Critical events as triggers and accelerators of building renovations in private residential buildings

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Working Paper from the TIMELAG research project

March 2020

available at https://timelag.joanneum.at/results/

Abstract

Current carbon emission targets call for energy efficiency improvements in existing residential buildings. Previous research highlights that renovations are commonly undertaken in reaction to urgent problems or opportunities. The present study estimates and compares the influence of critical events (technical failures, changes in household capacities or composition, subsidies) on retrofitting the building envelope, changing the heating system, and installing photovoltaics or solar heating. An online survey of 621 Austrian homeowners reconstructed individual timelines of critical events and renovations. Regression analysis identifies how strongly critical events influence the occurrence and the pace of implementing a renovation. Trigger effects are confirmed only for technical defects of the heating system, roof or windows. Other critical events show barrier effects, making renovations less likely. Accelerator effects, i.e. implementing a renovation more swiftly if preceded by a critical event, appear rarely. Instead, critical events mainly delay planning and preparation of renovation activities. The results underscore the need for a differential perspective, as trigger and accelerator effects do not emerge consistently across different critical events and renovations. Windows of opportunity open only in regards to replacing a broken building component; in all other instances, critical events preclude or protract the implementation of renovations.

Keywords

retrofitting; building energy efficiency; implementation process; biographical events

1 Introduction

Austria has committed to the EU carbon emission reduction target of -36% until 2030 (European Commission 2014, Umweltbundesamt 2019). This concerns also the building sector which contributed 16.1% of Austria's total carbon emissions in 2017 (excluding sectors subjected to emission trading). Even though the building sector has already achieved considerable reductions of -33.1% from 2005 to 2017, additional efforts are needed. While strict energy efficiency standards are enforced in the construction of new buildings, current policy instruments for existing buildings fall short of expectations (BMNT & BMVIT 2018, Umweltbundesamt 2019). Federal and provincial subsidy programs incentivise retrofits of existing buildings such as insulating the building envelope or installing heating systems using renewable energy sources. However, the realised annual renovation rate of private residential buildings has consistently undercut the stated target of 2% and did not exceed 0.8% in the 2006-2016 period (Seebauer et al. 2019).

The ambitious, yet hitherto unattained political objective of comprehensive building renovation raises the question what motivates households to retrofit their home. Homeowners decide to renovate for various reasons: financial profit from reduced energy costs and increased property value; improved living conditions in terms of thermal comfort, building aesthetics and operational convenience; enacting pro-environmental beliefs; access to effective measures and reliable contractors; and other reasons (Achtnicht & Madlener 2014, Aravena et al. 2016, Hafner et al. 2019). However, conceptualising renovations as deliberate, instrumental decisions would be simplistic (Michelsen & Madlener 2010, Laes et al. 2018). Instead, renovations are commonly undertaken in reaction to urgent problems or opportunities, such as technical defects (Zundel & Stiess 2011, Hecher et al. 2017), amenity remodelling (Klöckner & Nayum 2016, Wilson et al. 2018), or transitions in family life (Wilson et al. 2015, Baginski & Weber 2017).

In the present study, these one-off, extraordinary problems or opportunities are termed *critical events*. Critical events are understood as external disruptions of the normal life course, which manifest at a discernible point in time and demand a rearrangement of practices in domestic energy consumption. Critical events are not restricted to technical emergencies from breakdown or damage; they also include turning points in household needs or conditions of domestic life (Wilson et al. 2015). Critical events may have a twofold effect on renovations: a *trigger effect*, initiating the renovation; or an *accelerator effect*, speeding up the implementation of the renovation. This distinction between a trigger and an accelerator effect of critical events connects to the debate that renovations do not happen in singular moments of adoption, but as gradual, drawn-out processes of deciding, planning and ultimately completing the renovation (Friege & Chappin 2014, Klöckner & Nayum 2016).

The aim of the present study is to estimate and compare the influence of critical events on building renovations. A survey among Austrian homeowners reconstructs how renovations were preceded by critical events. The study expands on the previous literature by systematically testing the differential impacts of a broad scope of critical events on several renovations, thereby highlighting that critical events do not uniformly apply to all kinds of renovations. Furthermore, the study not just determines whether a critical event brought about a renovation (trigger effect), but also whether this event incurred a faster progression through the stages of implementing the renovation (accelerator effect).

