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ORIGINAL PAPER

Temperature and school absences: evidence from England

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Abstract
Extreme temperature affects children's health, cognitive abilities, and behavior with implications for human capital accumulation. For example, several studies documented both heat and cold to decrease cognitive abilities and being consequential for test scores. An alternative, less explored pathway, by which temperature is consequential for educational achievement, is absenteeism. In this study, we explore how heat affects school attendance leveraging administrative data on more than 22,000 schools in England from the school years 2011/2012 to 2018/2019. Using a fixed-effects approach largely used in the literature, we exploit the variations in temperature by school year to estimate the effect of heat and cold days on absences. The results expose hot days to increase absences. Inquiring specific types of absences, we observe hot days to increase illness-related absences and authorized holidays. Conversely, we do not find any substantive impact of cold exposure, except for illness-related absences in energy-poor neighborhoods. In conclusion, we provide additional evidence on the impact of temperature on children and propose an alternative pathway through which societal challenges associated with climate change and energy poverty could affect human capital accumulation.

Keywords Temperature · Children · School absences · Health · England

Introduction

Climate change and the increase in global temperatures pose several threats to children's health and human capital accumulation. Heat has been documented to exert a detrimental effect on human health especially for children and older individuals due to their weaker cardiorespiratory system (Åstrom et al., 2011; Jhun et al., 2017; Park et al., 2020; Xu et al., 2014). Considering children, several studies found heat to be particularly harmful early in life increasing the likelihood of negative birth outcomes

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(Chen et al., 2020; Chersich et al., 2020; Conte Keivabu & Cozzani, 2022), and sudden infant death (Jhun et al., 2017; Scheers-Masters et al., 2004), and epidemiological studies documented an increase in hospital admissions during hot days for children and adolescents (Bernstein et al., 2022; Xu et al., 2014). Additionally, heat negatively impacts children's cognitive performance with critical implications on their test scores, educational attainment, human capital accumulation, and future life. Studies documented heat to decrease test performance on the day of the test (Graff Zivin et al., 2018; Park, 2020), affecting learning in the months preceding an exam (Cho, 2017) and during the school year (Park et al., 2020). Also, evidence on the negative relationship between heat and learning has been shown at a global level (Park et al., 2021). Cold exposure has been less investigated but has been shown to decrease test performance in university students (Cook & Heyes, 2020). Nevertheless, extreme temperatures could affect other features of children's schooling with possible implications on learning and human capital accumulation.

In this study, we aim to bring novel evidence to the literature interested on the effect of temperature on children's education focusing on the impact of extreme temperature on school absences. To the best of our knowledge, only one study has so far investigated how temperature affects school attendance in South Africa finding a small increase in absences with temperatures outside the comfort zone (Pule et al., 2021). However, the study focused on indoor temperature (in the classroom), used a small number of schools, and only analyzed one school year. Other studies have investigated work absenteeism in adults. For example, a study has shown heat to increase work absenteeism in industrial plants in India (Somanathan et al., 2021). Similarly, a study based on global survey data showed high temperatures increase work absences in several contexts, but more so in developing countries (Yu et al., 2019). Also, a study found heat to lower the time allocated to work in the USA based on information provided by time use data (Graff Zivin & Neidell, 2014). Conversely, a study in Jamaica failed to find an association between heat and work absenteeism (Spencer & Urquhart, 2021). Even though less investigated, also cold temperatures could increase school absences due to negative health impacts (Rasi et al., 2017), determining an uncomfortable classroom temperature (Pule et al., 2021) or altering the spread of infectious diseases (Jaakkola et al., 2014). In fact, a study found the provision of effective heating to asthmatic children to improve their attendance during winter in New Zealand (Free et al., 2010). Overall, we expect extreme temperatures (heat and cold) to increase absenteeism in school children and this to be related mostly to an increase in illness-related absences based on existing epidemiological literature documenting negative health consequences of heat and cold exposure. Moreover, we expect the impact of cold days on illness-related absences to be larger in neighborhoods with a higher prevalence of energy-poor households.

We investigate the impact of temperature on school absenteeism focusing on England. England has a humid temperate oceanic climate but is expected to experience an increase in summer temperatures of about 4.9 °C by 2070 according to recent climate projections (MET Office, 2022). Worryingly, in the past years, summers have already shown record high temperatures with 2022 becoming the hottest summer on record and exceeding maximum temperatures of 40 °C.[1] Importantly, children attend school until mid-July, air conditioning is not present in most buildings, and currently, there are no clear regulations defining the maximum temperature at which school attendance should be avoided.

In this article, we first discuss the evidence on the impact of temperature on children's health, educational attainment, and the mechanisms that could link temperature to school absences. Also, we describe the context of our study, England. Followingly, we present the data, variables, and empirical strategy used to uncover the impact of temperature on school attendance. Furthermore, we provide results on the impact of temperature on school absenteeism, how this varies by types of absences, and we provide sensitivity analysis. Finally, we conclude with a discussion of the results.

