (3.06), and Spain (3.42). Table 3 gives the basic statistical summary for the 21 OECD countries examined from 1960 to 2005.

Table 3: Basic Statistics of Heating Degrees Months in 21 OECD Countries from 1960 to 2005 (> 15°C)

Country	*Mean*	*Minimum*	*Maximum*	*Standard Deviation*
Australia	9.58	5.24	12.88	1.53
Austria	75.13	61.59	89.19	6.24
Belgium	64.79	52.60	80.10	6.76
Canada	110.54	89.66	123.91	7.68
Denmark	79.90	57.60	94.80	8.31
Finland	131.95	106.50	156.96	11.71
France	52.00	36.19	67.26	6.84
Germany	77.23	61.35	92.84	7.32
Greece	19.12	13.70	25.30	3.02
Ireland	73.40	62.30	85.30	5.44
Italy	45.02	36.80	53.28	4.21
Japan	39.31	32.08	49.39	3.74
Netherlands	67.04	52.20	87.20	7.84
New Zealand	31.20	24.81	39.65	3.76
Norway	118.91	96.78	137.51	11.19
Portugal	17.99	10.72	23.70	3.06
Spain	24.79	17.31	30.49	3.42
Sweden	105.49	82.03	127.67	10.43
Switzerland	76.13	61.82	90.82	6.97
United Kingdom	63.39	47.68	76.85	6.71
USA	50.72	38.67	60.32	5.67
All countries	63.51	5.24	156.96	34.01

In order to test the validity of the data, the HDMs are compared with the HDDs of the European Commission. A comparison with 14 West European countries over a time period from 1980 to 2005 was conducted. Over all the countries and years, Pearson's r is 0.93. This demonstrates a high correlation between the HDMs with the HDDs data of the European Commission. Concerning the individual countries, Pearson's r varies from 0.83 in Ireland to 0.97 in Sweden.[11] Overall this is a very high

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[10] California had 8.8 % of the US population in 1960 and 12.04 % in 2000. The East Coast states and the states aligned to the climate station of Chicago had half of the population in 1960. This figure went down to 38.8 in the year 2000. In Finland, the population in the South was 70 % in 1960 and 77% in 2000. In Sweden, the northern population went down from 12.4% to 9.9 % and in Norway, the northern and central Norwegian population fell from 21.3 % in 1960 to 18.9% in 2002.

[11] The correlation for all 14 EU countries is: Austria 0.94; Belgium 0.97; Denmark 0.94; Finland 0.96; France 0.94; Germany 0.94; Greece 0.83; Ireland 0.83, Italy 0.85; Netherlands 0.95; Portugal 0.88;

correlation which supports the validity of the HDMs for the time period from 1960 to 2005. The correlation between the HDDs of the US with a base temperature of 65° F and the HDMs with a base temperature of 15° C is 0.87[12]. With this country and time coverage the data set in this study is unique.[13]

The same index has been developed for Cooling Degree Months (CDM). I used the same climate zones and population data. As mentioned above, I use the cut-off point of 18°C and 26°C, above which high temperatures enter the CDM index. The equation is shown below:

$$CDMs_{ct} = \sum_i^n \left(\sum_{m=1}^{12} \left[18^\circ C + \begin{cases} T_m, if\ T_m > 18^\circ C \\ 18^\circ C, if\ T_m \leq 18^\circ C \end{cases} \right] * \sum_i^n \frac{P_i}{P_n} \right)_{c,t} \tag{2}$$

In the equation *i* stands for the *i*th region of a country *c*, *m* are the months reaching from January (1) to December (12). *Tm* is the mean temperature of a respective month where *T* > 18°C (or 26°C) and when *T* ≤ 18°C (or 26°C), *T* is set to 18 (26) for that month. *Pi* is the population in the *i*th region aligned to the climate station which is representative for the region and *Pn* is the total population. Table 4 refers to the 18°C threshold and shows that Greece, Japan, USA, Italy, Australia and Spain have the hottest and/or longest summers of the 21 OECD countries under investigation. Ireland has zero CDM and in many countries the degree of CDM is low. The differences in summer temperatures are high in the countries with hot summers such as Greece, Italy, Spain and Japan. Over all countries and years, the standard deviation for CDM (10.43) is much lower than for HDM (34.01). The hottest summer was in Greece in 2003. All summers after 1998 have more than 38 CDM in Greece and before only the summer of 1962 had more than 35 CDM during the period of 1960 to 1993. For the other countries in our study, we also see that in recent years summers require more CDM. This trend can also be seen from figure 7. As with HDM, it is difficult to make a causal statement due to human migration. Table 4 shows the basic statistics for CDM.

Spain 0.88; Sweden 0.97; and the UK 0.96. The correlation between the HDDs of the US with a base temperature of 65° F and the HDMs with a base temperature of 15° C is 0.87.

[12] The data for the US were taken from: (http://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp; accessed June 2012).

[13] The data set can be downloaded under: www.comparativepolitics.uni-greifswald.de.