2 Method

2.1 Data

At the turn of the year 2019/2020, data were collected in an online survey contracted to a commercial online panel provider. The survey population was defined as Austrian homeowners of a detached, semi-detached or terraced house who have their principal residence in this house and who had renovated this house at least once during the last seven years. After excluding fragmentary or negligent responses, the sample comprised n=621 valid cases for analysis.

As data were collected by non-randomised sampling, the sample should not be considered representative for the population of Austrian homeowners. The results might be biased by respondent self-selection, for instance because online panels cannot reach all groups of Austrian citizens. Furthermore, the definition of the survey population excluded homeowners who did not renovate their house within the last years; thus, frequency counts of renovation activities reported in Table 2 are presumably higher than among all Austrian homeowners. However, the interest of the present study lies in exploring the relationship between critical events and renovations, and not in extrapolating to the uptake of energy efficiency renovations on the Austrian property market.

The survey included additional renovation activities and topics on personal drivers for undertaking renovations, energy consumption before and after the renovation, practices of energy consumption and domestic life, as well as attitudes and control beliefs on building technologies. These topics are addressed in a subsequent companion paper and are not subject of the present study.

2.2 Measures

Respondents were asked to retrospectively reconstruct their building and household history, looking back seven years for eliciting renovations, and ten years for eliciting critical events. Respondents stated if and the calendar date when a specific event occurred for six types of renovations, four types of building events, three types of circumstantial events, three types of household events, and two types of subsidies. The range of renovations was selected to cover the main energy efficiency improvements recommended for private buildings (Umweltbundesamt 2019). Critical events were selected to cover the scope of household disruptions discussed in previous studies on triggers of renovation (see Section 1).

Renovations. Refurbishing wall insulation, windows, roof insulation, cellar insulation; changing the heating system; installing a photovoltaics or solar heating module. Renovations were instructed as major building modifications costing several thousand Euro or more and requiring at least one week of labour by the homeowner or contracted craftspeople. Due to restrictions in survey length, respondents could describe up to three renovations in detail. During the last seven years, 127 respondents had conducted more than three renovations. These respondents were directed to report the three main renovations, preferably wall insulation, windows, or heating system, because these renovations typically have the highest impact on residential energy consumption or carbon emissions.

Building events. Breakdown of the heating system, blockage or rupture of water or heating pipes, roof damage, window damage. Building events were instructed as major deficiencies necessitating immediate repair, not just minor servicing for maintenance.

Circumstantial events. Windfall availability of a large sum of money (e.g. inheritance, dismissal pay after quitting employment, expiration of a building loan contract), availability of more personal time for doing construction work (e.g. retirement, reduction in working hours, unemployment), need of care or physical disability (e.g. from sickness or accident).

Household events. Birth of a child, moving in of an adult, moving out or death of an adult. If a household encountered one of these household events multiple times during the last ten years, the event most recent to the analysed renovation is used.

Subsidies. Subsidies co-financing the renovation costs issued by public authorities (from national, provincial or municipal bodies), by private companies (from construction or plumbing businesses). Subsidies are analysed similar to critical events, but do not qualify as such in a strict sense because they do not occur at a specific point in time. Subsidies play out over a longer time period as a household becomes aware of, applies for, submits bills for, and finally receives the payment of a subsidy. Consequently, subsidies are only rated whether they were received for a specific completed renovation or not; subsidies are not linked to a specific calendar date.

Calendar dates of renovations and critical events were given as years; if known, as quarter of the respective year. In renovations, calendar dates were given separately for the steps of the implementation process: (i) considering the renovation for the first time, (ii) concluding planning, (iii) commencement of construction work, (iv) completion or cessation of construction. The time periods between these steps were calculated as the duration of the planning (i-ii), preparation (ii-iii), construction (iii-iv) and total implementation (i-iv) phases. Calendar dates might be inaccurate due to memory bias. However, accurate recollection by respondents was supported by anchoring dates to an overall household timeline, limiting the hindsight period to seven or ten years, and by establishing that the events hold an exceptional and therefore lasting status during the biographical course.