Conceptual framework

Temperature and children's health

Children are more vulnerable to environmental stressors such as heat waves. A recent systematic review described the risks of heat waves for children's health relatable to physiologic, metabolic, cardiovascular, and behavioral factors (Xu et al., 2014). In older individuals (i.e., above age 65), several studies documented a steep increase in mortality during hot days (Gasparrini & Armstrong, 2011; Gasparrini et al., 2015). Conversely, the risk of death for children above the age of 0 is low or not existent (Xu et al., 2014). However, outcomes related to morbidity show an increase. For example, epidemiological studies documented an increase in children's hospitalization with exposure to hot temperatures in the USA (Bernstein et al., 2022), in New York (Sheffield et al., 2018) and the Netherlands (van Loenhout et al., 2018). In these studies, the cause-specific hospitalizations mentioned are related to a vast array of conditions such as heat illnesses, respiratory conditions, dehydration, bacterial enteritis, otitis, and injuries. Moreover, in adolescents, heat seems to be particularly detrimental during sports activities as triggering heat illnesses (Kerr et al., 2013).

Furthermore, children's health could be detrimentally impacted by cold temperatures. Cold exposure could worsen existing cardiorespiratory conditions such as asthma (Free et al., 2010). Another mechanism through which colder conditions influence children's health is by modifying their susceptibility to contracting infectious airborne diseases. Children are particularly at risk during the autumn and winter seasons, as the likelihood of contracting influenza rises significantly (Munoz, 2002) in particular in the school environment (Endo et al., 2021). Moreover, crowded school environments have been shown to be more severely affected by

[1] More information is available in the MET press release on summer 2022: https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2022/2022-provisionally-warmest-year-on-record-for-uk.

influenza outbreaks (Donaldson et al., 2020). Importantly, contracting influenza can lead to serious complications for children, potentially resulting in long-term health conditions (Kondratiuk et al., 2021; Munoz, 2002). Also, numerous studies from diverse climatic regions have demonstrated an association between lower temperatures and increased incidence of seasonal influenza (Jaakkola et al., 2014; Matsuki et al., 2023; Sooryanarain & Elankumaran, 2015). Interestingly, it is not only the cold weather itself that increases the spread of influenza, but also drastic temperature declines, which have been linked to elevated influenza prevalence (Jaakkola et al., 2014; Matsuki et al., 2023).

Temperature and education

Extreme temperatures have implications for children's educational outcomes. In recent years, evidence has been mounting on the impact of heat on learning (Wargocki et al., 2019) due to exposure early in life (Randell & Gray, 2016, 2019), during the school year (Park et al., 2020, 2021) or on test performance with exposure on the day of the test (Park, 2020). In contrast, while the scholarly understanding of cold temperature's impact on educational success is somewhat limited, one study identified a decrease in test performance among university students who were exposed to cold conditions prior to high-stakes examinations (Cook & Heyes, 2020). Additionally, studies focused on the impact of heat on adult workers' productivity found a decrease in output with exposure to heat (Dunne et al., 2013; Somanathan et al., 2021) or bad weather conditions (Lee et al., 2014). Some of the mechanisms explaining how extreme temperatures affect learning relate to the negative impact that temperature has on health (Xu et al., 2014), cognitive performance (Hocking et al., 2001), and on increasing a sensation of fatigue (Bidassey-Manilal et al., 2016). However, the links between temperature and learning are not yet fully elucidated. For instance, the performance of teachers, which directly impacts the quality and volume of content absorbed by children, could be compromised during hot days (Park et al., 2021). Furthermore, evidence from India suggests an increase in teacher absenteeism during periods of high temperature, which could have implications for student learning (Borgen et al., 2023). Yet, these hypotheses do not exhaust all possible mechanisms.

Temperature and absenteeism: health, behavior, educational institutions, and energy poverty

An alternative mechanism explaining the link between temperature and learning is children's absenteeism. Existing studies described a link between school absences and test scores (Cattan et al., 2023; Liu et al., 2019; Mooney et al., 2022). Also, a study documented snow days to increase absences and reduce test scores (Goodman, 2014). This is expected as exposure to schooling is predictive of test scores (Passaretta & Skopek, 2021). Importantly, several mechanisms could link temperature to school absences.

School absences increase with exposure to extreme temperatures due to their negative health effects. Negative impacts of heat on children have been documented by the existing epidemiological literature that found an increase in children's hospitalization during hot days in several country contexts (Bernstein et al., 2022; Xu et al., 2014). Also, heat could affect children's sleep and increase school absences. A global study found hot temperatures to affect sleep quantity (Minor et al., 2022), and a study in the USA found an increase in self-reported insufficient sleep with exposure to nighttime heat (Obradovich et al., 2017), and several measures of sleep quality and quantity have been shown to affect school absences (Hysing et al., 2015). Considering cold exposure, as previously stated, extreme cold events could determine the worsening of existing cardiorespiratory conditions and increase the spread of infectious disease decreasing school attendance (Aldridge et al., 2016; Free et al., 2010; Jaakkola et al., 2014).

