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Health implications of housing retrofits: Evidence from a population-wide weatherization program[☆]

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ABSTRACT

This study provides the first population-representative quasi-experimental estimates on the impact of housing upgrades on occupant health. We analyze the exceptional period of renovations in East Germany following the German reunification during the 1990s. Triggered by one of the largest governmental loan programs in history, 3.6 million dwellings were renovated, focussing on upgrades to the building insulation, windows and heating systems. Using rich survey data based on the Socio-Economic Panel (SOEP) as well as administrative records of hospital admissions in Germany, we consistently show that housing weatherization upgrades sustainably reduce the demand for health care among the elderly sample of the population.

1. Introduction

The reduction of greenhouse emissions in the building stock is being set as a key policy target across most major global economies (IEA, 2019; EC, 2020). Currently, governments worldwide are actively rolling out ambitious energy efficiency incentive programs aimed at enhancing the insulation and heating systems of their housing infrastructure. Despite these efforts, there is a shortage of evidence evaluating how households are affected by such retrofit initiatives, beyond their immediate energy-saving implications (Gillingham et al., 2018).

Upgrading housing infrastructure via upgrades in building insulation or heating systems has the potential to reduce the exposure of occupants to environmental threats associated with increased mortality and morbidity. In particular, building insulation and well-functioning heating and cooling equipment may limit household exposure to extremely cold or hot temperatures, which have been associated with increased risk of cardiovascular disease and heat stroke, respectively (for a review, see Gasparrini et al., 2015). This is exacerbated by the ongoing energy poverty crisis, which constrains the ability of households to defend themselves against outdoor temperatures. In the US and EU, about 8% of households reported being unable to keep their homes adequately warm in 2020, reaching 17% among the population in risk of poverty (AHS, 2021; Eurostat, 2021). Weatherization programs targeted at improving buildings' insulation and heating systems can, therefore, have large impacts on (vulnerable) populations by mitigating thermal stress, outdoor noise, or outdoor air pollution.[1] However, there is a dearth of reliable estimates on the health implications of

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weatherization programs on population health, hindering the addition of these (non-)monetary benefits to cost-benefit calculations by public authorities in their planning of ongoing energy retrofit programs. Existing evaluations of weatherization programs focus on impacts for household energy savings (e.g., Fowlie et al., 2018), omitting individual well-being and health from the analysis.

This study provides, for the first time, quasi-experimental evidence on the health consequences of weatherization programs using the case of the German reunification in the 1990s, an event that triggered the largest renovation wave in the modern history of developed economies not preceded by a war or natural disaster.[2] At the time of the reunification, the conditions of the Eastern German housing portfolio were severely deficient, lacking basic amenities such as modern heating systems and/or building insulation. In the 1990s, the reunified German government devoted significant financial resources to bring the housing portfolio in East Germany to western standards, providing subsidized loans and tax credits to the real estate industry to modernize existing dwellings and create new ones. The main program, the *KfW-Wohnraum-Modernisierungsprogram* (KfW weatherization program hereafter), allocated a total of 40 €billion over a period of 7 years to renovate 3.6 million dwellings in East Germany (about 50% of existing dwellings). The clear majority of renovations financed by the KfW program captured weatherization measures, with 88% of all applications to the KfW program and 83% of its total budget spent on renovations of the heating systems and building envelope (i.e. wall and roof insulation). Therefore, the core focus of the KfW weatherization program in the 90s in East Germany is very similar to ongoing initiatives in Europe and the US. For instance, the U.S. Department of Energy offers a *Weatherization Assistance Program* or the European Commission provides excessive funding to national states for energy efficiency retrofit investments in residential housing as part of the *Renovation wave*. Such initiatives are triggered by the need to reduce greenhouse gas emissions, but mainly focus on weatherization of buildings, making it comparable to the KfW program.

We exploit this exceptional period of renovations and the staggered roll-out of the KfW weatherization program to generate exogenous variation in the probability of receiving a renovation to estimate the causal impact of improved housing quality on occupants' health. We implement two separate empirical approaches using both survey and administrative data and both suggest that the renovation wave triggered by the KfW weatherization program resulted in an improvement in population health.

The first part of our analysis relies on individual data using the *German Socio-Economic Panel* (SOEP), which is the largest population-representative household panel in Germany. We restrict the analysis to tenants in East Germany in the period immediately after reunification (1992–2002), when the bulk of renovations subsidized by the German government took place. Given these sample restrictions, and conditional on individual fixed effects, we argue that the remaining variation in the probability of receiving a renovation as a tenant is exogenous given the large renovation wave during this period. We show that the roll-out of the renovation program strongly predicts the individual probability of reporting a renovation and that the occurrence of a renovation significantly improved housing conditions. Most importantly, we find that experiencing a renovation reduces the likelihood of hospital visits among older individuals in the sample ($\geq$ 45 years). The number of hospital visits dropped by 0.5 (corresponding to 0.1 of a standard deviation) in the years following the renovation of the household. Results from an event-study design show that the effect remains stable for years after the renovation works were completed in the dwelling. A series of tests confirms the strong robustness of our estimates, including the implementation of the estimator proposed by Callaway and SantAnna (2021) accounting for the staggered adoption of the treatment in our sample.

The second part of the empirical analysis relies on the *German Hospital Statistic* (GHS) containing the universe of hospital admissions in Germany. We replicate the results based on the self-reported outcomes from the SOEP and explore the underlying mechanisms behind the reduction of hospital visits. The microdata from hospital statistics provides the exact date and diagnosis for each record, together with the county of residence, age and gender of the patient. Applying a fixed effect strategy, we exploit variation in the KfW weatherization program within a county over time to predict the number of hospital admissions. In addition, we control for a rich set of time-varying regional indicators regarding economic activity, demographic change and other local indicators (e.g., annual changes in available hospital beds in each county) to show the lack of the co-existence of other public investment programs confounded with the renovation wave.

In our preferred specification, we find that the roll-out of the KfW weatherization program in the 1990s significantly reduced the number of older patients (45 years or older) with cardiovascular problems. In particular, a raise in subsidized loan take-up by 100 Euro per inhabitant (corresponding to about one standard deviation in our sample) reduces admissions to the hospital of patients 45–64 years old (65 years and older) with circulatory problems by 2.6% (1.5%). Based on a back-on-the-envelope calculation, we quantify the total medical cost savings due to reduced admissions related to circulatory problems because of the introduction of the program at about 636 million Euro for the adult population within our observation period 1995–2002. To address concerns about confounding factors invalidating our results, we (i) run placebo tests showing no impact of the weatherization program on unrelated diagnoses, and (ii) link outdoor temperatures to show that strongest impacts of the renovation program on hospital admissions follow extreme cold or hot days. This finding is in line with the health science literature documenting that exposure to cold and warm temperatures can be expected to impair individuals' cardiovascular health (Nayha, 2002), and that the improvement in the weatherization of buildings should lead to more stable indoor climate, ultimately affecting occupants' health. The result of placebo tests as well as the effect heterogeneity with respect to outdoor temperature strongly support the assumption that the reduction in hospital admissions with cardiovascular health problems is indeed due to the weatherization program and the associated

[1] Weatherization is defined as the practice of "protecting a building and its interior from the elements, particularly from sunlight, precipitation, and wind, and of modifying a building to reduce energy consumption and optimize energy efficiency".

[2] Previous evidence looking at the impact of housing conditions on human health (e.g. Palacios et al., 2021) are rather descriptive relying on changes in housing conditions driven by owner decisions, and therefore not exogenous to homeowners.

improvements in building quality yielding a better protection against outdoor hazards, and most likely not due to confounding factors. Finally, we stress that the combination of both data sources (SOEP and GHS) is a clear strength of our analysis, allowing for cross-validation of results and an in-depth analysis of dynamics over time as well as underlying effect mechanisms. The evidence based on both data sources reveals a very consistent and clear pattern that housing upgrades sustainably reduce the demand for health care among the elderly sample of the population.

This article makes several contributions to the literature. Most importantly, it is the first study providing evidence of the returns for healthcare systems from residential weatherization programs. An increasing body of quasi-experimental studies has documented significant societal costs associated with outdoor hazards in the form of mortality rates, demand for healthcare services, and lower life expectancy and happiness (for a review of the literature, see Zivin and Neidell, 2013; Deschenes, 2014).[3] More recently, a set of studies sought to explore the effectiveness of different adaptation strategies in reducing the damage of extreme temperatures on human health. Changes in housing infrastructure can reduce or eliminate the exposure of households to harmful outdoor temperatures. Increasing the energy efficiency of buildings is particularly important, given the recent raise in energy prices, making it difficult for disadvantaged households to keep their homes adequately warm. While the average individual in western societies spends 90% of the time indoors, most of it at home, surprisingly little is known about how indoor environmental conditions shape human health and well-being (Klepeis et al., 2001).[4]

The literature investigating the impacts of suboptimal thermal conditions in houses on health is still scarce, and several methodological issues challenge its external validity. Most of the current evidence relies on cross-sectional studies, randomized control trials in small populations with existing health problems (e.g., asthmatics), or laboratory experiments (for a recent survey of the literature, see World Health Organization, 2018). The extrapolation of results from small samples in targeted populations is challenged by the heterogeneity in dose–response functions and by the presence of numerous confounding variables that directly affect the health status of individuals and the chances of being exposed to suboptimal thermal conditions (Banzhaf et al., 2019). This is the first study that explores population-wide weatherization programs whose primary goal is to upgrade the thermal performance of dwellings.

This paper also contributes to the literature exploring the role of general housing infrastructure on the health and well-being indicators of occupants. Recent quasi-experimental research in large samples focusing on primitive housing in developing countries shows a significant impact of improvements in the indoor environment (e.g., flooring or electrification) on occupant health and quality of life (Cattaneo et al., 2009; Galiani et al., 2017; Barron and Torero, 2017). These studies rely on existing government renovation programs to explore how upgrades in housing conditions translate into better health and cognitive outcomes for the occupants. Although these studies provide robust evidence of the beneficial effects of house upgrades on human health and well-being, their settings are hardly applicable to the general building stock in most developed countries. In contrast, our study analyzes a population-wide renovation program in East Germany which was, prior to reunification, the most prosperous and technologically advanced country in the "Soviet Bloc" with well-developed health institutions similar to other developed countries (Baylis, 1986; Becker et al., 2020).

This paper is organized as follows: Section 2 describes the housing conditions in East Germany at the time of reunification and explains the renovation programs in the 1990s and also documents its impact on a wide range of outcomes. Section 3 presents the data and methodology used for the empirical analysis, describes the estimation sample, and defines the variables of interest. Section 4 presents the results, and Section 5 concludes.

2. The East German housing portfolio around the reunification

2.1. Initial housing conditions

Over the four decades that the two sides of Germany were divided, the two subregions diverged substantially in terms of economic activities, institutions, infrastructure among other macro economic indicators. On November 9, 1989, the Berlin wall came down, and on October 3, 1990, Germany was reunited. In the following decade, East Germany received substantial reforms and financial support to facilitate the transition and convergence to the West German part of the country. Although East Germany still underperforms the West German economy (GDP, worker productivity, unemployment etc.) nowadays at the end of the 20th century, infrastructure and living conditions are almost equalized compared to West Germany (Sinn, 2000).

Focusing on the housing portfolio, the differences between East and West Germany were substantial at the time of the reunification. The closed planned economy in East Germany highly restricted access to building materials and resources. In addition, the capacity to maintain older buildings was limited, because the focus was on the construction of new industrialized building blocks to satisfy the high demand for dwellings in the GDR. At the time of the reunification, fifty-two percent of the dwellings were constructed before 1945 (vs. 29% in West Germany), 40% of apartment buildings were massively damaged, and 11% were

[3] Quasi-experimental studies provide evidence of peaks in daily mortality associated with short-term exposure to extreme temperatures. Using high-frequency data from the US, Deschênes and Greenstone (2011) finds an extra day with a mean temperature above 32 C°(below −7 C°) degrees leads to a 0.11% (0.07%) increase in the annual age-adjusted mortality rate, relative to days with mean temperatures in the 10–15 C° range. Given the lower mobility and greater vulnerability of their bodies, the effects are more pronounced among infants and the elderly.

[4] Several recent studies have provided evidence on the role of air conditioning in reducing the damage of heat waves on human health and performance. As a relevant example, Barreca et al. (2016) showed that the spread of air conditioning across US residences was associated with a remarkable decline in the number of deaths linked to extreme temperatures over the course of the 20th century, thereby helping occupants reduce their exposure.

Table 1
Home amenities in German dwellings at reunification in 1990.
Source: GdW Gesamtverband der deutschen Wohnungswirtschaft.

	West Germany	East Germany
Central heating system	75	48
Centralized warm water system	55	36
Bathtub or shower	97	74
Indoor toilet	98	79

Note: Numbers are in percentages and based on a survey on housing associations and municipal housing companies in 1990 (figures for West Germany refer to 1987). They operate 3.4 million dwellings which corresponds to ~74% of all rented dwellings in East Germany at this time.

uninhabitable. As a result, the *German Federal Ministry of Transport, Building and Housing* describes the East German housing portfolio at the time of reunification as the oldest real estate substance within the developed, industrialized countries (Federal Ministry of Transport, Building and Housing, 2000).

Table 1 provides a distribution of home amenities between East and West Germany at the time of the reunification. The numbers are based on a survey by the *German Federal Association of Housing Associations and Real Estate Companies* (GdW, *Bundesverband deutscher Wohnungs- und Immobilienunternehmen*) on housing associations and municipal housing companies in 1990 (figures for West Germany refer to 1987).[5] It clearly documents the significant disparity between the East and the West German housing portfolio. Only 48% of the dwellings had access to a centralized heating system, compared to 75% in the West. Furthermore, 26% (21%) of the dwellings did not even have a bathtub or shower (indoor toilet), corresponding to about 800,000 (600,000) dwellings. This implies sanitary issues and increases exposure time of occupants to outdoor conditions. The GdW (1990) concludes the equipment of East German dwellings lags about 20 years behind the West German standard.