2.3 Analytical approach

The analysis addresses two dependent variables: first, the occurrence of a renovation (dummy variables; 1=occurred, 0=did not occur); second, the duration of the planning, preparation, construction, and total implementation phases of a renovation (metric variables; measured in years). The occurrences of critical events (dummy variables; 1=occurred, 0=did not occur) are employed as independent, explanatory variables. Events are counted as 1=occurred if their calendar date lies before the completion of construction of the specific renovation

(=implementation step iv); thereby, the temporal precedence of cause (the critical event) before effect (the renovation) is leveraged as a prerequisite of causality.

Linear multiple regression analysis identifies how strongly critical events influence renovations, regarding the occurrence of a renovation (i.e. the trigger effect of events; Section 3.2) and the pace of implementing a renovation (i.e. the accelerator effect of events; Section 3.3). Entering all events in a joint regression equation allows determining the unique effect of each event while controlling for the effects of other events; this allows for clearer interpretation as events may co-occur or instigate each other. Technically, the nominal data on renovation occurrence would call for logistic instead of linear regression; however, linear regression facilitates interpretation of unstandardized regression coefficients. Results from the linear regression on renovation occurrence are confirmed by complementary logistic regressions in which the same predictors turn out statistically significant; for reasons of brevity these replication results are omitted from the present paper.

In the regression on occurrence, unstandardized coefficients of events are interpreted as the increase or decrease in the probability of a renovation if the respective event had happened before the renovation. The dummy variable of renovation occurrence is coded as 0 (similar to the probability of an impossible event) or 1 (similar to the probability of a certain event). Thus, an unstandardized coefficient of B=0.22 (the effect of the building event heating failure on the renovation heating system; see Table 3) translates into an increase in renovation probability by 22%. In the regression on pace of implementation, unstandardized coefficients of events refer to the increase or decrease in the duration of a specific implementation phase. For instance, an unstandardized coefficient of B=0.42 (the effect of the household event birth of a child on the planning phase of the renovation wall insulation; see Table 4) means that it takes a household .42 years, or five months, longer to conclude this renovation if a child is born.

3 Results

3.1 Frequency of critical events and duration of renovations

Renovations typically take from one to one and a half years, with the planning phase constituting the main share of the overall implementation process (Figure 1). Wall insulation and cellar insulation are most time-consuming, whereas the installation of photovoltaics or solar heating takes the least time of all studied renovations. However, variance between households is substantial (see SD column in Table 1), suggesting that households draw on a wide range of resources and face different challenges when tackling renovations.

Only few households did not experience any critical event preceding the renovation (see first row in Table 2). In most renovations, just a quarter of the sample undertook the renovation in absence of an event; in photovoltaics and solar heating, this share is comparatively higher (40.8%), indicating that conducting this renovation is less dependent on external impulses.

Across all renovations, the availability of a large sum of money and the birth of a child occur fairly often (ca. 20% to 30%), whereas physical disability or moving out / death of an adult are encountered rarely (ca. 5% to 10%; Table 2). Technical failure of a particular building component is closely related to the corresponding renovation: breakdown of the heating system affected 38.0% of households who changed the heating system; roof damage preceded 34.2% of roof insulations. However, some critical events unfold apart from technical failures. For instance, cellar insulation is often preceded by a breakdown of the heating system, blockage or rupture in piping, and the availability of a large sum; these high frequencies of critical events in cellar insulation should be taken with a grain of salt, though, due to the small subsample (see Table 2 footnote).

About a third of renovations benefited from a public subsidy; about a tenth from a private subsidy (see bottom rows in Table 2). Considering the broad subsidy landscape in Austria, this rather low share may indicate that many households forgo applying for a subsidy because they consider that the involved paperwork and regulations do not pay off against the monetary benefit. Photovoltaics and solar heating is the exception, as 65.7% of this renovation were co-funded by the public authorities.