Another pathway that could explain temperature impact on absences is behavioral. For example, school absences might increase as parents could decide to enact protective measures and refrain from sending children to school during hot days to prevent exposure to heat, as shown for exposure to air pollution and attendance of preschool in China (Zhang, 2022). Also, parents could change their time use depending on the weather conditions and increase their children's absences due to additional vacation days (Klein et al., 2022). Studies have found temperature to affect time allocation for outdoor and indoor leisure activities (Chan & Wichman, 2020; Dundas & von Haefen, 2020; Fan et al., 2023; Obradovich & Fowler, 2017) and to reduce time allocated to work (Graff Zivin & Neidell, 2014). Similarly, studies focused on sunlight found an increase in leisure time spent outdoors on sunny days (Laidley & Conley, 2018). Conversely, a study found lower exposure to sunlight to increase time spent reading (Blaabæk, 2020). Nevertheless, absences could also depend on factors beyond parental control or children's agency.

Attendance at school could decrease due to institutional decisions. When environmental conditions are considered, to not be appropriate, school closures could be mandated. For instance, schools often close due to extreme snow days (Goodman, 2014). However, such closures, despite affecting all students, do not appear to have an impact on their overall learning (Goodman, 2014). However, several countries lack specific regulations on the maximum temperature at which children should avoid attending school or at which the work environment is not deemed safe.[2]

Heating and cooling technologies could moderate the impact of temperature on school absences. In fact, the availability of effective heating at home has been found to reduce absences in asthmatic children (Free et al., 2010). Conversely, the presence of air conditioning in schools has been shown to reduce the impact of heat on learning in the USA (Park et al., 2020). Similar results on cooling and heating have been found when investing in other outcomes. For example, lower gas prices have been found to reduce cold-related mortality in the USA (Chirakijja et al.,

[2] A country that set a rule for the maximum temperature in workplace is Germany where it is at 26 °C: https://www.euronews.com/next/2022/08/11/too-hot-to-work-what-labour-laws-in-european-countries-say-about-working-in-a-heatwave.

2019) and higher air conditioning penetration to moderate the impact of heat on mortality in the USA (Barreca et al., 2016). Consequently, access to efficient heating and cooling technologies appears to protect from the negative impacts of heat and cold exposure.

England, climate change, and school absences

In this article, we study the impact of temperature on school absences in England. Compared to other countries in Europe, England is expected to suffer less the consequences of climate change in terms of lives lost (Carleton et al., 2022; Forzieri et al., 2017). Nevertheless, temperatures are expected to increase substantially and have recently been shown to reach unexpectedly high levels (MET Office, 2022) with critical public health impacts (ONS & UKHSA, 2022).

The 2022 heat wave sparked a vivid public discussion on the feasibility of attending school during extremely hot days.[3] Currently, there is no regulation specifying the maximum or minimum temperature at which work is deemed unsafe and for schools' only some guidelines have been issued on precautions to take in the classroom (e.g., keep windows and shutters closed during heat spells).[4]

In England, children attend school until the second half of July when temperatures are particularly high; most school buildings are not equipped with air conditioning, and parents can be sanctioned with a fine starting from £60 for not bringing their kids to school without a valid reason. Non-domestic buildings exhibit the highest demand for cooling technologies. However, educational institutions only account for 4% of this demand, a stark contrast to offices, which constitute 51% (Khosravi et al., 2023). Breaking down the cooling demand within the educational sector reveals that state primary schools make up a mere 0.5%, and state secondary schools contribute 1.5%, with universities consuming the vast majority of the remaining demand (BEIS, 2021a). Conversely, only 3 to 5% of domestic buildings are equipped with cooling technologies (BEIS, 2021a). Importantly, the proportion of non-domestic and domestic buildings is expected to increase in the future to cope with the warmer summers (Khosravi et al., 2023).

Considering heating, this is widespread across households in England, but fuel poverty remains a problem. Approximately 74% of households in England use gas-based heating, 10% use electricity, 10% combine two or more types of heating, and the remainder uses alternative sources (e.g., oil).[5] Despite heating being widespread, several households experience fuel poverty. For example, 11% of households or about 2.5 million households experienced fuel poverty in 2015 (BEIS, 2021b).

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[3] Several newspaper articles raised questions on the feasibility of school attendance during the heatwave: https://www.bbc.com/news/uk-england-berkshire-62156746 or https://www.huffingtonpost.co.uk/entry/how-hot-does-it-have-to-be-to-close-schools-in-the-uk_uk_5b31fb8de4b0b745f1776c44.

[4] On governmental suggestions on the classroom environment: https://educationhub.blog.gov.uk/2022/07/14/advice-for-schools-and-other-education-settings-during-a-heatwave/ and the work environment: https://www.gov.uk/workplace-temperatures

[5] Data is based on the 2021 census and available at https://commonslibrary.parliament.uk/constituency-data-central-heating-2021-census/.

Moreover, there is a large spatial variation in fuel poverty and persistence in these inequalities over time (Bridgen & Robinson, 2023).

Consequently, England offers an interesting context to test how cold and heat affect school absences, as regulations and infrastructures to affront increasing summer temperatures are lacking, unauthorized school absences have a high cost for parents, and energy poverty limits households in coping effectively with cold.