2.2. Governmental support

A major policy goal right after the reunification focussed on equalizing living conditions in East and West Germany (Sinn, 2000).[6] The German government implemented one of the largest loan programs in history, providing significant financial means to encourage building landlords to invest in their properties to increase the living comfort. The program consisted of reduced interest payments and eased collateral conditions for public housing associations. The program was implemented by the German public bank *(KfW)* (*Kreditanstalt für Wiederaufbau*). Accordingly, the program was commonly called the KfW Modernization Program (*KfW-Wohnraum-Modernisierungsprogram*), and its main aim was to incentivize the East German real estate industry to modernize their properties and hence equalize living conditions in West and East Germany. Table A.1 in the Appendix provides an overview of the key characteristics of the program.

The subsidy program consisted of the provision of loans with a reduced interest rate of up to 3 percentage points below the capital market interest rate and was fixed for 10 years. The maximum amount was 400 Euro/m^2 with a maximum maturity of 25 years. Private landlords had to provide standard collateral in order to get the subsidized loan, public landlords such as municipalities and larger housing associations owning about 60% of the residential properties in 1990 had no collateral requirements. All landlords (private and public) modernizing pre-defined parts of their dwellings as well as creating new dwellings were eligible for funding. As shown in Table A.1, the targeted measures for renovating existing dwellings are very broad covering the building envelope (doors, windows, insulation, roof), energy efficiency (heating, warm water), sanitary installation and other indoor and outdoor facilities. However, the overwhelming majority of the renovations financed by the program were weatherization measures, with 88% of all applications to the KfW program and 83% of its total budget spent on renovations of the heating systems and building envelope of the property (Reich, 2000). Therefore, this program can serve as a adequate case study to learn about health implications of ongoing weatherization programs in Western countries (e.g. the *U.S. Weatherization Assistance Program* or the European *Renovation Wave*). While the scope of the KfW weatherization program was broader than current weatherization programs, the core of the program was targeted at upgrading the building envelop (i.e., roof and wall insulation) and heating systems, improving protection against outdoor environmental hazards.

All loan applications fulfilling the eligibility criteria received funding. Therefore, the German government gradually increased the budget over time to satisfy the demand, resulting in a total budget of 79 billion DM (corresponds to 40 billion Euro) between October 1990 and January 2000. The majority of the budget (93%) was used for renovations of existing buildings, whereas only

[5] Housing associations and municipal housing companies owned 3.4 million dwellings, which corresponds to ~50% of all dwellings in East Germany at this time. The numbers are likely to represent an overestimation of the actual housing conditions given that housing associations and municipal housing companies predominately own younger and modernized buildings.

[6] Among other reasons, a vast convergence of living conditions (in terms of wage level, housing, etc.) was supposed to reduce the East-West migration. For instance, between January 1989 and January 1992, about 870,000 East Germans migrated to West Germany, which corresponds to 5% of the entire East German population (Burda, 1993). After 1992, the internal migration decreased and stabilized at around 140,000 to 180,000 per year.

7% was used to build new dwellings (see Reich, 2000). Renovations funded by the KfW weatherization program comprised an investment of 250 Euro/m^2 on average, while the subsidized loan covered 160 Euro/m^2 (Reich, 2000). The remaining investments were covered by landlords' capital. In total, 3.6 million dwellings have been renovated based on the program, which corresponds to about 52% of all existing dwellings in East Germany at the time of the reunification. In Section 4.1, we empirically show the impact of massive governmental support in the 90s strongly influenced local renovation rates in Eastern Germany.

In addition to this main program, the German government implemented other complementary policies to stimulate the modernization of housing in East Germany: (i) Federal states set up specific programs focusing on heritage-protected buildings, in particular in city centres. (ii) In addition to the loan programs, the federal government introduced special tax-amortization rules for the modernization and creation of dwellings. It allowed landlords to deduct 50% of the expenses from taxation within the first five years. It should be emphasized that the KfW weatherization program was the main, leading financing tool and these other programs are accompanying and even building upon the KfW program.[7] Between 1990 and 1999, a total amount of 124 bn Euro were invested in renovations of residential buildings. Half of such investments (113 bn Euro) were fully or partly subsidized by the KfW program (Reich, 2000). This illustrates the financial and institutional significance of the KfW weatherization program. Lastly, note that next to the monetary incentives, the reunification abandoned the restricted access to resources (e.g., building material) due to abolishment of the closed planned economy system in the former GDR.

2.3. Expected health impacts

Given the core part of the renovation program focuses on weatherization measures, this section discusses expected health consequences for occupants. The improvement in the building envelop and heating systems leads to improved thermal comfort for occupants and hence reduces exposure to cold and heat. Therefore, the renovations can be expected to reduce cardiovascular stress. Exposure to cold and heat triggers the thermoregulatory system maintaining a steady internal body temperature, changing the heart rate, blood pressure and blood components which could induce hypertension, heart attacks and atherosclerosis (Gasparrini et al., 2015; Barreca et al., 2016; Fan et al., 2023). Therefore, a more stable indoor climate can be expected to reduce diseases of the cardiovascular system, in particular for more vulnerable groups with higher risk factors including age, obesity, diabetes and unhealthy life styles. The reduction of other environmental stressors could reinforce the thermal comfort channel. For instance, the renovations reduce noise pollution (Toma et al., 2021), protect against exposure to outdoor air pollution due to reduced air infiltration rates (Lamb et al., 1985) and possibly improve occupants' well-being (Shortt and Rugkåsa, 2007).

Furthermore, the targeted renovations can be expected to affect the respiratory health with ambiguous outcomes. Living in cold homes accumulating damp and mold has been associated with respiratory tract infections, including colds and more chronic diseases such as wheezing and asthma (Fyfe et al., 2022; Maidment et al., 2014). In this regard, the weatherization program improves indoor climate resulting in reduced respiratory diseases. But at the same time, it can be expected that insulating and sealing homes increases airtightness and reduces ventilation. This will raise relative humidity and increase levels of air pollutants in dwellings causing respiratory problems and allergic symptoms including asthma (Ortiz et al., 2020; Maidment et al., 2014).

To sum up, the renovations are expected to particularly affect the cardiovascular health of (vulnerable) occupants due to creating a more stable indoor climate and reducing the impact of other environmental stressors such as outdoor noise and air pollution. In addition, we can hypothesize an effect on respiratory health, which is however difficult to predict ex ante because of the existence of opposing effects.

3. Data

The empirical analysis of the health consequences of the KfW weatherization program relies on two main data sources: (i) The *German Socio-Economic Panel* (SOEP, version 36) which is the largest population representative panel study in Germany, and (ii) the *German Hospital Statistic*, which is an administrative register containing the universe of hospital admissions in Germany. These data are combined with information on the roll-out of the KfW weatherization program, aggregate statistics on regional and economic indicators as well as local weather conditions. In this section, we describe the different data sources, and define and describe the estimation samples.

3.1. The German socio-economic panel

The SOEP is a yearly population representative longitudinal study of about 11,000 households and 30,000 individuals in Germany (Goebel et al., 2019). It contains detailed information on house conditions and renovations executed in the house over the year. The SOEP also includes extensive information about respondents' health status, healthcare utilization, migration and socioeconomic characteristics. The SOEP started interviewing households in 1984 in West Germany, and expanded to households in East Germany in 1990.

For the empirical analysis, we focus on East Germany and consider the period right after the reunification,1992–2002, when 98% of the dwelling renovations part of the program were executed (see Section 2). We apply the following restrictions to ensure

[7] The state-specific subsidy programs focusing on heritage-protected buildings actually require that the applicant already uses the KfW program, to ensure that federal resources are used first. The additional program was implemented in order to capture additional investments beyond the maximum amount of 400 Euro/m2. The special tax-amortization rules also apply for renovations based on the KfW program.

Table 2
Descriptive statistics treated and non-treated households in the first year of the sample (1992).

	Non renovated $N = 158$	Renovated $N = 262$	Diff-means	t-stat
Individual and household characteristics				
Years education	12.545	12.223	0.321	−1.255
Labor Income	761.432	766.673	−5.241	(−0.185)
Household Income	1481.07	1433.676	47.394	−0.829
Age of respondent	40.411	40.912	−0.501	(−0.456)
Female (1 = Yes)	0.494	0.496	−0.003	(−0.050)
Working(1 = Yes)	0.835	0.817	0.019	−0.49
Dwelling Characteristics				
Construction year	1959.639	1956.871	2.769	−0.97
Rent (in €)	133.312	122.011	11.300*	−2.455
Ratio household members per room	0.951	0.998	−0.047	(−1.393)
Health Outcomes				
Days sick leave	6.452	6.069	0.384	−0.237
Bad/Poor health (1 = Yes)	0.057	0.084	−0.027	(−1.052)
Number of hospital visits	0.671	1.168	−0.497	(−1.265)

Note: The table shows descriptive statistics for treated and non-treated individuals who are observable at the beginning of our observation window in 1992. t-stat shows the *t*-statistic of a simple t-test of equal means in both samples. */**/*** indicate statistically significance at the 10%/5%/1%-level.

the stability of our sample, and that the timing and decision of renovation was exogenous to them: (1) We restrict the sample to individuals being part of the initial sample of the SOEP in East Germany in 1990, and exclude individuals joining the SOEP in 1998 as part of a refreshment sample. Most of the renovations were already executed in 1998, and we would not be able to know whether individuals joining the SOEP in 1998 were treated or untreated. (2) We focus on tenants, since for tenants the timing and type of renovation is plausibly exogenous in this time period, given their initial choice of residence. In East Germany, the renovations in those dwellings are mainly decided by large housing corporations that own and operate large building portfolios.

We take advantage of the comprehensive information in the SOEP to identify the individuals that have experienced a renovation that is part of the KfW weatherization program. Every year, individuals in our sample have to report whether their dwelling received a major renovation, and describe the renovation activities that took place in their homes based on five categories: (1) kitchen, (2) bathroom, (3) heating, (4) windows and (5) other major renovations. In addition, tenants report whether the renovation was financed by themselves or by the landlord. Based on this information, we build a treatment indicator capturing the targeted renovations in the KfW weatherization program, i.e., heating systems and building envelope of the property. While we directly observe renovations of the heating system and replacement of windows, wall and roof insulations are not directly recorded but included in the residual category "other major renovations". To restrict this category to renovations of the building envelope, we focus on major renovations paid by the property owner and hence exclude other renovations of the interior design of dwellings which are paid for by occupants (similar to kitchen renovations), as specified by German tenant agreements. Consequently, we define a yearly binary treatment variable that takes the value of 1 if respondents report category (3) heating, (4) windows or (5) other major renovations, and also report that those renovations were paid for by the landlord, and zero otherwise. The average treatment probability is 10.2% in our estimation sample, starting with 7.5% in 1992 and peaking at 13.5% in 1997. Furthermore, respondents have to evaluate the conditions of the maintenance of their dwellings as (1) in good condition, (2) in need of partial renovation, (3) in need of full renovation, or (4) ready for demolition. This information allows the construction of a binary outcome variable taking the value of 1 if the respondent reports that her house is in need of partial or full renovation, and zero otherwise. This information is used to validate that the renovation did indeed improve the living conditions of households that were part of the program.

With respect to individual health, the SOEP includes a rich set of questions on respondents' health status and their demand for health care. We focus on the three most objective measures to assess individuals' health: (1) Every year respondents are asked to report the number of visits to the general practitioner during the last three months before the date of the interview. (2) Respondents were asked about the number of hospital overnight stays during the entire last year before the interview. (3) Finally, we build a continuous outcome variable capturing the number of days on sick leave in the year before the interview. Note that this variable is only available for individuals that are employed at the time of the interview.

In addition, the SOEP has rich information on the socio-demographic profile of households, together with continuous monitoring of their labor market status, income and place of residence. Table 2 shows the distribution of socio-economic characteristics and outcome variables among treated and non-treated individuals in the first year of our sample (1992), that is, before renovations part of the governmental programs took place. The underlying sample is the estimation sample excluding individuals with missing data within our observation period 1992–2002. The table shows no significant differences in age, gender, years of education, income, household members, or construction year between the two groups before the renovation program. Similarly, we find no statistically significant differences in average health status or demand for health care between the two groups.

3.2. Hospital statistic

In addition to the SOEP data, we use the *German Hospital Statistic* to validate the survey results and to investigate effect heterogeneity in more detail. The hospital statistic contains the universe of hospital admissions in Germany since 1995. The data document the patient's gender, age and county of residence, as well as admission related characteristics such as the exact diagnosis (3-digit ICD codes), the date of admission and the duration of stay. We restrict the estimation sample to admissions in East Germany within the calender years 1995–2002. 1995 is the earliest available year, and we do not consider years beyond 2002 because the KfW weatherization program ended in 2000. Moreover, we restrict the sample to short-term hospital stays of five days or less in order to reduce noise and to focus the analysis on the demand for acute or emergency care and to exclude hospital admissions due to more chronic diseases with long-planned surgeries.[8] In total, we observe 11.9 million admissions to a hospital in East Germany within the selected time window and with a maximum length of stay of five days.

3.3. Complementary information

KfW weatherization program:. To document the roll-out of the KfW weatherization program, we received yearly data on the total loan take-up that was approved by the KfW to landlords. The data are available at the county level, and are provided by the German public bank *KfW* (*Kreditanstalt für Wiederaufbau*) which implemented the weatherization program on behalf of the German government. The spatial and temporal distribution of the program intensity (in thousands of euros per inhabitant) is shown in Fig. A.1 in the Appendix, showing a wide dispersion and variation in the timing of the investments over the decade across counties. The distribution of renovations in our sample is driven by two key factors: (1) First, mostly large institutional landlords decided if and when to apply for the KfW subsidized loan to renovate their properties. In the 90s, 74% of all rented dwellings were owned by housing associations and municipal housing companies managing on average 3,500 dwellings in East Germany. Therefore, differences in the knowledge and efficiency of institutional landlords to plan renovations and to apply for the KfW program (including clarifying property rights and fulfilling collateral requirements) could explain the observed variation in program take-up. This is supported by Fig. A.1 showing no systematic regional clusters. (2) Second, the distribution is also impacted by potential supply side restrictions in executing renovations. As described above, the program implemented a total of 3.6 million renovations within a decade in East Germany. The Association of Construction Industry East (*Bauindustrieverband Ost*) reports rising order intakes in the 90s in East Germany, reaching its peak in 1996 with a 225% increase compared to 1991. This peak in demand for construction created challenges to execute those renovations in a timely manner. While landlords of these apartment blocks are able to request funding at any point, the execution of those renovations depends on the availability of qualified contractors that are able to execute the renovation, and the supply of materials used as inputs in the renovations (e.g., insulation materials, windows, heating systems, etc.).