Compared to the mean duration of renovations (Table 1), the occurrence of a critical event tends to extend the time span needed for completing a renovation. Circumstantial and household events may prolong renovations by several years. Roof insulation seems particularly susceptible to delay by critical events. Again, high variance in the durations of renovations points to inter-household differences in renovation pace.

Figure 1. Mean duration of implementation phases.

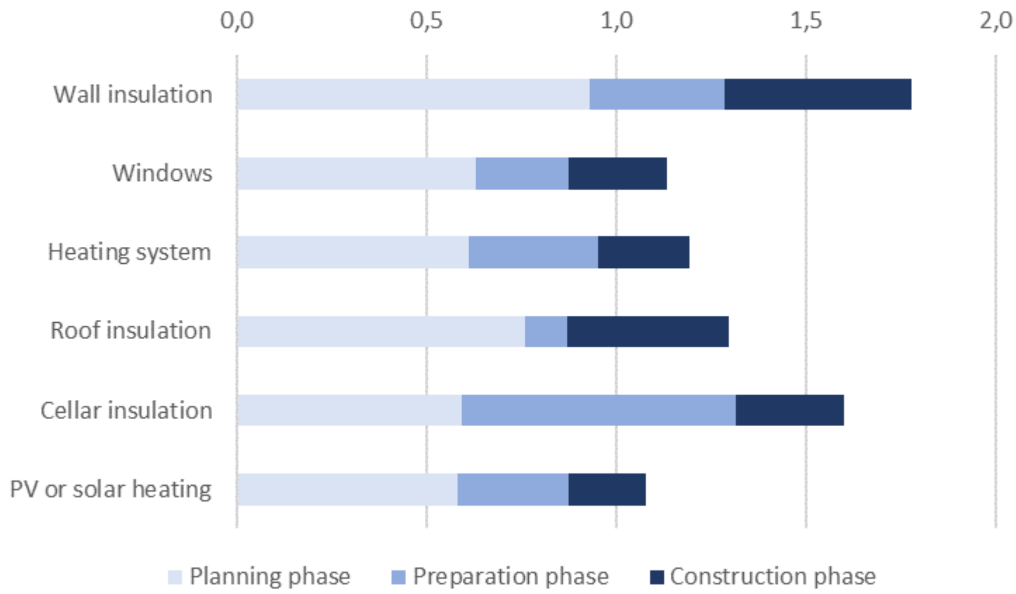

Table 1. Duration of implementation phases.

	Planning		Preparation		Construction		Total implementation	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Wall insulation	0.9	1.2	0.4	0.8	0.5	0.9	1.7	1.5
Windows	0.6	1.0	0.2	0.7	0.3	0.7	1.1	1.3
Heating system	0.6	1.1	0.3	0.8	0.2	0.7	1.2	1.4
Roof insulation	0.8	1.0	0.1	0.6	0.4	1.1	1.2	1.3
Cellar insulation	0.6	0.8	0.7	1.3	0.3	0.6	1.6	1.7
PV or solar heating	0.6	1.0	0.3	0.6	0.2	0.7	1.1	1.5

Duration given in years. Means as in Figure 1. SD=standard deviation.

Table 2. Occurrence of critical events and duration by renovation.