Data, variables, and empirical strategy

Data and variables

In this study, we leverage three main sources of data. First, we use information on school locations and school absences collected by the British Department of Education on students attending primary and secondary schools and aged between 5 and 15 years from the school year 2011–2012 to 2018–2019. Information is publicly accessible through the open data portal of the Ministry. An important feature of this data is that it provides absences by specific categories. For example, besides the overall absences (% of sessions missed from the total number of school days possible), it provides information on absences due to illness, medical appointments, holidays, unauthorized holidays, late arrival (after the morning registration), or religious absences. For the purpose of our study, we focus on overall absences and due to illness, medical appointments, holidays, and unauthorized holidays as these are the most pertinent to our research question. Also, we leverage information on the school characteristics in each school year. More precisely, we collect data on the percentage of pupils by gender, free school meal eligibility, and native British. Some schools do not provide complete information on all of these variables and have missing values for some years making our sample unbalanced. In our estimation sample, we include schools that provide information for at least 5 school years comprising a total of 22,909 schools and totaling 140,396 school years.

Secondly, we collect meteorological information provided by E-OBS at a 0.1° resolution (Cornes et al., 2018). More precisely, we gather daily data on average temperature and precipitation and we capture the daily values of the grid that falls closest to the school position to have one meteorological observation per unit of analysis. As a common practice in the environmental literature, we capture exposure to temperature calculating the number of days during each school year within certain temperature ranges (Hsiang, 2016; Park et al., 2020, 2021). We rely on absolute temperature ranges capturing school days that fall within temperatures < 0 °C, 0 to 3 °C, 3 to 6 °C, 6 to 9 °C, 9 to 12 °C, 12 to 15 °C, 15 to 18 °C, and > 18 °C. To count the number of school days in each school year, we use information on school holidays provided by WorldPop (Lai et al., 2022). Importantly, we exclude weekends and festivities in the count of days to capture only exposure during school days. For precipitation, we constructed bins based on percentiles derived from the school-specific distribution of precipitation. We include in the model the number of days with precipitation between the 75th to the 90th, 90th to 95th, 95th to 99th, and above the 99th percentile. Days below the 75th percentile are set at the comfort zone as they record little to no rain.

Thirdly, we capture yearly average air pollution at the school premises using the same process adopted to collect the meteorological values. We use three measures of air pollution largely used in the public health literature, namely particulate matter 2.5 (PM2.5), particulate matter (PM10), and nitrogen dioxide (NO_2). The measures are provided by the modeled background pollution data produced by DEFRA (Ricardo Energy & Environment, 2021).

Finally, we collect data on fuel poverty at the district level. The indicator measures the proportion of households falling within the classification of low income and high cost indicator (LIHC)[6] and is provided by the Department for Business, Energy and Industrial Strategy.[7] A household is classified as energy poor when they have fuel costs that are above average (the national median level) and were they to spend that amount, they would be left with a residual income below the official poverty line. Based on the LIHC classification, we collected data on the proportion of households falling within such classification from 2011 to 2018 for 324 districts.[8]

Followingly, we present the empirical strategy.

Empirical strategy

We expose our estimation strategy based on an ordinary least squared (OLS) regression in Eq. (1):

$$Yst = TEMPstj + Xst\beta + \delta s + \upsilon t + \gamma cl + \varepsilon st \tag{1}$$

The outcome Y_{st} refers to the % of absences recorded in the school s and school year t. TEMP is the exposure to the sum of days in the abovementioned temperature ranges at each school location and school year. We do not include the temperature range 6 to 9 °C, and we consider it as our temperature of comfort. We introduce a vector X of time-varying control variables at the school level for the percentage of students eligible to free school meals, male students and being native British. Also, we control for environmental factors such as air pollutants NO_2, PM2.5, PM10, and for our precipitation measure. Also, we control for the proportion of households classified as experiencing fuel poverty at the district level. We add year δ_t and school α_s level fixed effects (FE) and add a linear time trend for each county γ_{tl}. Also, we cluster standard errors at the county level. Counties are in total 151 in our analysis and are based on the 2011 geographical boundaries,[9] and in each county, there are

6 Such indicator has been in use between 2011 and 2018 has been updated to the low income low energy efficiency (LILEE) in 2019, that takes into consideration also the property's energy efficiency rating.

7 Data available here: https://www.gov.uk/government/collections/fuel-poverty-statistics.

8 These districts are based on the 2011 definition of English Districts, UAs and London Boroughs: https://borders.ukdataservice.ac.uk/easy_download.html

9 Geographies are available in the UK data portal: https://borders.ukdataservice.ac.uk/easy_download.html, and we used the 2011 county and inner/outer London files. For simplicity, we refer to these units as counties.