Weather conditions:. To provide evidence on our hypothesis that positive health effects are explained by a better protection against extreme temperatures, we merge information on outdoor conditions to the hospital statistic. The temperature data are extracted from the *Global Historical Climatology Network daily* (GHCNd) as provided by the *National Oceanic and Atmospheric Administration* (NOAA). The data include station-level data for more than thousand weather stations across Germany. We computed daily measures of maximum, minimum and mean temperature for each county in the sample using the daily average of all city stations within the county in the entire sample period.

Regional indicators:. We enrich the empirical analysis with the inclusion of annual regional indicators of economic activity, population growth and infrastructure in each county of East Germany. This data is retrieved from the *INKAR* database provided by the *Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR)*. The database provides regional indicators for Germany and is based on official statistics as collected by different public authorities including the *German Statistical Office* and the *German Federal Employment Office*.

4. Results

In this section, we describe the empirical strategies and results linking the KfW weatherization program to tenants' health. Thereby, we exploit the unique setting in the 90s in East Germany and conduct the analysis in three steps in order to quantify the health benefits of the building retrofits.

In a first step, in Section 4.1, we start by showing that the temporal and spatial roll-out of the weatherization program predicts the observed renovations in the SOEP data. This is important in order to confirm the hypothesis that the KfW weatherization program was a significant driver of actual renovations in East Germany in our sample. In the second step (in Section 4.2), we exploit the rich information in the SOEP data about individual living conditions to validate that the reported renovations significantly improved housing conditions, which is a necessary condition to facilitate health effects. Afterwards, we investigate heath effects due to the renovation and estimate the causal treatment effects of receiving a major renovation on days of sick leave as well as the demand for health care (doctor visits, hospital overnight stay) of tenants. Finally, in Section 4.3, we use the administrative hospital statistic to estimate the effect of the roll-out of the KfW weatherization program on hospital admissions. The information on the exact date of admission as well as the exact diagnosis allows us to provide evidence on the underlying mechanisms, and conduct placebo tests validating our results.

[8] For robustness, we replicate our main results as shown in Fig. 7 using all admissions with a maximum length of stay of 10 days. Results are very similar and are shown in Fig. A.2 in Appendix.

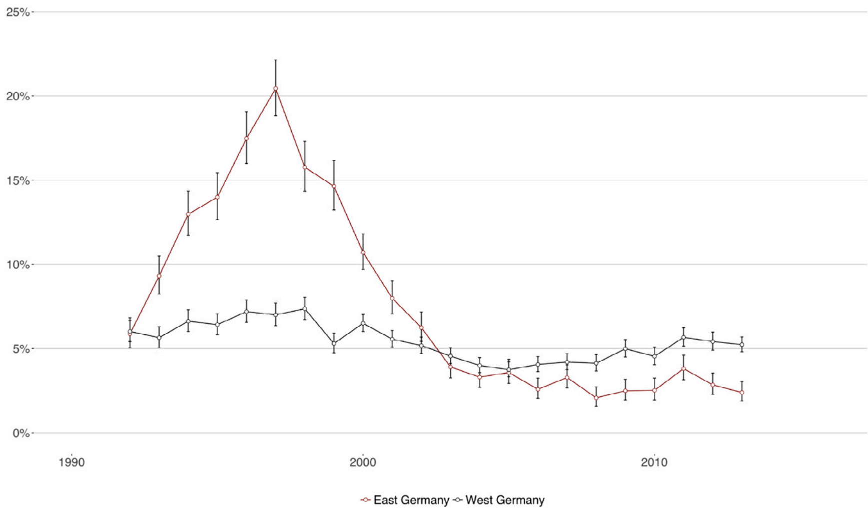

Fig. 1. Percentage of households reporting a renovation in East and West Germany. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Source: SOEP data, own calucations.

4.1. Impact of KfW weatherization program on renovations

This section provides empirical evidence supporting the hypothesis that the massive governmental support indeed resulted in extraordinary renovations during the 90s.[9]

Fig. 1 shows the share of households reporting a major renovation in their dwelling in the SOEP data. The massive renovation wave in East Germany during the 90s is clearly visible. The time series line for East Germany shows that renovation rates increased from initially 5% in 1991 to its peak of 20% in 1997, and then converged back to West German levels in the mid 2000s. For West Germany, we see no change with shares remaining stable at around 5% over time. The delayed start of the renovation wave in 1992 is due to the ongoing privatization process of East German assets (including real estate) in the aftermath of the reunification (see Sinn, 1993, for a documentation of the privatization process after reunification). Ownership of real estate had to be clarified before investments took place.

Similarly, Fig. 2 presents the percentage of households reporting problems with the conditions of their dwellings. The figure shows a significant gap in living conditions between the East and the West. In the early 90s, the differences in the proportion of households reporting their houses were in need of partial renovation between the East and the West was around 20%, and the differences in the proportion of households reporting their houses were in need of full renovation was over 10%. The renovation programs implemented in Eastern Germany managed to reduce the gap to almost zero by the beginning of the 21st century.

Finally, Fig. 3 shows the improvement in amenities in East German dwellings over time. The significant gap in housing amenities between East and West Germany was mostly removed by the end of the 20th century. In 1998, Eastern dwellings converged to the western standard, with 78% having a centralized heating system. In terms of sanitary installments, the gap reduced significantly from 92% having an indoor bathtub or shower in the East compared to 98% in the West (GdW, 1999).

In addition to the descriptive statistics, we provide results of a regression analysis in Table 3. Using the sample from the Socio-Economic Panel, we regress individuals' probability to report a major renovation of their dwelling in year t on the county-specific KfW weatherization program intensity including time and county fixed effects, as well as a set of individual control variables. The KfW weatherization program intensity contains the yearly loan take-up in county j based on the KfW weatherization program. The results show a strong correlation on the second lag. This time gap of two years between the subsidy approval and the completion of the renovation in the dwelling is likely due to the time needed to arrange and execute major renovation by the landlords. The coefficient on the second lag in column 1 in Table 3 (coef = 0.060) shows that a one standard deviation increase in regional loan take-up (corresponding to a 55% increase in our sample) correlates with an increase in the share reporting a renovation in the SOEP

[9] Section 2.2 describes the massive governmental support during the 90s in East Germany with the aim to update the housing portfolio in East Germany and hence equalize living conditions compared to West Germany. The KfW weatherization program was the main policy instrument, with a total budget of 40 billion euro.

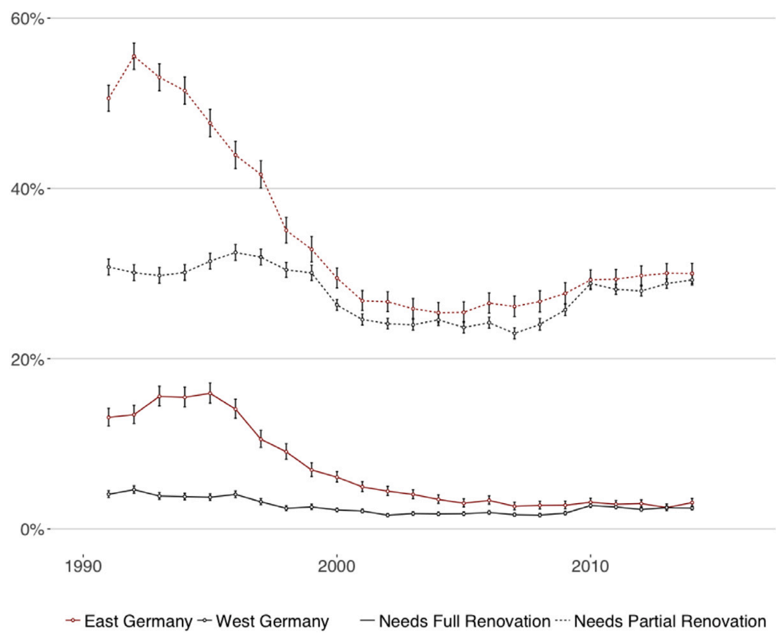

Fig. 2. Percentage of households reporting a dwelling in need for partial or full renovation in East and West Germany. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Source: SOEP data, own calucations.

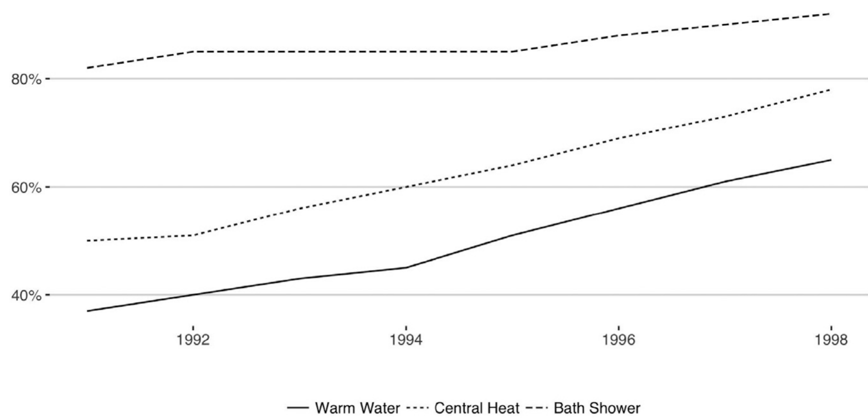

Fig. 3. Home amenities in East German dwellings over time.
Note: Numbers are based on a survey on housing associations and municipal housing companies.
Source: GdW (1999).

Table 3
KfW program regional intensity and SOEP treatment indicator.

	(1) $Renovated_t$	(2) $Renovated_t$	(3) $Renovated_t$	(4) $Renovated_t$	(5) $Renovated_t$	(6) $Renovated_t$	(7) $Renovated_t$	(8) $Renovated_t$
$ln(Subsidy_{ct-2})$	0.060***					0.076**	0.081***	0.192**
	(0.019)					(0.032)	(0.030)	(0.085)
$ln(Subsidy_{ct-1})$		0.056**				−0.042	−0.045	−0.054
		(0.025)				(0.047)	(0.038)	(0.082)
$ln(Subsidy_{ct})$.			0.049			0.079	0.069	−0.006
			(0.030)			(0.059)	(0.048)	(0.088)
$ln(Subsidy_{ct+1})$				−0.024		0.005	0.021	−0.037
				(0.023)		(0.052)	(0.044)	(0.070)
$ln(Subsidy_{ct+2})$					−0.035	−0.049		
					(0.025)	(0.049)		
Observations	9,480	10,387	11,345	12,599	10,553	4,538	5,871	2,155
County Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES	YES	YES
Individual Controls	YES	YES	YES	YES	YES	YES	YES	YES
Regional Controls	NO	NO	NO	NO	NO	NO	NO	YES

Note: The table shows the estimated correlation between individuals' probability to report a major renovation of their dwelling in year t that were part of the scope of the KfW program on the KfW program intensity which is measured as the total subsidy per head in year t in county c. Following our main results, we only consider renovations paid by the landlord of the property. Major renovations include upgrades in heating systems, windows and each specification contains county as well as year fixed effects, and a set of individual characteristics including age of the respondent (i.e., dwelling rent, gender, household income, and the ratio of household members per room). The list of regional controls contains the unemployment rate, tax revenue, and number of hospital beds and general practitioners per inhabitant. The regional controls are available at the county level and have been accessible since 1996 onwards. The limited duration for which we have regional controls restricts the number of leads that we can include to only one lead, due to the insufficient cohorts in our sample for specifications with regional controls. */**/*** indicate statistically significance at the 10%/5%/1%-level. Standard errors are in parentheses and clustered at the county-year level.

two years later by 2.6 percentage points. Given the average probability to receive a renovation in the initial year 1992 in our sample of 7.5% this corresponds to an increase of 34%. This finding provides clear evidence that the KfW weatherization program was a significant driver of renovations in East Germany.

Finally, Table A.3 in the Appendix shows how each of the five types of renovations recorded in the SOEP (i.e., heating, windows, bathroom, kitchen and other major renovations) correlate with the intensity of the KfW program, described as the total amount of subsidized loans per head in the county of residence of the individual. The results indicate that the largest correlation of the program is with the category "other major renovations", followed by windows and heating, indicating that the main renovations included in "other major renovations" in our sample are related to weatherization. Given that the remaining categories capture renovations in heating systems and windows, the key renovation associated with weatherization captured by the category "other major renovations" is therefore upgrades in the insulation of the building (roof, wall, and/or floor insulation). In addition, the table shows a lack of correlation with bathroom and kitchen upgrades, that are not related to weatherization of the dwelling. These results provide further evidence that our estimates are mainly driven by upgrades in the weatherization of homes in our sample, and not with other upgrades in the house, as described in Section 2.2.

4.2. Impact of renovations on households

After having shown that the KfW weatherization program led to more renovations, we now explore whether the renovations led to significant improvements of the living conditions and health of tenants.

Empirical model. We first examine the impact of renovations on household outcomes using the SOEP sample. As discussed above, the initial condition of the housing portfolio in East Germany at the beginning of the sample period was greatly underperforming contemporaneous living standards in Europe. This allows to estimate the first order impacts of home renovations: Improving living conditions of the Eastern German population, and evaluate whether those changes were visible to the average individual in our sample, as reflected in the drop in responses reporting a need for renovation in their dwellings.

Using the SOEP data, we estimate the following regression model:

$$Y_{ijt} = \alpha_i + \theta_t + \delta RenovatedHouse_{ijt} + \beta X_{ijt} + V_{ijt} \quad (1)$$

where i denotes individuals living in dwelling j in year t, and Y_{ijt} describes the outcome variables measuring individual health and living conditions as described in the previous section (Section 3). α_i and θ_t represent the individual and year fixed effects, respectively. The term $RenovatedHouse_{ijt}$ represents a binary variable taking the value of one after dwelling j experiences a renovation considered to be part of the KfW weatherization program, and zero otherwise. X_{ijt} contains a set of time-varying socioeconomic characteristics, namely, income, age (and age square), education, ratio of household members per room, occupational

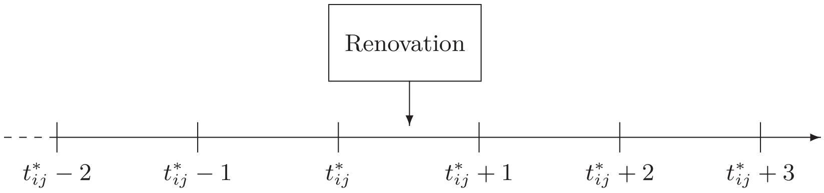

Fig. 4. Timing of the empirical model.
Note: The figure illustrates the exact timing of the empirical model.

status, and working hours. Standard errors are clustered at the household level. Our coefficient of interest δ describing the changes in the outcome variable following a renovation in the house of treated individuals.