Table 4: Basic Statistics of Cooling Degree Months in 21 OECD Countries from 1960 to 2005 (< 18°C)

Country	*Mean*	*Minimum*	*Maximum*	*Standard Deviation*
Australia	17.42	14.01	20.17	1.97
Austria	3.02	0	10.94	2.22
Belgium	0.74	0	4.64	1.26
Canada	4.02	0.77	10.07	1.93
Denmark	0.51	0	3.44	0.88
Finland	0.30	0	2.01	0.61
France	4.23	1.05	13.76	2.65
Germany	1.08	0	6.17	1.43
Greece	33.15	24.12	46.12	5.00
Ireland	0.00	0	0	0
Italy	18.54	13.64	30.31	3.42
Japan	26.94	19.22	34.13	2.29
Netherlands	0.47	0	3.54	0.90
New Zealand	0.31	0	1.32	0.42
Norway	0.04	0	0.80	0.16
Portugal	8.54	5.29	14.83	2.11
Spain	16.84	9.75	26.17	3.29
Sweden	0.38	0	2.91	0.71
Switzerland	1.52	0.04	11.79	1.96
United Kingdom	0.28	0	2.63	0.60
USA	23.55	17.71	27.98	2.68
All countries	7.71	0	46.12	10.43

The data clearly show the extraordinarily hot summer of 2003. The 2003 European Heat Wave is one of the hottest summers on record in Europe. The heat wave led to health crises in several countries while drought led to a crop shortfall in Southern Europe. More than 40,000 Europeans died as a result of the heat wave. France was particularly affected with almost 15,000 heat-related deaths and in Switzerland, glaciers in the Alps melted and caused avalanches and flash floods. A new nationwide record temperature of 41.5°C was recorded in Grono, Graubünden. In these countries and also in the rest of Europe, rivers and lakes had record low water levels. In Australia, there were hot summers in 1968 and 1979. Japan experienced hot summers in 1961 and 1994. In 1980, 1983, 1988 and 1995 heat waves hit the USA with severe effects for agriculture and the environment. In the new millennium, the summers of 2002 and above all 2005 reach record high CDM.

Figure 7: Annual Cooling Degree Months in 21 OECD Countries from 1960 to 2005 (< 18°C)

6 Conclusion

In this paper, I constructed annual indices for Heating and Cooling Degrees Months (HDM and CDM) for 21 OECD countries over the time period from 1960 to 2005. These indices may be of great importance in explaining environmental pollution and energy requirements. Cold winters may increase energy requirements and thus increase emission levels. This is particularly true when atmospheric emissions have not been reduced by political regulations or technological development (Jahn 2013). The same is true for hot summers. Hot summers may increase the use of air conditioning and, in turn, the use of energy and the emission of air pollutants. Hot summers lead to droughts, health problems and severe weather conditions. Furthermore, they lead to decreased water levels in rivers and lakes. This in turn results in an increased concentration of water pollutants and deteriorated water quality. Knowing to which degree changing summer temperatures are responsible for pollution levels is essential to estimate what environmental measures should be introduced in order to keep pollution levels low even during hot summers. In any case, HDM and CDM are important control variables in any analysis of environmental degradation.

This index also shows the consequences of migrations within a country. In the USA, many people moved from the cooler climate zones to the warmer “sun belt states” in the latter half of the 20th century. California and Las Vegas are the fastest growing areas in the USA. This migration may have resulted in an “increase” in the average temperature per capita in the USA. In turn, this has an effect on atmospheric emissions through the extensive use of air conditioning and the water quality, because more water is used in the warm regions, leading to severely decreased water levels during hot summers. A case in point is the destiny of the Colorado River in the United States. On the one hand, growing metropolitan areas such as Las Vegas, Phoenix and Los Angeles and, on the other, increasing agricultural activities in the rural states of Colorado, Wyoming, Utah, New Mexico and Arizona use so much water that the Colorado River does not reach the Pacific anymore.[14]

My indices of HDM and CDM are unique first steps towards analyzing the impact of climate on environmental pollution in a more sophisticated way. This is important because thus far the main focus has been on the impact of atmospheric emissions on climate change. However, understanding the reverse causal mechanism is also essential. It could turn out that political action has been less efficient than previously thought and that a great deal of the variation of atmospheric emissions and other environmental problems is mainly determined by the winter and summer temperature. Therefore, HDM and CDM are important control variables for environmental as well as energy policy.

However, challenges remain for improving indices of the impact of climate on environmental degradation. Climate is certainly a more complex construct than just differences in temperature. Including precipitation, humidity, air pressure and wind would improve a climate index. There could also be improved thresholds which more closely address specific environmental issues than the thresholds used in this paper. However, these first steps already reveal a new causal path: not only does environmental pollution affect the climate, the climate also effects pollution, even if this effect is indirect.

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[14] I am grateful for in depth information on this point from Steven Parker during my research stay at the Department of Political Science of the University of Nevada, Las Vegas. At this point I would also like to thank Professor Dennis Pirages for his hospitality.

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