Table 1 Summary statistics

	Mean	Standard deviation
Outcomes		
Total absences (%)	4.63	2.11
Illness(%)	2.64	0.87
Authorized holiday (%)	0.18	0.28
Unauthorized holiday (%)	0.33	0.27
Medical appointments (%)	0.30	0.31
Temperature exposures *N*° days		
< 0 °C	3.16	3.46
0 to 3 °C	15.13	9.04
3 to 6 °C	35.81	9.45
6 to 9 °C	49.96	7.79
9 to 12 °C	45.05	8.02
12 to 15 °C	38.29	7.78
15–18 °C	24.73	7.86
> 18 °C	7.13	5.57
Control variables		
% of native British	72.26	27.76
% boys	51.91	9.59
% eligible to free school meal	16.09	12.79
% fuel poverty	10.68	2.56
Rain *N*° days 75th to 90th p.[a]	33.79	7.7
Rain *N*° days 90th to 95th p	11.41	3.97
Rain *N*° days 95th to 99th p	9.07	3.16
Rain *N*° days > 99th p	2.29	1.58
PM2.5 (μg/m^3)	10	1.92
PM10 (μg/m^3)	14.69	2.48
NO_2 (μg/m^3)	16.07	6.85
Observations		
Total schools	22,909	
Total school years	140,396	

In the table, we present summary statistics of our main variables, reporting the mean value and the standard deviation of the values recorded at the schools during our period of analysis 2011/12–2018/19

[a]P. refers to percentile

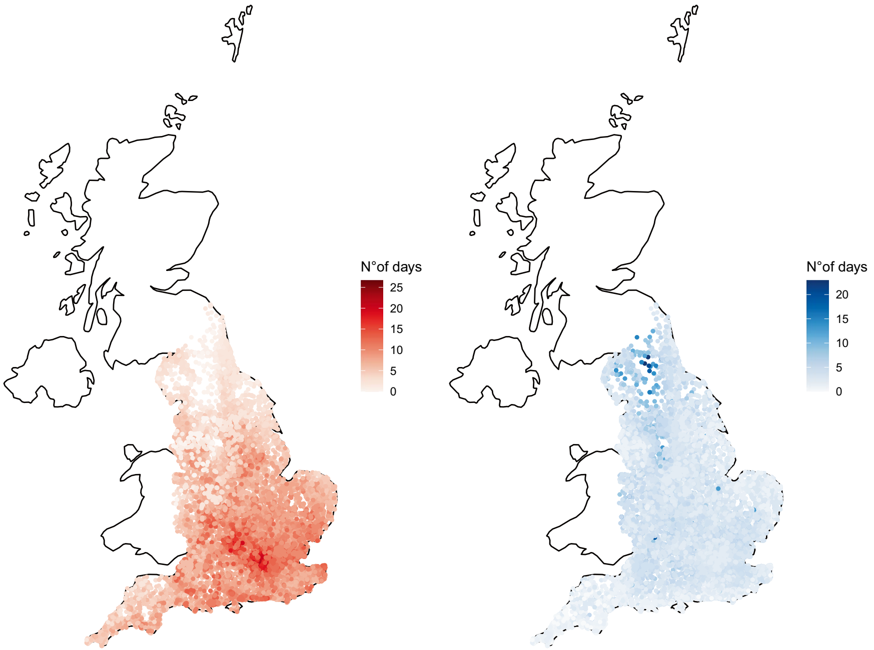
on average 250 schools with a minimum of 22 schools (except for the city of London in which we record only 1 school) and a maximum of 584. Adopting this estimation strategy used in previous similar studies (Park et al., 2021), we account for possible biases and capture the effect of an additional day in a certain temperature bin on school absences relative to a day in the comfort zone that is set at the range 6–9 °C (Hsiang, 2016).

Results

Descriptive results

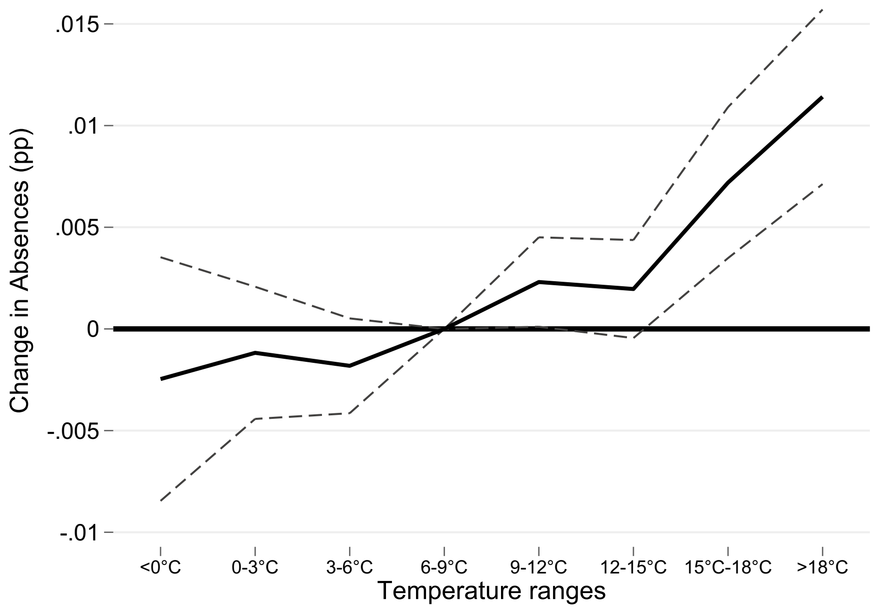
In Table 1, we report the summary statistics for our main variables. We can observe an average of 4.6% of absences during our study period and schools. Focusing on specific types of absences, illnesses account for the largest share of absences with 2.6% of sessions missed from the total number of school sessions. The temperature range 6 to 9 °C is the one with the highest prevalence during the school year, substantiating our choice of this range for the comfort zone. As expected, days with temperature below 0 °C and above 18 °C are the least common in our study period.