Next to the static approach, we adopt an event-study approach to explore the differences in treatment effects for each year before and after the renovation (see, e.g., Lafortune et al., 2016):

$$Y_{ijt} = \alpha_i + \theta_t + \sum_{\tau=-2}^{-1} \lambda_\tau \mathbb{1}(t = t_{ij}^* + \tau) + \sum_{\tau=1}^{3} \delta_\tau \mathbb{1}(t = t_{ij}^* + \tau) + \beta X_{ijt} + V_{ijt} \tag{2}$$

Eq. (2) is identical to our main model (Eq. (1)), except that we replace the single indicator variable $Renovated House_{ijt}$ for the pre ($\mathbb{1}(t < t_{ij}^*)$) and the post trend ($\mathbb{1}(t > t_{ij}^*)$) with a set of indicators $\mathbb{1}(t = t_{ij}^* + \tau)$ indicating the years before and after the renovation year t_{ij}^*. For instance, t_{ij}^*+1 indicates the first year right after the renovation (see Fig. 4). We set the year before the home renovation as reference year. The effects described by δ_τ measure the effect of the renovation on outcomes τ years later, relative to the reference year t_{ij}^*, which is excluded.

Identification and mobility of residents. Conditional on individual and year fixed effects, the key identifying assumption of the approach is that the exact timing of the renovation cannot be altered by the tenants and therefore is as good as random. We argue this assumption is plausible within the selected observation period given the institutional structure of landlords in East Germany and the renovation wave as triggered by the massive governmental support in the aftermath of the reunification. The majority of dwellings were in need of renovation at the time of reunification and were renovated during the first 10 years thereafter (see Fig. 1). Moreover, the subsidy was paid to the landlords who determined the need and timing of the renovation. During the 90s, around 90% of tenants in East Germany lived in buildings with three or more apartments usually operated by larger housing associations or municipal housing companies (German Federal Statistical Office, 2003). In our estimation sample, about 80% of the tenants live in buildings with three or more apartments. Further, we emphasize that about 74% of all rented dwellings in East Germany in the 90s were owned by large institutional landlords managing on average 3,500 dwellings which is the result of the former centralized, communistic system in East Germany where real estate was basically publicly owned (GdW, 1990). Given the high ratio of tenants to landlords yielding anonymity in the relationship between tenants and landlords, and the size of portfolios of the average landlord in East Germany in the 1990s, it is almost impossible that a single tenant had any influence on the renovation decision of the landlord.

However, although tenants might not have influence on landlords' decisions, they could still move residence. This would be a threat to our identification if individuals would self-select into the renovation by moving into dwellings that were planned to be renovated in the near future. In this regard, Fig. 5 presents (in blue bars) the changes in the probability of moving residence in the years before and after experiencing a renovation in our sample period. Every year, individuals in our sample are asked to report whether they have changed their home address. We use an event study, to see whether there are any changes in the propensity of individuals to report a change in their home address in the years before and after the renovation, using a dummy variable taking the value of one if an individual reports a change in their home address. The findings suggest no existence of a selection of individuals into renovated houses. The estimates represented by the blue bars show a lack of significant (and positive) coefficients associated with the years preceding the renovation. In the years following the renovation, the results suggest a slight decrease in the probability of changing address, implying that individuals are less inclined to relocate after a renovation. This is in line with the evidence based on aggregate statistics as shown in the Appendix in Table A.2.[10] The evidence clearly shows that conditional on the individual fixed effects, that is, tenants' choice of residence, and the specific setting in the 90s in East Germany, the exact timing of the renovation can be considered as good as random for tenants.

[10] In addition to the methodological aspect, the analysis of sorting patterns contributes to the literature has identified individual preferences for avoiding environmental health risks in the living environment (see, e.g., Chay and Greenstone, 2003). Research has shown individuals are willing to pay rent or a price premium to limit or avoid exposure to hazards such as air pollutants or lead (Billings and Schnepel, 2017).

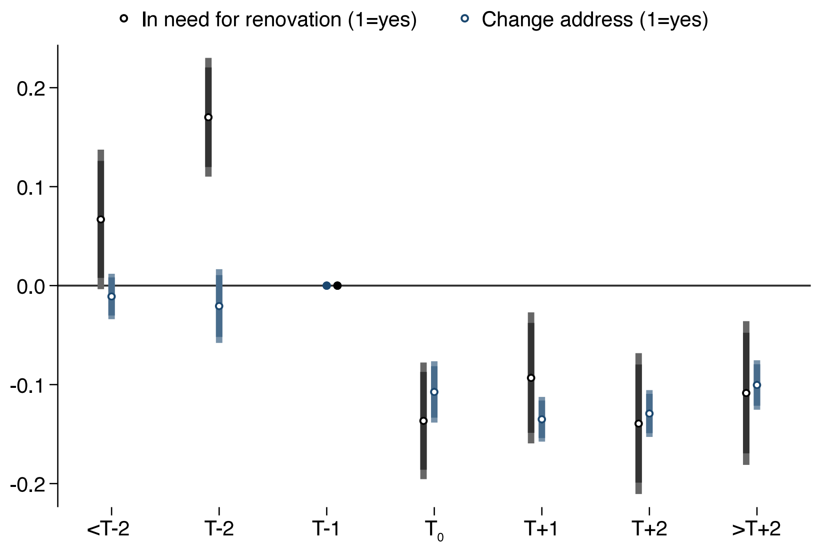

Fig. 5. Changes in respondents' house and housing conditions around renovation year.
Notes: Figure displays the estimated coefficients (λ and δ) of the event-study approach as described in Eq. (2), including as outcome variables (1) a dummy variable indicating that the house is in need for minor or major renovation (in black) and (2) a dummy variable indicating a change in address of the respondent that year (in blue). The baseline or comparison year is set as the year before the renovation took place in the household. The estimation sample is restricted to tenants living in Eastern Germany. The renovations considered in this analysis are those that are part of the main KfW program (insulation, windows and heaeting systems paid by the landlord). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

This assertion is finally also supported by the estimation results where we find λ_τ in Eq. (2) equals zero for all health outcomes. Fig. 6 shows that before the renovation there are no significant changes in the number of visits to the hospital among treated respondents compared to non-treated observations, indicating a lack of pre-trends in our study. We interpret this evidence as a strong indication that our identifying assumption holds.

Finally, we present a number of robustness checks showing that our results are unlikely to be driven by concurrent events. First, we show below in Section 4.2.1 that renovations of the bathroom or kitchen had no impact on hospital visits, underlining that it is indeed the renovations related to the KfW weatherization program generating the health effects. Second, the placebo analysis presented in Section 4.3 shows that the roll out of the KfW weatherization program only affected hospital admissions linked to circulatory problems which are caused by the renovation. The existence of concurrent events, next to the renovations, is likely to also affect admissions with other diagnoses, which we do not find.

Living conditions. To evaluate the impact of a renovation on individuals' living conditions, we estimate Eq. (2) and define the outcome variable Y_{ijt} as a binary indicator taking the value of 1 if the respondent i reports that her dwelling j is in need of partial or full renovation in year t. Each year, individuals in our sample are asked to classify the condition of their dwelling as: (1) in good condition, (2) in need of partial renovation, or (3) in need of major renovation. Fig. 5 uses an event study to estimate the changes in the probability of reporting the need of partial or major renovations in the years immediately before and after the renovation took place in the residence of the individual. The figure shows a clear pattern of changes in housing conditions around the renovation. The results indicate that, in the years preceding the renovation, individuals are more likely to report the need for renovation, while in the years following the renovation, individuals are significantly less likely to report the need for renovation. After the renovation took place, households are 15 percentage points less likely to report that the house requires a renovation. This indicates that the renovation wave created a significant improvement in living standards among the East German population, and those were visible and satisfactory for individuals. This evidence confirms the consistency and reliability of responses to the questions on the occurrence of renovation and housing conditions. Moreover, it shows a real impact of the treatment on the quality of the dwelling, which is a necessary condition in order to be able to observe impacts on health outcomes.

Impact of renovations on health. After having shown the impact of the KfW weatherization program on renovations as well as that a renovation significantly improved housing conditions, we now address the main question of the article: What are the health implications of the weatherization program? Based on the SOEP data, Table 4 presents the estimated coefficients $\hat{\delta}$ describing the change in health outcomes after the renovation event, as defined in Eq. (1).

Table 4
Impact of weatherization on health outcomes.

	(1) Visits hospital	(2) Visits GP	(3) Days on sick leave
Panel a. Full sample			
RenovatedHouse (1 = Yes)	−0.136	0.081	−1.852
	(0.186)	(0.189)	(2.202)
Observations	4,870	4,449	4,882
R-squared	0.062	0.021	0.042
Panel b. Young individuals (age < 45)			
RenovatedHouse (1 = Yes)	0.107	0.247	0.259
	(0.337)	(0.279)	(2.608)
Observations	2,482	2,225	2,485
R-squared	0.096	0.055	0.078
Panel c. Old individuals (age≥45)			
RenovatedHouse (1 = Yes)	−0.485**	−0.017	−4.731
	(0.236)	(0.240)	(3.558)
Observations	2,388	2,224	2,397
R-squared	0.072	0.050	0.060
Individual Fixed Effects	YES	YES	YES
Year Fixed Effects	YES	YES	YES
Controls	YES	YES	YES

Note: The table displays the estimated coefficients $\hat{\delta}$ describing changes in health outcomes in individuals being part of the renovation program, after receiving the renovation in their houses, as defined in equation 1. Panel a displays the estimates for the full sample, panel b displays the estimates for the sample of individuals whose age is below the sample median (45 year old), and Panel c displays the results for the subsample of individuals 45 years and older. All regression specifications include individual and year fixed effects, and include the full set of time-varying socioeconomic characteristics, i.e., income, age (and age square), education, ratio of household members per room, occupational status, and working hours. */**/*** indicate statistically significance at the 10%/5%/1%-level. Standard errors are in parentheses and clustered at the household level. All regressions are weighted using SOEP weights to correct for biases due to the over-sampling of households and potential attrition.

Column (1), (2), and (3) in Table 4 show the effect of renovations on hospital visits, doctor visits and days of sick leave, respectively. Panel a shows the result for the full sample of tenants in East Germany. We do not find significant changes in demand for health care or days of sick leave on the full sample of individuals.

Panel b and c in Table 4 display the coefficients for the subsample of young (< 45 years) and old subjects (45 years and older) in our sample, respectively.[11] The results show no effects among the young sample, but significant drops in hospital visits among the older sample. In particular, in the years following the renovation works in the house, older individuals report on average 0.48 visits less to a hospital. For the old cohort, we do not observe changes in days of sick leave (which might be less relevant because of retirement) or visits to general practitioner. This suggests that the main effects of renovation are reflected in changes in demand for acute or emergency care among the older, presumably a more vulnerable cohort of individuals in the sample.

Fig. 6 explores the timing of the effects on hospital admissions, and presents the estimated coefficients describing the change in health outcomes before $\hat{\lambda}$ and after $\hat{\delta}$ the renovation event as defined in Eq. (2). Again, we provide separate estimates for the full sample of tenants in East Germany, and the subsample of elder and young individuals. The pattern shows that the effects on hospital visits observed in the older cohort are visible one year after the completion of the renovation, and remains stable in terms of magnitude and statistical significance for several years after the renovation took place. In addition, the figure shows that before the renovation there are no significant changes in the number of visits to the hospital among treated respondents, indicating a lack of pre-trends in our study. As discussed above, we interpret this evidence as a strong indication that our identifying assumption holds.

Table A.4 in the Appendix presents the estimated coefficients for various types of upgrades implemented in the studied dwellings. While the estimates in Column (1) of Table A.4 suggest that insulation alone accounts for the observed health impacts from the KfW program, with windows and heating appearing to have no effect on hospital visits in the sample, these findings should be approached with caution. Renovations occur in packages,[12] emphasizing the complementary nature of different components in weatherization programs, including wall, roof, and floor insulation, as well as windows and heating systems. The frequent co-occurrence of window and heating upgrades alongside insulation improvements in the sample complicates the isolation of insulation's effects.

[11] We divide our sample of individuals in two groups, using the sample median as cutting threshold.

[12] Fig. A.3 in the Appendix shows a strong clustering among the renovations that form our treatment, i.e., heating, windows, and other major renovations (e.g., insulation). The figure shows that, for instance, about 60% (50%) of renovations in the heating systems (other major renovations, e.g., insulation) of houses coincided with window upgrades. Similarly, over 35% and 40% of window upgrades coincide with heating upgrades or other major renovations in our sample.

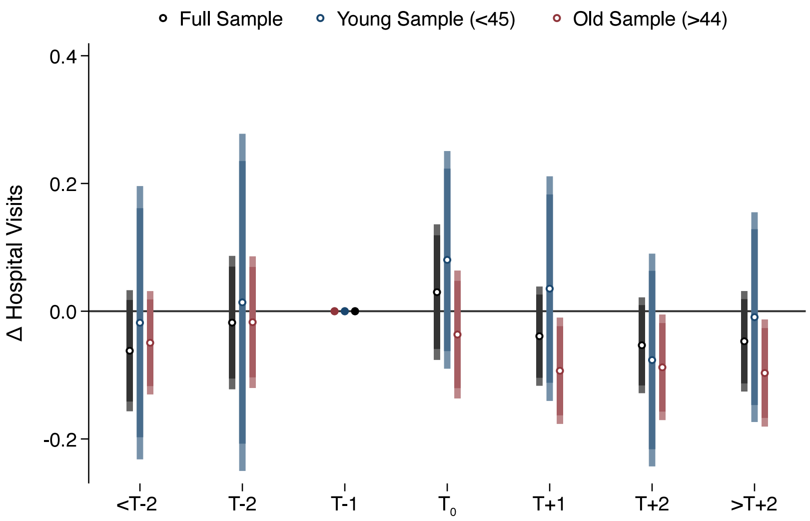

Fig. 6. Changes in hospital visits around renovation year.
Notes: Figure displays the estimated coefficients (λ and δ) of the event-study approach as described in Eq. (2), including as outcome variables (i) the number of hospital visits for full sample (black), (2) young sample (blue) and (3) elder sample (red). The outcome is standardize to allow comparisons across subsamples. The baseline or comparison year is set as the year before the renovation took place in the household. The estimation sample is restricted to tenants living in Eastern Germany. The renovations considered in this analysis are those that are part of the main KfW program (insulation, windows and heating systems paid by the landlord). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

In addition, it is highly unlikely that property owners choose to improve the insulation only without a prior assessment of the dwelling's existing heating infrastructure and windows. In this context, it is inappropriate to conclude that insulation alone is effective without considering the contributions of window and heating conditions/upgrades, or to assert that windows or heating systems are ineffective in improving health outcomes. The three renovation measures considered in this study (windows, heating and insulation) are highly complementary and work together to enhance a property's thermal performance (see, for instance, Harvey, 2009).

Finally, Table A.5 in the Appendix presents the estimated impact of the house renovation on subjective health status, life satisfaction indicators, household income, rents and individuals' labor market status. The results indicate no significant changes in those outcomes around the renovation. Individuals did not report any changes in the labor market outcomes or life satisfaction around the renovation. Similarly, households did not report any changes in their rental contracts around the renovation.[13] This suggests that the observed health effects are primarily driven by the direct upgrade in housing infrastructure, and are not due to changes in labor market outcomes or other indirect channels such as well-being associated with the renovation.

In sum, we observe that individuals reported significantly fewer visits to the hospital in the years immediately after their houses were renovated. The results indicate the individuals did not experience significant changes in their contract type or their current labor market status. The changes experienced in the house amenities did neither affect the probability of being unemployed nor household income.

4.2.1. Robustness of main difference-in-differences results

Staggered adoption of treatment. The timing of the renovation in our study varies across the households in our sample, creating a staggered roll-out of the program. Recent econometric literature describes the risk of bias in two-way fixed effects estimators (TWFE) in the presence of staggered roll-out of the treatment (Roth et al., 2023). For robustness checks, we use the Callaway and SantAnna (2021) (CS) estimator. This estimator is robust to biases in conventional two-way fixed effects (TWFE) regression models caused by staggered treatments and treatment effect heterogeneity (Baker et al., 2022).

[13] Due to subsidy payments to the real estate sector in the 90s in East Germany, official reports document that the additional premium on the rent for renovated dwellings was minor, amounting to 0.64 euros per m^2 (Harris, 1998).

Table A.6 presents the estimates of changes in hospital visits using the CS estimator, which produces a difference-in-difference estimate by averaging treatments across all groups that received the treatment in each year of our sample, weighted by group size. Consistent with our main estimates presented in Table 4, the CS estimates on the impacts of renovations on hospital visits are negative, of similar magnitude to our main effects, and significantly different from zero for older individuals. Similar to our main analysis, we find no effects of renovations on visits to the GP or days of sick leave among individuals in our sample. Finally, Table A.7 displays the disaggregated treatment effects for each year before and after the renovation takes place in the house. The results show no evidence from pre-trends, both in the pool and disaggregated versions. The changes in hospital admissions are entirely observed in the years following the renovation.

Presence of bathroom and kitchen renovations. In our main specification (Table 4), we define the treatment group as those households living in a dwelling that has undertaken a renovation under the scope of the KfW weatherization program (i.e., windows, heating, and insulation). This definition puts in the control group those households that are living in dwellings that have undertaken no renovation, and those whose house has undertaken a renovation of bathroom or kitchen that are not part of the weatherization. In a robustness test, we include two additional control variables that describe the presence of renovations of bathrooms and kitchens. Evidence from developing countries shows that these renovations have health effects via improvements in sanitation, air quality, and hygiene levels of households (Hanna et al., 2016; Devoto et al., 2012; Headey and Palloni, 2019; Duflo, 2012). Table A.8 in the Appendix reports the results of our main estimates after controlling for the presence of kitchen or bathroom renovations. The results show that the effects remain significant and of similar magnitude compared to our main specification (Table 4). In addition, the results show that in our sample, bathroom and kitchen renovations had no impact on hospital visits, doctor visits, or days of sick leave reported by individuals in our sample.

4.3. Roll-out of the weatherization program and hospital admissions

In this section, we exploit the German hospital statistic to validate the health effects as identified in the SOEP data and to explore the mechanism behind the health effects associated with the KfW weatherization program.

Empirical model. We merge the KfW weatherization program intensities to the hospital statistic based on the county and year level. The program intensity strongly predicts renovations in East Germany with a lag of two years as shown above in Section 4.1. We estimate the following regression model:

$$ln(HospitalAdmission_{ct}) = \alpha_c + \theta_t + \delta KfW subsidy_{ct-2} + \beta X_{ct} + V_{ict} \tag{3}$$

where $HospitalAdmission_{ct}$ denotes the number of patients with residence in county c being admitted to a hospital in year t. We take the natural logarithm of the continuous outcome variable to allow for a non-linear relationship between the outcome and the right hand side variables, as well as imposing a more normal distribution of the outcome variable. $KfW subsidy_{ct-2}$ contains the yearly loan take-up (in thousand Euro per inhabitant) that was approved to landlords in county c and year $t-2$ based on the KfW weatherization program. We are using the second lag to take into account the time gap between subsidy approval and completion of the renovations. We conducted a specification analysis testing different lags and leads, see Table A.9 in Appendix. Consistent to the SOEP results (compare Table 3), we find that the effect on the second lag clearly dominates other lags. Lead values of the KfW subsidy intensity do not predict hospital admissions at all. α_c and θ_t represent county and year fixed effects, respectively. X_{ct} contains a set of time-varying regional characteristics such as the local GP density, the number of available hospital beds, tax revenues, net immigration, traffic accidents, population density, and number of inhabitants by age cohorts. δ is the parameter of interest and captures the correlation between hospital admissions and the program intensity.

With the fixed effect strategy, we exploit variation in the program intensity within a county over time to predict the outcome variable. In addition, we control for a rich set of time-varying regional indicators capturing potential confounding factors such as economic activity, population growth or infrastructure. Furthermore, we (i) show in Table A.9 in the Appendix that lead values of the KfW subsidy program do not predict contemporaneous hospital admissions, and (ii) provide placebo tests regressing unrelated diagnoses of hospital admissions on the program intensity and do not find any significant results (see below). While this makes us very confident that the estimation of δ is likely to represent the causal parameter, we cannot finally stress a causal interpretation with the aggregate data because of the potential existence of unobserved confounding factors (being orthogonal to the included control variables).

The repeated cross-sectional structure of the hospital statistic (i.e. we cannot follow the same individual over time) prevents an event-study approach which we applied with the SOEP data in order to investigate dynamic effects over time. While we can estimate an aggregate effect of the roll-out of the KfW weatherization program on hospital admissions using the GHS data, we cannot distinguish between short- and long-term effects. But in this regard, the SOEP results are complementary and suggesting a longer lasting effect (see Fig. 6).

Main effects. Fig. 7 shows the estimated coefficient $\hat{\delta}$ based on Eq. (3) for the full sample as well as three different age cohorts. Given that older individuals are most vulnerable to varying indoor conditions, we defined one larger age cohort capturing younger patients (<45 years) and two more narrow age groups capturing older patients still in the labor market and those retired (45–64 and $\geq$ 65 years). In addition to the total number of admissions, we separately consider the number of patients with diseases of the

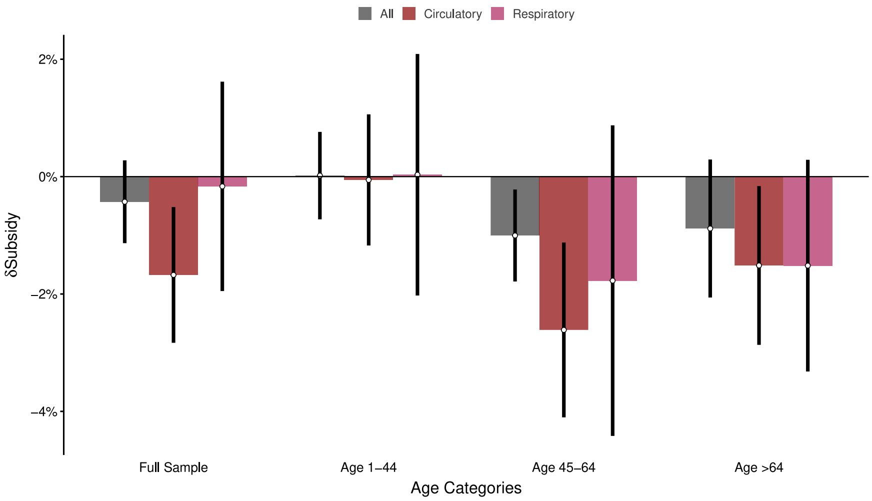

Fig. 7. Impact of KfW weatherization program on hospital admissions.
Notes: The figure shows the estimated coefficient $\hat{\delta}$ based on Eq. (3) using the German hospital statistic. Each bar represents a separate regression. The dependent variable is the logarithm of the total number of admissions within each category ($\leq$ 5 days of hospital stay). Bars indicate the point estimate, solid lines show the 95% confidence interval. Standard errors are clustered at the county level. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

circulatory and respiratory system. As discussed, cold and warm temperatures are particularly expected to impair cardiovascular health of vulnerable groups (Nayha, 2002). Therefore, improvements in insulation, heating and windows will lead to a more stable indoor climate and hence potentially reducing hospital admissions with cardiovascular problems, and eventually on the respiratory system.

Fig. 7 shows a clear pattern showing that the roll-out of the KfW weatherization program led to reduced hospital admissions among the older population which is solely driven by less admissions due to circulatory problems. Fig. A.4 in the Appendix shows that among those with circulatory problems, the home retrofits reduced particularly the risk of hypertension and heart diseases in the older sample. The estimated effect of −0.261 (−0.151) for patients 45–64 years old (65 years and older) suggests that if the subsidized loan take-up raises by 100 Euro per inhabitant (corresponding to about one standard deviation in our sample, s.d=145), admissions to the hospital with circulatory problems go down by 2.61% (1.51%) two years later.[14] We do not find statistically significant effects for the younger cohort (<45 years). The finding that the renovations only affect the health outcomes of older, more vulnerable individuals is consistent to the SOEP results as shown in Section 4.2.

Fig. 7 further shows that the effect on admissions due to respiratory problems becomes more negative for the elderly samples, but remains statistically insignificant (p-value = 0.195 for 45–64 years; p-value = 0.104 for the sample of 65 years and older). The zero effect might be explained by the theoretically opposing effects due to renovations (see the discussion in Section 2.3).

Using the significant estimates regarding circulatory problems, we conduct a back-on-the-envelope calculation to quantify the total costs savings associated with the introduction of the program. Given the average yearly subsidy amount of 210 Euro per inhabitant in our sample, the number of patients 45–64 ($\geq$ 65) years old admitted to a hospital with circulatory problems should be reduced by 5.48% (3.17%). This corresponds to about 35,302 (22,211) less admissions within our observation window.[15] Given the average direct medical costs of 11,049 Euro[16] per patient admitted to a hospital with cardiovascular problems in 1995, this results in total medical cost savings for the adult population of about 636 million Euro due to reduced hospital admissions because of the introduction of the program. This estimate is likely to be a lower bound of the social costs since it only considers direct medical costs, which might be significantly lower than the willingness to pay for avoiding the disease (Grossman, 1972).

[14] The slightly smaller effect for the 65+ cohort is most likely explained by the fact that we only have data on hospital admissions, but not on mortality. Therefore, the effect on hospital admissions might only partially capture the treatment effect for the older cohort.

[15] In total, we observe 644,202 (700,655) patients being admitted to the hospital with circulatory problems and being 45 to 64 ($\geq$ 65) years old.

[16] Schmid (2015) reports average direct medical costs of 14,628 Euro for acute and follow-up care up to 12 months after admission to a hospital for patients with cardiovascular problems in Germany in 2014. We deflate the amount to 1995 values based on the consumer price index as provided by the *German Statistical Office*.

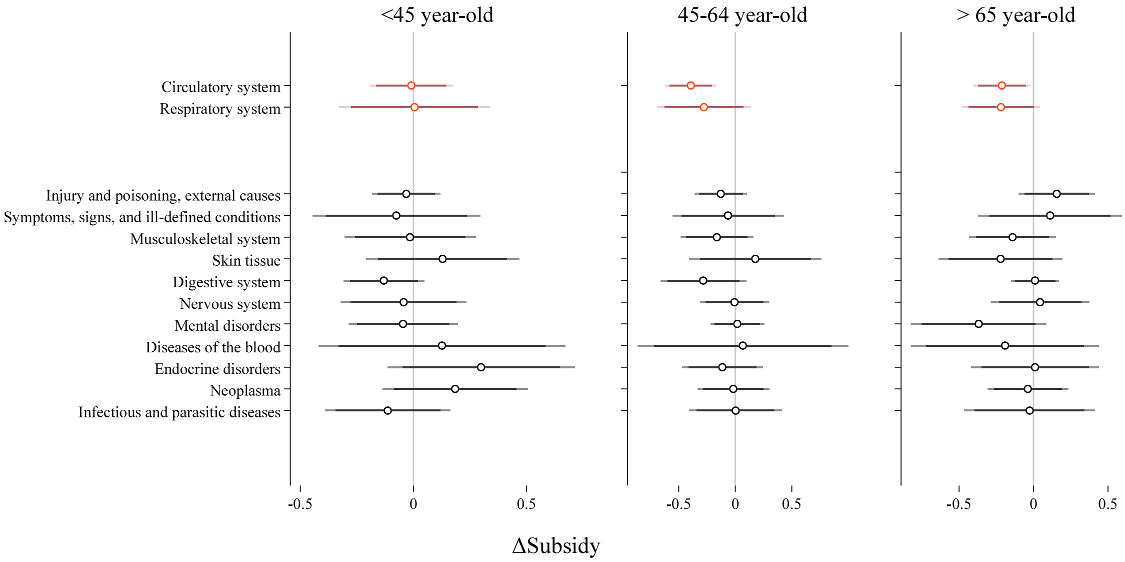

Fig. 8. Placebo tests: Impact of weatherization program on hospitalization by diagnoses.
Note: This figure shows the estimated coefficient $\hat{\delta}$ based on Eq. (3) using the German hospital statistic. Coefficients are standardized to facilitate comparisons across diagnoses. The dependent variable is the logarithm of the total number of patients admitted to a hospital with a certain diagnosis ($\leq$ 5 days of hospital stay). Circles indicate the point estimate, solid gray (black) lines show the 95% (90%) confidence interval. Standard errors clustered at the county level.