We visualize the geographical distribution of cold and hot days in Fig. 1. Here, we show the average number of hot days (average temperature > 18 °C) and cold days (average temperature < 0 °C) at the school premises in the period of analysis. We can observe a higher prevalence of hot days in the southern area, where these could add to more than 25 in a school year. Conversely, there is a higher prevalence of cold days in the northern parts of England, where they can be 20 per school year. Also, we looked at the trend in the average number of hot and cold days in each



Note: in the figure in the left panel are presented the average number of hot days (>18 °C) and in the right panel cold days (<0 °C) in the school-years analyzed in the study period at the school locations.

Fig. 1 Average number of days with hot (> 18 °C) and cold (< 0 °C) temperatures in the study period (2011/2012–2018/2019)



Note: the figure shows the results of exposure to the temperature ranges on overall absences, based on equation (1). Standard errors clustered at the county level. 95% confidence intervals.

Fig. 2 Temperature and school absences

year weighted by the number of pupils in each school. In Supplementary Materials (SM): Fig. A1, we can observe the highest prevalence of cold days in the school year 2012–13. Conversely, the highest number of hot days is recorded in the school year 2016–17 that was concomitant with the 2017 heat spell that happened in June.[10]

Main results

In Fig. 2 (Table A1 in the SM), we expose the effect of temperature on overall school absences based on the OLS regression model described in Eq. (1). We observe warm (15–18 °C) and hot days (> 18 °C) to increase school absences. Moreover, the effect size increases in a linear manner, being highest at the temperature bin > 18 °C. Contrary to our expectations, we do not observe cold days to increase absences. All coefficients for temperature ranges below 6 °C show a negligible effect size and large confidence intervals. In substantive terms, an extra day with temperatures > 18 °C relative to having a day in the comfort zone (6 to 9 °C) determines an increase in absences of 0.01 percentage points. Moreover, the effect of heat could be additive, and 3 extra days with temperature > 18 °C in a school year could determine an increase of approximately 0.03 percentage points. Nevertheless, the existence of additive effects should be interpreted cautiously as there could be threshold effects by which additional hot days could

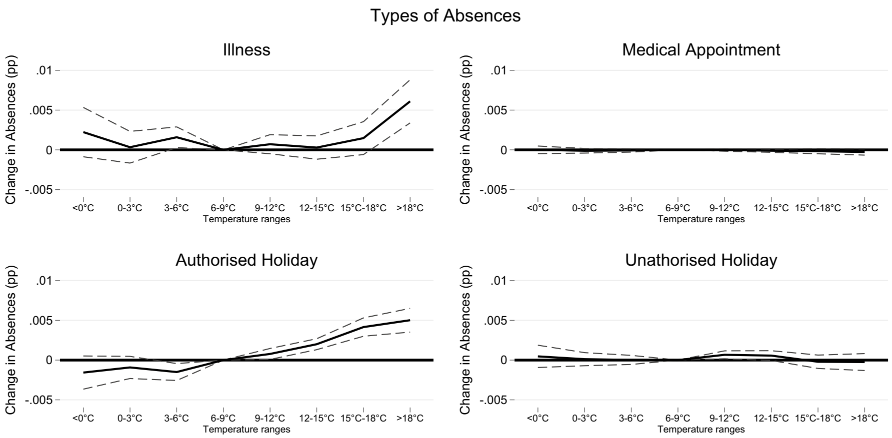
[10] More information on the summer of 2017: https://www.theguardian.com/uk-news/2017/jun/21/uk-heatwave-to-set-40-year-temperature-record

increase their effect size or decrease depending on the adaptive measures adopted by the population. Considering our control variables, we observe an increase in absences with a higher percentage of male students, pupils eligible to free meals at school, and days with heavy rain (precipitation at the 99th percentile).

In Fig. 3 (Table A1 in the SM), we analyze how different types of absences (illnesses, medical appointments, authorized holidays, and unauthorized holidays) are affected by extreme temperatures. On one hand, we observe no impact of temperature on medical appointments and unauthorized holidays. On the other hand, warm and hot days show to affect authorized holidays and illnesses. The effect of heat on holidays shows a similar pattern to the effect observed in Fig. 2, a linearly increasing impact on absences that is highest for the temperature bin > 18 °C. For illnesses, we observe a substantial impact only for the temperature range > 18 °C. Comparing the effect sizes, we observe one extra day with temperature > 18 °C to increase absences due to authorized holidays by 0.005 percentage points. Conversely, the effect of days > 18 °C on illness-related absences is of 0.006 percentage points and slightly larger than the effect found for authorized holidays. As we observed in Fig. 2, cold exposure fails to substantively affect school absences also in Fig. 3. However, we notice a small increase in illness-related absences with exposure to temperature 3 to 6 °C of 0.002 percentage points and a similar effect size for days < 0 °C, but for this range, results are not statistically significant at the 95% confidence level.