Placebo tests. We are able to test the validity of our main results by running a placebo test showing the impact of the weatherization program on unrelated diagnoses. This is particularly important because we have to rely on the regional program intensity as a proxy for patients' exposure to a renovation. While we find that the program intensity strongly predicts the individual probability to receive a renovation based on the SOEP data, one might still be concerned that other unobserved confounding factors bias the estimates. Next to the investment in building infrastructure due to the weatherization program, other infrastructure and economic programs occurred in parallel. This may still raise doubts whether the estimates presented above indeed single out the effect of the weatherization program, although we control for time-invariant as well as time-variant confounding factors in our empirical strategy.

Fig. 8 shows the results of placebo tests using the number of patients admitted to a hospital with all diagnoses categories recorded in the data, and compares the estimates to the significant effect on hospital admissions due to circulatory problems. All outcomes are standardized to facilitate comparisons across diagnoses. The coefficients displayed for the older cohorts show that we only find one statistically significant effect different from zero of the program: Problems with the circulatory system. All other unrelated diagnoses are statistically zero. This strongly supports the validity of our results, by providing the clear connection between the KfW weatherization program and problems with the circulatory system, the first order health problem linked to exposure to suboptimal temperatures.

In addition, the results of the placebo analysis mitigate concerns about other channels through which renovations might affect health. For instance, the renovations may have impacts on the health of individuals via changes in the utility costs of households. The use of the increased disposable income of households (e.g due to energy savings) might be linked to changes in health investments. The results of our placebo tests show no significant effects on hospitalizations associated with other diseases other than cardiovascular, suggesting a lack of changes in nutrition or other health related behavior/investments.

Mechanism. Finally, we show that the positive health effects are driven by improvements in dwelling conditions and hence, a better protection against extreme temperatures. As explained in Section 2.3, the renovation improves the insulation and heating of buildings resulting in a more stable indoor climate reducing tenants' exposure to cold or heat and hence, reducing the risk of cardiovascular problems (due to increased heart rate, blood pressure). To provide direct evidence on this mechanism, we merge daily information on outside weather conditions on the county level (Source: *National Oceanic and Atmospheric Administration* (NOAA), see

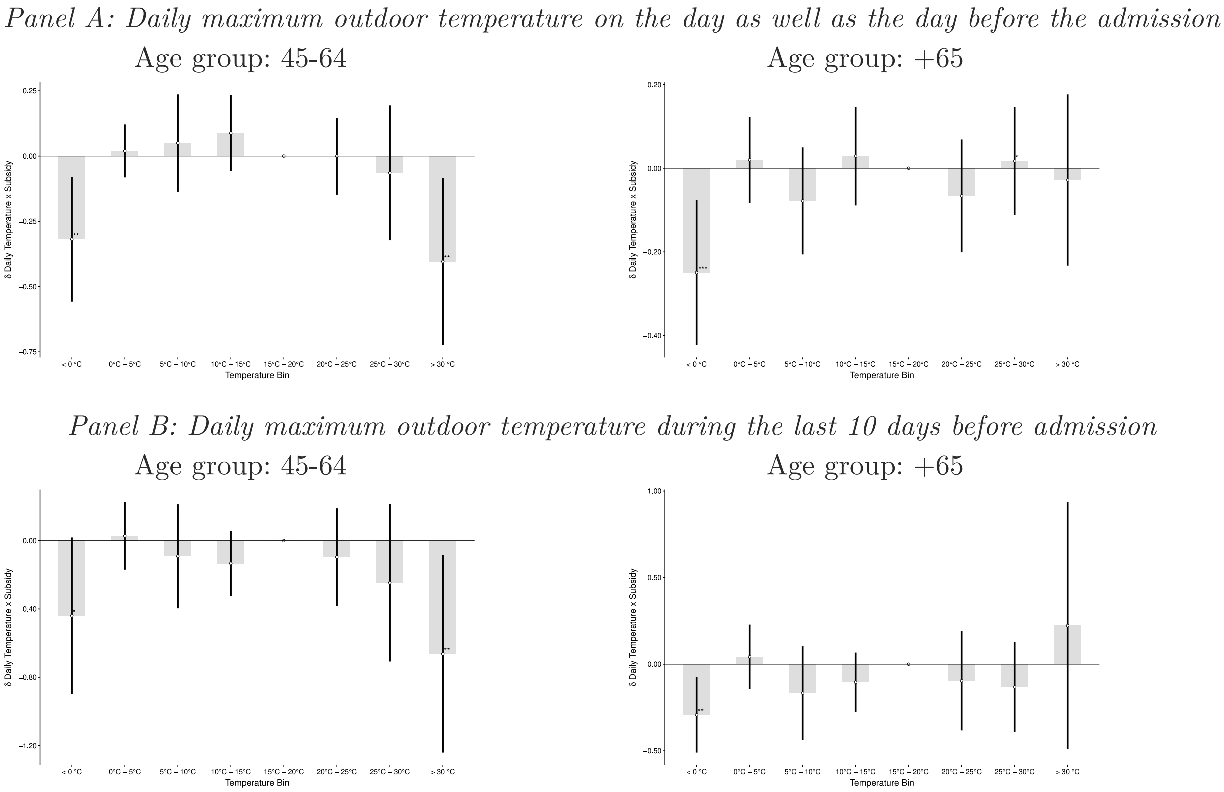

Fig. 9. Impact of weatherization program on hospitalization by outdoor temperature.
Note: The figure shows the estimated coefficient $\hat{\delta_s}$ based on Eq. (4). The dependent variable is the logarithm of the total number of patients admitted to a hospital with diseases of the circulatory system (≤5 days of hospital stay). Gray bars indicate the magnitude of the point estimate. Solid black lines show the 95% confidence interval. Standard errors are clustered at the county level. Full estimation results are shown in Table A.10 in Appendix.

Section 3.3) to the hospital statistic, and include interaction terms with the outdoor temperature. We follow the approach by Cohen and Dechezleprêtre (2022) and estimate the following regression model:

$$\begin{aligned} ln(HospitalAdmission_{cdmt}) = &\sum_{k=0}^{\tau}\sum_{s}\beta_{ks}Temp_{scmtd-k} \\ &+\sum_{k=0}^{\tau}\sum_{s}\delta_{ks}Temp_{scmtd-k}KfWsubsidy_{ct-2} \\ &+\gamma KfWsubsidy_{ct-2}+\alpha_c+\lambda_m+\theta_t+V_{cdmt} \end{aligned} \tag{4}$$

where the number of hospital admissions in county c on a specific date d, in calendar month m and year t is regressed on a set of binary variables $Temp_{scmtd-k}$ taking the value of 1 if the daily maximum temperature in county c falls into temperature bin s on day $d-k$, as well as the interaction between the temperature bins and $KfWsubsidy_{ct-2}$ which represents the country-specific KfW weatherization program intensity lagged by two years. The parameter of interest is $\delta_s = \sum_{k=0}^{\tau}\delta_{ks}$ which is a cumulated effect of outdoor temperature on hospital admissions. Next to the immediate effect $\tau = 1$, we also consider a lagged effect of outdoor temperature up to 10 days before ($\tau = 10$) to take delayed hospital admissions into account. The regression includes county (α_c), calendar month (λ_m) and year (θ_t) fixed effects.

Fig. 9 shows the estimate of δ_s using the daily maximum outdoor temperature on the day and the day before the hospital admission in panel A ($\tau = 1$) as well as considering the cumulated effect of outdoor temperature up to 10 days before in panel B ($\tau = 10$). We focus on the number of older patients admitted to a hospital with diseases of the circulatory system because this outcome variable shows the strongest effects in the main analysis. Regarding the age cohort 45 to 64 years, the estimates show a clear inverse-u shaped relationship between hospital admissions due to problems with the circulatory systems and the outdoor temperature interacted with the KfW weatherization program intensity. Apparently, tenants in this age range are less vulnerable to outdoor cold and heat if they live in counties which received higher subsidy payments two years before. This supports our hypothesis that the renovation program improved the quality of buildings with a better protection against outdoor conditions resulting in less hospital admissions due to extreme cold or hot days. For the oldest cohort 65 years and older, we only find a significant effect for extreme cold temperatures but not for heat.

Finally, please note that the analysis does not claim that better protection against extreme temperatures is the only channel through which renovations affected circulatory diseases. A reduction of other environmental stressors such as outdoor noise and air pollution could possibly explain part of the effects too (as discussed in Section 2.3).[17] However, data restrictions do not allow a detailed analysis of such channels.

In summary, the evidence as presented in Fig. 9 together with the result of the placebo test showing no impact on diagnoses being unrelated to the weatherization program, clearly supports our notion that the reduction in hospital admissions with circulatory problems is indeed due to the weatherization program and the associated improvements in building quality, and most likely not due to confounding factors.

5. Conclusion

Understanding the impacts of weatherization programs is of high relevance given the ongoing plans in Europe and the United States to retrofit a large proportion of their housing portfolios as a part of their overall energy transition. This study uses the large housing renovation wave (3.4 million dwellings) in East Germany in the aftermath of the German reunification to provide the first population-representative quasi-experimental evidence on the health consequences of weatherization programs in a developed country. During the 1990s, the German government implemented a major subsidy program of €40 billion, renovating about 50% of extant dwellings in East Germany with a clear focus on weatherization measures.

In the empirical analysis, we exploit this exceptional period of renovations during the 1990s in East Germany and the staggered roll-out of the weatherization program generating exogenous variation in individuals' probability of receiving a renovation. The analysis relies on population-representative household data (SOEP) as well as administrative records of hospital admissions. The combination of both data sources is a clear strength of our analysis, allowing for cross-validation of results and more detailed analysis. While the survey data allow a causal analysis and investigation of effect dynamics over time, the administrative records facilitate a detailed consideration of underlying effect mechanisms including placebo tests and validate the survey results. Together, the evidence, which is based on both data sources, reveals a very consistent and clear pattern that weatherization upgrades sustainably reduce the demand for health care among residents by reducing hospital admissions among the elderly sample of the population, mainly due to a reduced risk with circulatory problems.

Our findings have strong policy implications and should be considered when evaluating and planning (public) renovation programs in the housing sector. This is particularly important given the recent developments regarding the implementation of large-scale renovation programs such as the *Renovation Wave* program within the European Green Deal, or the US infrastructure plans to upgrade the energy efficiency of the building stock. Next to a reduction in greenhouse emissions, our results now clearly show that such renovation programs also yield considerable health benefits, enriching the cost–benefit analysis of such projects. In fact, a back-on-the-envelope calculation based on our estimation sample reveals total medical costs savings for the adult population of about 636 million Euro due to reduced hospital admissions because of the implementation of the KfW weatherization program.

CRediT authorship contribution statement

Steffen Künn: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Juan Palacios:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix. Additional tables and figures

See Figs. A.1–A.4 and Tables A.1–A.10.

[17] Based on the SOEP analysis in Section 4.2, we show in Table A.5 that house renovation did not impact individuals' overall life satisfaction, household income, rents and labor market status. This suggests that the observed health effects are primarily driven by the direct upgrade in housing infrastructure, and are not due to other channels such as well-being associated with the renovation.

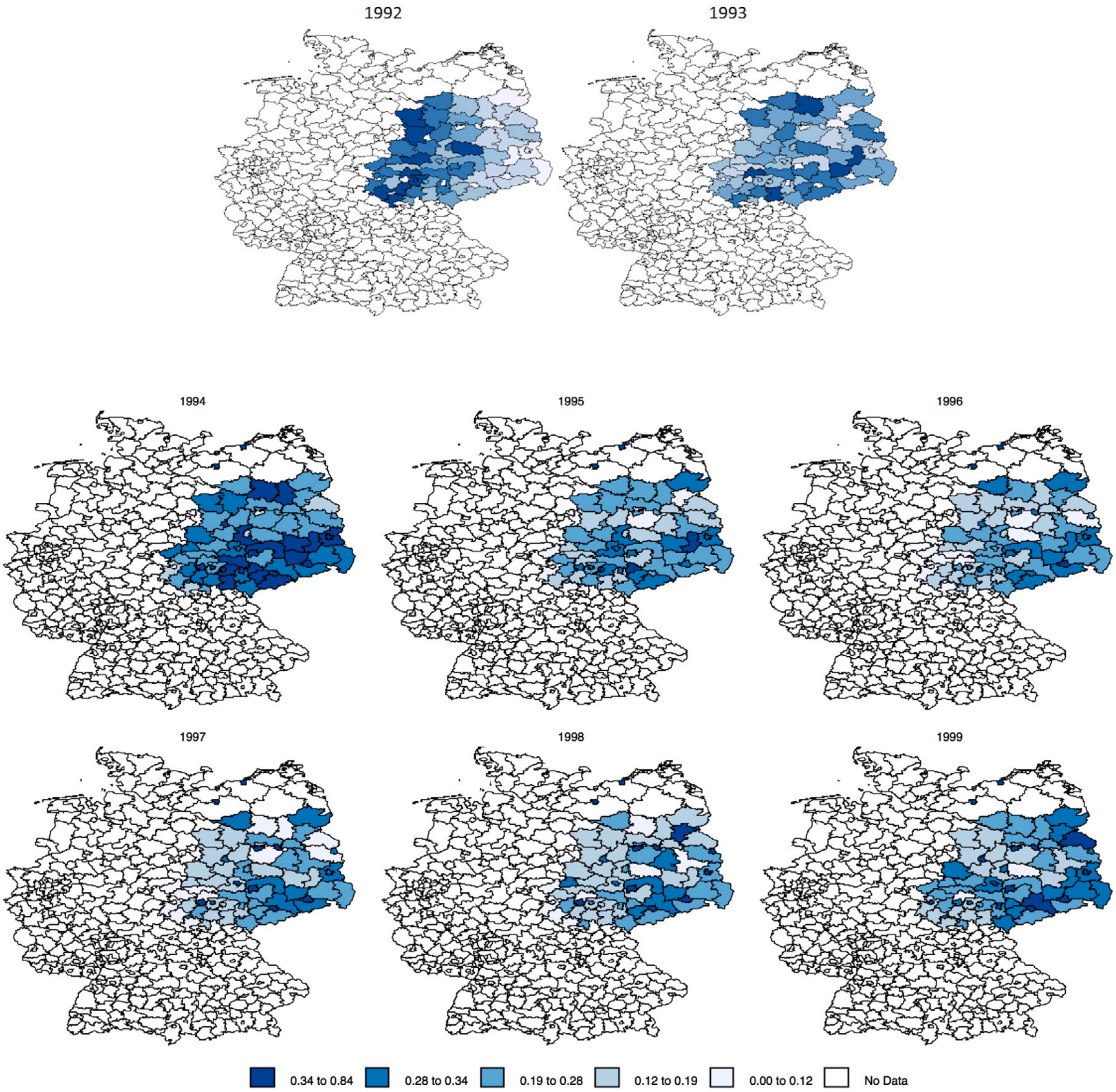

Fig. A.1. Distribution loan take-up per inhabitant across counties over years of the program.
Note: Loan take-up in thousand Euro per inhabitant that was approved to landlords based on the KfW weatherization program.

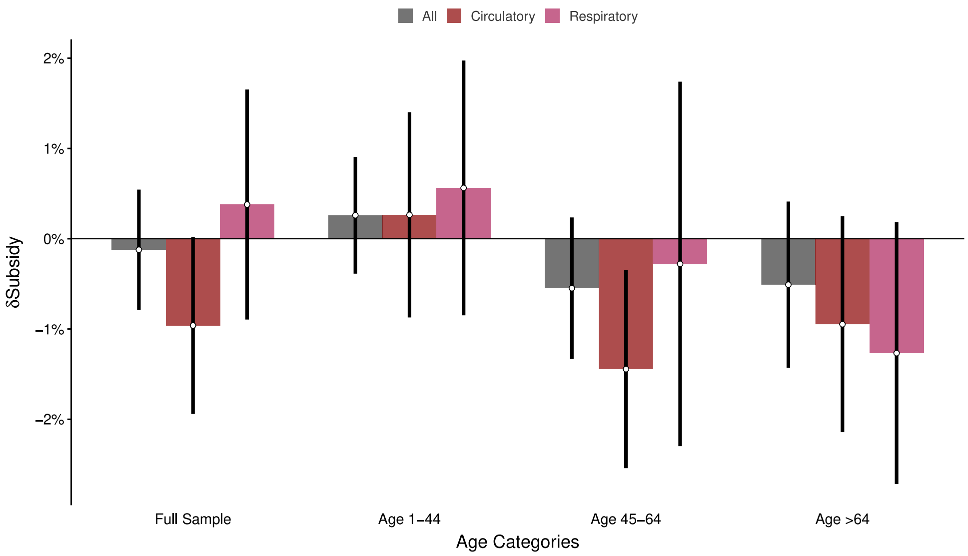

Fig. A.2. Impact of KfW weatherization program on hospital admissions (≤ 10 days of hospital stay).
Notes: The figure shows the estimated coefficient $\hat{\delta}$ based on Eq. (3) using the German hospital statistic. Each bar represents a separate regression. The dependent variable is the logarithm of the total number of admissions within each category. Bars indicate the point estimate, solid lines show the 95% confidence interval. Standard errors are clustered at the county level. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

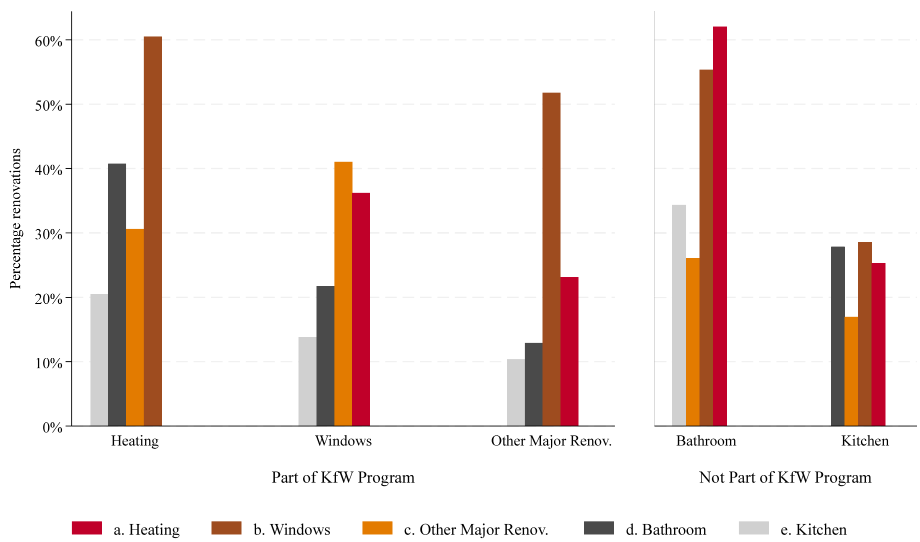

Fig. A.3. Share of overlapping renovations.
Notes: The figure shows the percentage of overlapping renovations that coincide with the three types of renovations that are part of the KfW program (heating, window, and other major renovations mainly including insulation), plus bathroom and kitchen renovations. Each bar represents the percentage of renovations that coincide in time for a given household in our sample with each of the renovations described by the subtitles on the horizontal axis. Please, note that the distributions displayed in the graph are conditional on a household reporting the renovation described in the horizontal axis. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

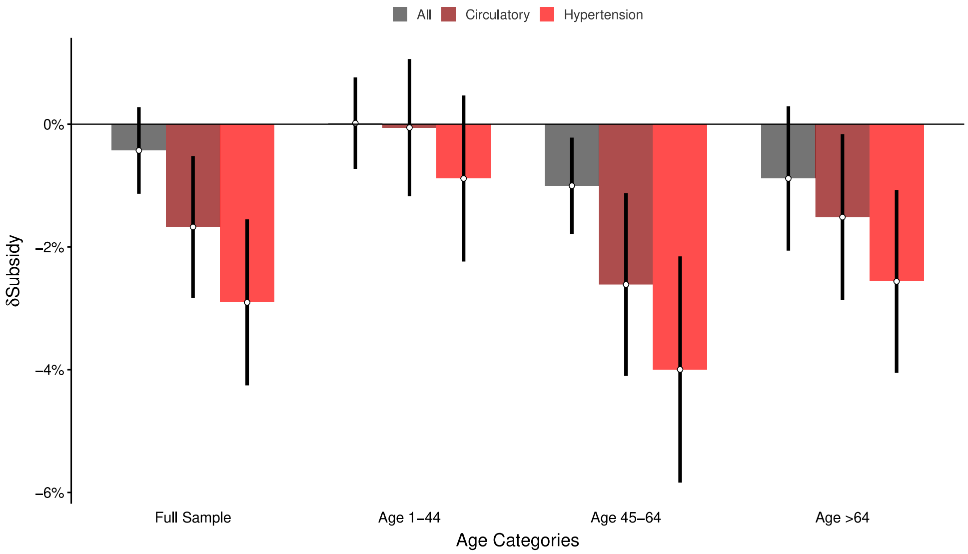

Fig. A.4. Impact of KfW weatherization program on hospital admissions: Hypertension and heart diseases.
Notes: The figure shows the estimated coefficient $\hat{\delta}$ based on Eq. (3) using the German hospital statistic. Each bar represents a separate regression. The dependent variable is the logarithm of the total number of admissions within each category (≤ 5 days of hospital stay). Bars indicate the point estimate, solid lines show the 95% confidence interval. Standard errors are clustered at the county level. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table A.1
Overview *KfW-Wohnraum-Modernisierungsprogram* 1990–1999.

Main objective	Increase living comfort in East Germany to equalize living conditions compared to the West.
Targeted measures	(1) Renovation of existing dwellings • Improvement of the value of the property: Sanitary facilities, noise insulation, flat layout, installation of elevators, extension of balconies • Investments to increase energy efficiency and to reduce CO_2 emissions: Installation of (central) heatings, window replacement, insulation, warm water production • Rectification of structural defects and repair of damages: Roofs, stairwells, floors etc. (2) Building new properties + Renovating the outside environment belonging to the properties • New apartments • Playgrounds, parking lots, parks
Support	• Reduced interest rate up to 3%-points below capital market interest rate fixed for 10 years • Maximum maturity: 25 years (no repayment within first 5 years) • Maximum amount: 400 Euro/m^2 • Collateral: – Standard banking practice for private property owners – None collateral requirements for municipalities or publicly owned housing associations

Table A.2
Impact of KfW program on local migration pattern.

	(1) $KfWSubsidy_{t-1}$	(2) $KfWSubsidy_{t-2}$	(3) $KfWSubsidy_{t-3}$	(4) $KfWSubsidy_{t-4}$
Immigration	0.150	0.197	0.035	0.205
	(0.716)	(0.635)	(0.934)	(0.716)
Emigration	−0.100	−0.429	−1.557***	−1.982***
	(0.812)	(0.279)	(0.002)	(0.000)
Emigration by age				
30–49 years	−0.013	−0.112	−0.597***	−0.767***
	(0.929)	(0.448)	(0.005)	(0.000)
50–64 years	0.004	−0.055	−0.190***	−0.245***
	(0.933)	(0.195)	(0.003)	(0.009)
≤ 65 years	0.019	−0.009	−0.046	−0.097
	(0.615)	(0.760)	(0.331)	(0.148)
Observations	479	547	478	409
Number of counties	69	69	69	69
County FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Controls	YES	YES	YES	YES

Note: The table shows $\hat{\delta}$ resulting from the following regression: $Y_{ct} = \alpha_c + \theta_t + \delta KfWSubsidy_{ct-\tau} + \beta X_{ct} + V_{ct}$ where Y_{ct} is the outcome variable measured in county c in year t (1995–2002). The estimation is based on the ***Migration Matrix*** containing a registry of internal migration flows within Germany and is provided by the ***German Federal Statistical Office***. The parameter of interest is δ measuring the correlation between the KfW program intensity (measured as the total subsidy per head in year t in county j) on the outcome variable. α_j and θ_t are county and year fixed effects respectively. X_{jt} contains a set of county-level control variables including population density, average living space and age of inhabitants, foreigner rate, tax revenue as well as the number of births, deaths and students. V_{jt} is clustered at the county level. */**/*** indicate statistically significance at the 10%/5%/1%-level. *P*-values are in parentheses.

Table A.3
KfW program regional intensity on types of renovations.

	(1) Heating renov.$_t$	(2) Windows renov.$_t$	(3) Other major renov.$_t$	(4) Bathroom renov.$_t$	(5) Kitchen renov.$_t$
$ln(Subsidy_{ct-2})$	0.011*	0.024**	0.026***	−0.002	0.002
	(0.006)	(0.010)	(0.007)	(0.006)	(0.007)
Observations	9,480	9,480	9,480	9,480	9,480
County Fixed Effects	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES
Individual Controls	YES	YES	YES	YES	YES

Note: The table shows the estimated correlation between individuals' probability to report different types of renovations in their dwelling in year t on the KfW program intensity which is measured as the total subsidy per head in year t in county c. Following our main results, we only consider renovations paid by the landlord of the property. Column (1) explains the probability of reporting a heating upgrade in year t for an individual living in county c, Column (2) explains the probability of reporting a window upgrade in year t for an individual living in county c, Column (3) explains the probability of reporting the presence of other major renovations in their dwelling (wall and roof insulation) in year t for an individual living in county c, Column (4) explains the probability of reporting a bathroom upgrade in year t for an individual living in county c, Column (5) explains the probability of reporting a kitchen upgrade in year t for an individual living in county c. Each specification contains county as well as year fixed effects, and a set of individual characteristics (i.e., age, dwelling rent, gender, household income, and the ratio of household members per room). */**/*** indicate statistical significance at the 10%/5%/1%-level. Standard errors are in parentheses and clustered at the county-year level.

Table A.4
Decomposition treatment by renovation types.

	(1) Visits hospital	(2) Visits hospital	(3) Visits hospital	(4) Visits hospital	(5) Visits hospital	(6) Visits hospital
Other major renovations	−0.477**					−0.443*
(e.g., insulation) (1 = Yes)	(0.227)					(0.241)
Heating (1 = Yes)		−0.014				0.357
		(0.310)				(0.257)
Windows (1 = Yes)			−0.268			−0.150
			(0.229)			(0.212)
Bathroom (1 = Yes)				−0.296		−0.398
				(0.365)		(0.323)
Kitchen (1 = Yes)					0.162	0.236
					(0.219)	(0.224)
Observations	2,255	2,255	2,255	2,255	2,255	2,255
R-squared	0.081	0.079	0.079	0.083	0.079	0.090

Note: The table displays the estimated coefficients $\hat{\delta}$ describing changes in hospital admissions for individuals whose age is above the sample median (45 year old) after receiving the renovation in their houses. Each column displays the coefficient associated with each type of renovation. "Other major renovations (e.g., insulations)" captures other major upgrades to the building, such as the insulation of the house (roof and wall insulation). Baseline year is set as the year before the renovation took place in the house. All regression specifications include individual and year fixed effects, and include the full set of time-varying socioeconomic characteristics, i.e., income, age (and age square), education, ratio of household members per room, occupational status, and working hours. */**/*** indicate statistically significance at the 10%/5%/1%-level. Standard errors are in parentheses and clustered at the household level. All regressions are weighted using SOEP weights to correct for biases due to the over-sampling of households and potential attrition.

Table A.5
Impact of renovations on subjective well-being indicators and labor market outcomes.