Heterogeneity: fuel poverty and climatic regions

Heterogeneous impacts of temperature could be expected based on neighborhood characteristics. Fuel poverty could limit the ability of households to use heating during particularly cold months increasing the likelihood of illnesses and school



Note: the figure shows the results of exposure to the temperature ranges on absences due to Illnesses, Medical Appointment, Authorized Holiday and Unauthorized holidays based on equation (1). Standard errors clustered at the county level. 95% confidence intervals.

Fig. 3 Temperature impact by types of absences

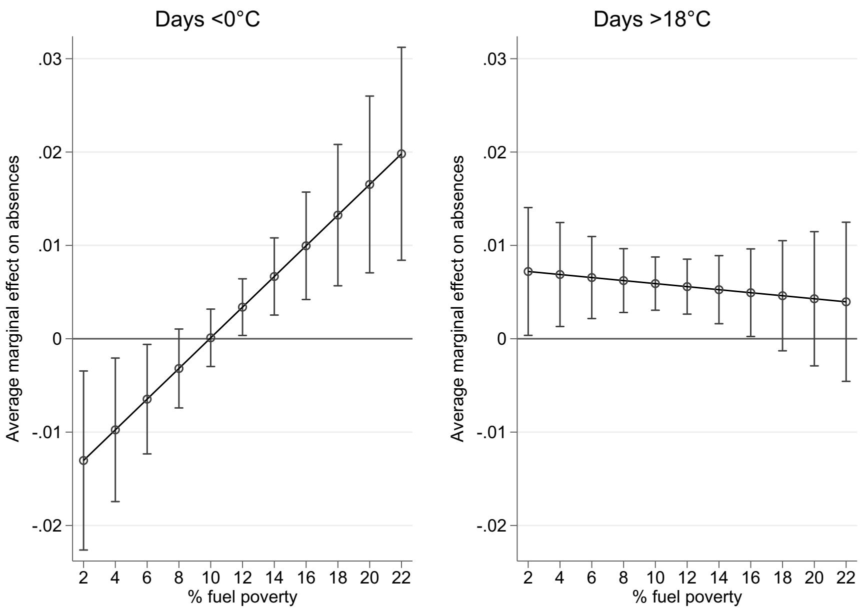
absences. We test how fuel poverty moderates the impact of temperature on school absences based on Eq. (2):

$$Yst = TEMPstj \times FUELb + Xst\beta + \delta s + \upsilon t + \gamma cl + \varepsilon st \quad (2)$$

Compared to Eq. (1), we add an interaction between the temperature bins and $FUEL_b$ representing the average proportion of households experiencing fuel poverty across the study period in district *b*. We report results of such interactions in Table A2 in the SM using as outcomes all types of absences. We observe substantive results for such interactions only for exposure to cold (< 0 °C) and illness-related absences as the outcome.

In Fig. 4, we plot the results of the interaction between cold (< 0 °C) and hot days (> 18 °C) and fuel poverty and illness-related absences as the outcome. We observe higher levels of fuel poverty to be associated with a higher impact of cold days on illness-related absences. Conversely, the impact of hot days does not change depending on the percentage of fuel-poor households in a district.

Variation in the vulnerability to heat and cold could be expected based on the climatic regions. Existing epidemiological studies focused on temperature-related mortality showed a larger vulnerability to heat in cold regions and heat in warmer regions (Barreca et al., 2016; Conte Keivabu, 2022; Medina-Ramón & Schwartz, 2007). We tested an interaction between the temperature bins and the



Note: the figure shows the results of an interaction between the temperature ranges and % fuel poverty on illness related absences based on equation (2). In the left panel we show results for the interaction with cold (<0°C) and on the right panel the interaction with heat(>18°C). Standard errors clustered at the county level. 95% confidence intervals.

Fig. 4 Impact of cold (< 0 °C) and heat (> 18 °C) on illness-related school absences by fuel poverty local temperature, captured as the 50th percentile in the temperature distribution of each school over the period of analysis. The 50th percentile ranges from 6.55 °C in the Northern regions to 11.56 °C in the Southern regions. We report results in Table A3 in the SM. Here, we do not observe any substantive results for the interaction on overall and illness-related absences. However, we observe a positive interaction between hot days (> 18 °C) and the 50th percentile for authorized holidays and a negative interaction between hot days (> 18 °C) and the 50th percentile for unauthorized holidays. The results could suggest a higher likelihood of having absences authorized by school authorities in areas that are more used to higher temperatures compared to colder locations. Nevertheless, we are not able to test for this explanation.