	(1) Bad Health (1 = Yes)	(2) Life satisfaction	(3) Household income	(4) Rent	(5) Unemployed (1 = Yes)
Panel a. Full sample					
$Renovated House$	0.010	−0.060	−39.777	0.034	−0.028
	(0.017)	(0.085)	(27.767)	(0.025)	(0.024)
Observations	7,004	7,683	7,480	7,588	4,949
R-squared	0.039	0.058	0.277	0.667	0.133
Panel b. Young individuals (age < 45)					
$Renovated House$	−0.014	−0.079	−48.951	0.064*	−0.018
	(0.020)	(0.128)	(48.048)	(0.036)	(0.032)
Observations	2,602	2,912	2,790	2,845	2,656
R-squared	0.054	0.101	0.318	0.666	0.160
Panel c. Old individuals (age ≥ 45)					
$Renovated House$	0.032	−0.073	−29.817	0.020	−0.018
	(0.023)	(0.100)	(26.663)	(0.033)	(0.026)
Observations	4,402	4,771	4,690	4,743	2,293
R-squared	0.051	0.056	0.298	0.667	0.147
Individual Fixed Effects	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES

Note: Table displays the estimates $\hat{\delta}$ describing changes in individuals' well-being and labor market outcomes after receiving a major renovation in their houses, as defined in Eq. (1). Panel a displays the estimates for the full sample, panel b displays the estimates for the sample of individuals whose age is below the sample median (45 year old), and Panel c displays the results for the subsample of individuals 45 years and older. All regression specifications include individual and year fixed effects, and include the full set of time-varying socioeconomic characteristics, i.e., income, age (and age square), education, ratio of household members per room, occupational status, and working hours. */**/*** indicate statistically significance at the 10%/5%/1%-level. Standard errors are in parentheses and clustered at the household level. All regressions are weighted using SOEP weights to correct for biases due to the over-sampling of households and potential attrition. The outcome "Bad Health (1 = Yes)" takes the value of one if the top two levels in a Likert scale ranging from 1 (very good health) to 5 (bad health). "Life Satisfaction" is a Likert scale ranging from 0 to 10. "Household Income" (in euros) is a continuous variable that describes the annual income of households in our sample. Similarly, rent is a continuous variable that "Rent" is a continuous variable that describes the monthly rent paid for the dwelling. Finally "Unemployed (1 = Yes)" is a dummy variable that takes the value of one if the individual is unemployed.

Table A.6
Impact of weatherization on health outcomes: Staggered treatment correction analysis using Callaway and SantAnna (2021) estimator.

	(1) Visits hospital	(2) Visits GP	(3) Days sick
Panel a. Full Sample			
Post-Renovation	−0.201	−0.107	−6.461
	(0.122)	(0.461)	(5.260)
Panel b. Young individuals (age < 45)			
Post-Renovation	−0.099	0.414	1.657
	(0.440)	(0.866)	(19.562)
Panel c. Old individuals (age ≥ 45)			
Post-Renovation	−0.391**	5.429	−36.475
	(0.190)	(5.701)	(104.766)

Note: The table displays the estimated coefficients, $\hat{\delta}$, describing changes in hospital visits in individuals who are part of the renovation program after receiving renovations in their houses, as defined in Equation 1 using the method proposed by Callaway and SantAnna (2021) to correct for biases driven by the staggered adoption of the treatment in our sample. Column (1) presents the estimates for the full sample, Column (2) presents the estimates for the sample of individuals whose age is below the sample median (45 years old), and Column (3) presents the results for the subsample of individuals 45 years and older. Panel A includes the results of the pool specification, where coefficients are pooled into pre- and post-renovation. Panel B displays the coefficients separately for each year before and after the renovation takes place in the dwelling of the individual. All regression specifications include individual and year fixed effects and incorporate the full set of time-varying socioeconomic characteristics, namely income, age (and age squared), education, the ratio of household members per room, occupational status, and working hours. */**/*** indicate statistical significance at the 10%/5%/1% levels, respectively. Standard errors are in parentheses and clustered at the household level. All regressions are weighted using SOEP weights to correct for biases due to the oversampling of households and potential attrition.

Table A.7
Changes in hospital visits around renovation year: Staggered treatment correction analysis using Callaway and SantAnna (2021) estimator.

	(1) Full sample	(2) Young sample (<45)	(3) Old sample (>45)
Panel a. Pool Effects			
Pre-Renovation	−0.016	0.074	−0.106
	(0.046)	(0.173)	(0.405)
Post_Renovation	−0.201	−0.118	−0.361**
	(0.122)	(0.522)	(0.175)
Panel B. Dynamic Effects			
T−3	−0.013	0.114	−0.080
	(0.132)	(0.369)	(0.137)
T−2	−0.072	0.054	−0.049
	(0.049)	(0.256)	(0.957)
T−1	0.037	0.054	−0.190
	(0.032)	(0.104)	(0.283)
T0 (Renovation Year)	−0.105**	−0.074	−0.202*
	(0.051)	(0.088)	(0.104)
T+1	0.021	0.515	−0.211
	(0.118)	(0.507)	(0.598)
T+2	−0.068	−0.046	−0.567
	(0.128)	(0.267)	(0.449)
T+3	−0.289	−1.094	−0.544**
	(0.247)	(2.962)	(0.217)
T+4	−0.411**	0.050	−0.107
	(0.166)	(0.125)	(0.149)
T+5	−0.351	−0.058	−0.535***
	(0.249)	(0.118)	(0.165)

Note: The table displays the estimated (standardized) coefficients (λ and δ) of the event-study approach as described in Eq. (2), describing changes in hospital visits in individuals who are part of the renovation program after receiving renovations in their houses, using the method proposed by Callaway and SantAnna (2021) to correct for biases driven by the staggered adoption of the treatment in our sample. Column (1) presents the estimates for the full sample, Column (2) presents the estimates for the sample of individuals whose age is below the sample median (45 years old), and Column (3) presents the results for the subsample of individuals 45 years and older. Panel A includes the results of the pool specification, where coefficients are pooled into pre- and post-renovation. Panel B displays the coefficients separately for each year before and after the renovation takes place in the dwelling of the individual. All regression specifications include individual and year fixed effects and incorporate the full set of time-varying socioeconomic characteristics, namely income, age (and age squared), education, the ratio of household members per room, occupational status, and working hours. */**/*** indicate statistical significance at the 10%/5%/1% levels, respectively. Standard errors are in parentheses and clustered at the household level. All regressions are weighted using SOEP weights to correct for biases due to the oversampling of households and potential attrition.

Table A.8
Impact weatherization on health outcomes after controlling for bathroom and kitchen renovations.

	(1) Visits hospital	(2) Visits GP	(3) Days sick
Panel a. Full Sample			
Renovated KfW (1 = Yes)	−0.113	0.143	−1.751
	(0.175)	(0.195)	(2.090)
Renovated Bathroom (1 = Yes)	−0.000	0.208	0.836
	(0.163)	(0.279)	(2.280)
Renovated Kitchen (1 = Yes)	−0.148	−0.161	−1.061
	(0.116)	(0.220)	(1.548)
Observations	4,870	4,449	4,882
R-squared	0.062	0.022	0.042
Panel b. Young individuals (age < 45)			
Renovated KfW (1 = Yes)	0.160	0.290	1.065
	(0.321)	(0.289)	(2.602)
Renovated Bathroom (1 = Yes)	−0.025	0.136	0.033
	(0.273)	(0.354)	(3.663)
Renovated Kitchen (1 = Yes)	−0.234	−0.067	−2.121
	(0.261)	(0.333)	(1.763)
Observations	2,482	2,225	2,485
R-squared	0.096	0.055	0.078
Panel c. Old individuals (age ≥ 45)			
Renovated KfW (1 = Yes)	−0.448**	0.026	−5.537*
	(0.219)	(0.247)	(3.264)
Renovated Bathroom (1 = Yes)	0.009	0.210	−1.180
	(0.190)	(0.436)	(3.188)
Renovated Kitchen (1 = Yes)	−0.160	−0.146	2.529
	(0.153)	(0.307)	(3.093)
Observations	2,388	2,224	2,397
R-squared	0.072	0.051	0.060

Note: The table displays the estimated coefficients $\hat{\delta}$ describing changes in health outcomes in individuals being part of the renovation program, after receiving the renovation in their houses, as defined in equation 1. The regression includes the presence of renovations in bathrooms and kitchens. Panel a displays the estimates for the full sample, panel b displays the estimates for the sample of individuals whose age is below the sample median (45 year old), and Panel c displays the results for the subsample of individuals 45 years and older. All regression specifications include individual and year fixed effects, and include the full set of time-varying socioeconomic characteristics, i.e., income, age (and age square), education, ratio of household members per room, occupational status, and working hours. */**/*** indicate statistically significance at the 10%/5%/1%-level. Standard errors are in parentheses and clustered at the household level. All regressions are weighted using SOEP weights to correct for biases due to the over-sampling of households and potential attrition.

Table A.9
Impact of KfW program on hospital admissions with circulatory problems - Specification tests.

	(1)	(2)	(3)	(4)	(5)	(6)
			Diseases of the circulatory system			
			Patients < 45 years old			
$KfWSubsidy_{ct}$	0.1441*					0.1382*
	(0.053)					(0.066)
$KfWSubsidy_{ct-1}$		0.056				0.0017
		(0.300)				(0.979)
$KfWSubsidy_{ct-2}$			−0.006			−0.0454
			(0.922)			(0.454)
$KfWSubsidy_{ct+1}$				0.1082		
				(0.214)		
$KfWSubsidy_{ct+2}$					0.0064	
					(0.933)	
			Patients 45–64 years old			
$KfWSubsidy_{ct}$	0.0534					0.045
	(0.557)					(0.563)
$KfWSubsidy_{ct-1}$		−0.1519*				−0.182**
		(0.066)				(0.032)
$KfWSubsidy_{ct-2}$			−0.261***			−0.254***
			(0.001)			(0.000)
$KfWSubsidy_{ct+1}$				0.000		
				(0.998)		
$KfWSubsidy_{ct+2}$					0.047	
					(0.604)	
			Patients ≥ 65 years old			
$KfWSubsidy_{ct}$	0.116					0.098
	(0.113)					(0.159)
$KfWSubsidy_{ct-1}$		0.017				−0.010
		(0.789)				(0.889)
$KfWSubsidy_{ct-2}$			−0.151**			−0.155**
			(0.031)			(0.018)
$KfWSubsidy_{ct+1}$				−0.035		
				(0.661)		
$KfWSubsidy_{ct+2}$					0.057	
					(0.449)	
Observations	420	490	490	350	280	420
Regional controls	YES	YES	YES	YES	YES	YES
County Fixed Effects	YES	YES	YES	YES	YES	YES
Year Fixed Effects	YES	YES	YES	YES	YES	YES

Note: The table shows the estimated coefficient $\hat{\delta}$ based on Eq. (3). Each column represents a separate regression. The dependent variable is the logarithm of the total number of admissions with circulatory problems (≤ 5 days of hospital stay). */**/*** indicate statistically significance at the 10%/5%/1%-level. *P*-values are in parentheses and clustered at the county level.

Table A.10
Impact of weatherization program on hospitalization by outdoor temperature - Full results.

	(1) Temp: 1 day	(2)	(3) Temp: 10 days	(4)
	45–64 years	≥65 years	45–64 years	≥65 years
$KfWSubsidy_{ct-2}$	0.0244	0.145*	0.126	0.194**
	(0.844)	(0.083)	(0.329)	(0.049)
Cumulated effect of daily maximum outdoor temperature (Ref.: 15 to <20 °C)				
<0 °C	−0.001	−0.009	0.052	0.055
	(0.964)	(0.720)	(0.371)	(0.103)
0 to <5 °C	−0.033*	−0.033**	−0.049	−0.033
	(0.099)	(0.043)	(0.169)	(0.256)
5 to <10 °C	−0.048*	−0.005	0.023	0.070
	(0.069)	(0.774)	(0.553)	(0.103)
10 to <15 °C	−0.028	−0.023	0.007	−0.008
	(0.190)	(0.194)	(0.819)	(0.780)
20 to <25 °C	0.006	0.026	−0.008	0.011
	(0.778)	(0.170)	(0.854)	(0.757)
25 to <30 °C	0.002	−0.012	0.008	−0.002
	(0.950)	(0.620)	(0.894)	(0.962)
≥ 30 °C	0.144***	0.035	0.269***	−0.011
	(0.006)	(0.331)	(0.006)	(0.899)
Subsidy ×Cumulated effect of daily maximum outdoor temperature (Ref.: 15 to <20 °C)				
$KfWSubsidy_{ct-2}$ × <0 °C	−0.319**	−0.249***	−0.439*	−0.292**
	(0.011)	(0.006)	(0.064)	(0.011)
$KfWSubsidy_{ct-2}$ × 0 to <5 °C	0.020	0.020	0.028	0.043
	(0.703)	(0.701)	(0.783)	(0.654)
$KfWSubsidy_{ct-2}$ × 5 to <10 °C	0.050	−0.078	−0.092	−0.167
	(0.602)	(0.236)	(0.557)	(0.230)
$KfWSubsidy_{ct-2}$ × 10 to <15 °C	0.088	0.029	−0.133	−0.104
	(0.242)	(0.630)	(0.174)	(0.237)
$KfWSubsidy_{ct-2}$ × 20 to <25 °C	−0.001	−0.066	−0.096	−0.096
	(0.993)	(0.340)	(0.511)	(0.516)
$KfWSubsidy_{ct-2}$ × 25 to <30 °C	−0.064	0.017	−0.246	−0.131
	(0.628)	(0.794)	(0.300)	(0.327)
$KfWSubsidy_{ct-2}$ × ≥30 °C	−0.404**	−0.028	−0.663**	0.223
	(0.016)	(0.788)	(0.028)	(0.543)
Observations	132,950	140,590	132,564	140,158
Number of counties	69	69	69	69
County FE	YES	YES	YES	YES
Calendar month FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Note: The table shows the estimated coefficients based on Eq. (4). Each column represents a separate regression. The dependent variable is the logarithm of the total number of admissions with circulatory problems (≤ 5 days of hospital stay). */**/*** indicate statistically significance at the 10%/5%/1%-level. *P*-values are in parentheses and clustered at the county level.
[Temp: 1 day] The daily maximum outdoor temperature is measured on the day as well as the day before the admission.
[Temp: 10 days] The daily maximum outdoor temperature is measured during the last 10 days before admission.

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