Robustness checks

Our results were further validated through additional sensitivity analysis. We employed an alternative approach to measure temperature exposure, using relative temperature instead of absolute values. This method, as recent research suggests, allows to capture the relationship between temperature and the outcome of interest across various locations accommodating for different levels of adaptation to extreme temperatures (Masiero et al., 2022). Accordingly, we calculated percentiles of the local temperature at each school location during the study period and show the values in SM: Figure A2. For example, the 99th percentile ranges from 16.7 °C in the Northern areas of England to 23.6 °C in some areas in the South. Conversely, the 1st percentile ranges from − 4.7 to 2.1 °C with a similar spatial distribution observed for the 99th percentile. Followingly, we used the percentiles to count the number of days < 1st percentile, from the 1st to 5th, 5th to 10th, 10th to 25th, 25th to 75th (comfort zone), 75th to 90th, 90th to 95th, 95th to 99th, and > 99th. We run the analysis of Fig. 2 using the temperature percentiles, and found very similar results (only hot days affecting absences) and similar effect sizes (SM: Figure A3). Consequently, our results appear to be robust to different specifications of temperature exposures.

We run a placebo test estimating the effect of lead values of temperature measured 1 year after. Using the placebo test, we assess whether the temperature effects can be observed in a period when we know the exposure did not take place. If such effects are observed, this would not corroborate the causal relationship between the exposure (temperature) and the outcome (absences), indicating that the observed effects in the treatment period could be due to confounding variables or chance. We report the results of the placebo test in SM: Figure A4 and find no effects, validating our main results.

Finally, we tested different model specifications and provide results of analysis without frequency weights for the number of students in the school (SM: Fig. A5) and clustering standard errors at the school level (SM: Fig. A6). Both analyses show to replicate the main results.

Discussion and conclusion

In this article, we have analyzed how temperature affects absences for children in more than 22,000 schools in England from the school year 2011/2012 to the school year 2018/2019. We report three main findings. First, we observed warm days and in particular hot days (> 18 °C) to increase school absences in children and contrary to our expectations, we did not observe cold to increase absences. Secondly, we considered sub-categories of absences and observed heat to increase illness-related absences and authorized holidays. Thirdly, we found cold exposure to increase absences only in neighborhoods experiencing fuel poverty. Consequently, we report for the first-time outdoor temperature to increase absences in children and provide evidence that illnesses and holidays are the primary factors driving this increase for heat exposure and that fuel poverty stratifies the impact of cold on illness-related absences.

In line with the existing literature on adult workers (Somanathan et al., 2021), we show heat to increase children's school absences. Similarly, the increase in illness-related absences corroborates existing epidemiological work finding an increase in children's hospitalization with exposure to hot days (Bernstein et al., 2022; Xu et al., 2014). Also, in line with existing evidence on the behavioral shifts determined by heat, we observe an increase in authorized holidays with exposure to hot days (Chan & Wichman, 2020). In fact, previous studies have shown a decrease in time dedicated to work during hot days (Graff Zivin & Neidell, 2014) and weather conditions to alter the decision to spend time in parks (Fan et al., 2023) or at the beach (Toubes et al., 2020). Interestingly, we did not observe any substantive effect of cold exposure on school attendance. However, we observed an increase in illness-related absences in neighborhoods with higher levels of fuel poverty. The findings corroborate existing evidence showing the beneficial role of heating in limiting absences during winter (Free et al., 2010) and in limiting the negative impact of cold on population outcomes (Chirakijja et al., 2019).

Our study has three main limitations on which basis we provide recommendations on the gaps that future research could tackle. First, our study on England might not be generalizable to other contexts. For example, the hottest temperature range for mean temperature is (> 18 °C) in our study, but an increase in absences could happen at different thresholds in other country contexts. Similarly, estimating the impact of heat on absences in a context where schools largely adopt air conditioning (e.g., USA) allows to estimate how such technology could reduce heat-related absences. Secondly, we are not able to provide information on which location of exposure (home, classroom, or outdoors) matters for the increase in school absences. Consequently, future studies could leverage information on the temperature in the classroom to disentangle the importance of exposure to temperature in the school environment compared to outdoors or home for school absences. Such studies are particularly important to advise policies to reduce temperature-related absences. Thirdly, we suggest absences to be a possible mechanism affecting learning in students, but the data does not allow us to directly test such link. Future studies could use individual-level student data with information on school absences and test scores to inquire how temperature affected their school attendance and how as a consequence this affected their learning trajectory during the school year and their test scores at the end of the school year.

Climate change, the increase in global temperatures, and energy poverty determine several risks for children's learning and human capital accumulation. Importantly, the educational environment of children should receive further attention to limit the impact of heat and cold on the skill acquisition of the future generations. The formulation of climate adaptation policies, aimed at maintaining thermal comfort in classrooms and creating optimal learning environments for children, will become increasingly urgent in the near future. Similarly, the occurrence of the energy crisis, as in recent years, could pose real threats for the well-being of children. Consequently, we conclude stressing the importance of additional studies inquiring the impact of temperature on children's schooling to inform adaptation policies to counteract such threats.

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Data availability Data and code for replication are available at the following repository: https://osf.io/c3j2m/.

Declarations

Competing interests The author declares no competing interests.

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