	Wall insulation			**Windows**			**Heating system**			**Roof insulation**			**Cellar insulation**			**PV or solar heating**		
	Freq.	Duration		Freq.	Duration		Freq.	Duration		Freq.	Duration		Freq.	Duration		Freq.	Duration	
	%	Mean	SD	%	Mean	SD	%	Mean	SD	%	Mean	SD	%	Mean	SD	%	Mean	SD
No critical event	26.2			30.2			24.4			29.9			24.1			40.8		
Breakdown heating	21.6	1.9	1.7	7.6	1.4	1.4	38.0	1.0	1.3	17.1	2.4	2.6	37.9	2.4	1.8	11.3	1.2	1.8
Rupture piping	16.5	1.7	1.4	11.6	1.2	1.0	13.7	1.4	1.5	5.3	3.8	4.5	37.9	1.7	1.2	11.3	1.4	1.5
Roof damage	18.0	1.3	1.2	15.1	1.2	1.2	10.7	1.7	2.2	34.2	1.9	2.5	13.8	1.3	2.2	5.6	2.2	1.0
Window damage	12.9	1.5	1.9	21.6	0.8	1.1	11.1	1.7	1.9	13.0	2.9	2.8	13.8	0.7	0.9	5.6	1.8	1.6
Availability large sum	28.1	2.0	2.1	28.4	1.2	1.1	24.8	1.8	1.8	27.3	1.8	1.8	48.3	1.8	1.7	22.5	1.4	1.6
Availability personal time	15.2	2.1	2.4	10.3	2.2	2.7	14.1	2.1	2.5	14.3	1.6	1.7	17.2	2.4	0.9	8.5	3.0	2.8
Disability	4.3	2.5	2.4	1.7	2.2	1.1	4.3	3.8	2.4	6.5	5.4	1.5	0.0	-	-	4.2	4.9	4.3
Birth child	21.5	3.5	2.6	18.1	3.8	2.9	21.4	3.9	2.9	16.9	3.3	2.7	10.3	6.8	0.6	16.9	6.1	2.2
Moving in adult	11.3	2.6	2.3	11.6	3.0	2.8	9.4	2.6	2.5	11.7	3.2	1.7	13.8	4.8	2.1	5.6	3.0	4.0
Moving out / death adult	9.0	2.3	2.1	9.9	2.8	2.2	14.1	2.4	2.4	15.6	3.2	2.5	0.0	-	-	7.0	2.6	3.3
Subsidy public	27.3			32.5			37.9			28.4			50.0			65.7		
Subsidy private	9.4			10.3			8.5			5.2			3.4			14.1		

Frequency (Freq.) among those households who undertook the respective renovation; column totals >100% because some households encountered multiple events. Duration given as length of the total implementation phase in years. SD=standard deviation. n(wall insulation)=256, n(windows)=232, n(heating)=234, n(roof insulation)=77, n(cellar insulation)=29, n(PV solar)=71.

3.2 Critical events as triggers of renovations

A trigger effect appears if a renovation becomes more likely if preceded by a critical event. Table 3 gives the regression results for all six analysed renovations. Regarding building events, the impulse of technical failure on renovating the failing building component emerges prominently: breakdown of the heating system increases the probability of its subsequent change by 22%; roof damage makes roof insulation more likely by 11%, window damage makes window renovation more likely by 24%. However, technical failures do not carry over to other, related building components; for instance, window damage could be expected to encourage households to renovate the entire building envelope in order to avoid thermal leakage. Instead of a bandwagon effect of one renovation carrying over to related renovations, the results point to an opposing effect: breakdown of the heating system decreases the probability of wall insulation, cellar insulation and window renovation by 6% to 9%; roof damage makes a change of the heating system less likely by 11%. Possibly, the need for rapid repair after technical failure exhausts the households' resources, which then need to be recovered before considering an additional renovation.

Yet, the role of household resources does not seem straightforward. Critical events providing additional resources and capacities to the household have a barrier effect: availability of a large sum of money decreases the probability of changing the heating system by 8%; availability of more personal time makes window renovation and photovoltaics or solar heating less likely by 9% and 4%, respectively. Apparently, if they have any statistically significant effect, additional resources direct interest away from renovation, as households might be inclined to spend these resources for recreational purposes. In an alternative interpretation, window renovation or installing photovoltaics or solar heating might necessitate skilled craftspeople so that homeowners cannot contribute personal time to these renovations. At the most basic level, household capacities include the ability to undertake manual work; unsurprisingly, the circumstantial event of need of care or physical disability decreases the probability of window renovation considerably by 17%.

Household events turn out as barriers to renovation, too. The birth of a child makes window and roof renovation less likely by 8% and 6%, respectively; moving out or death of an adult makes wall insulation less likely by 11%, cellar insulation by 3% and photovoltaics or solar heating by 4%. Possibly, these changes in household structure direct attention away from renovation and tie up available income. In case of death of an adult, the remaining, often elderly, partner may no longer wish to and may not have the financial capacity to invest in building maintenance. This overall barrier effect of household events opposes previous findings that homes are continuously adapted to changing demands of domestic life, in particular if practices of everyday life change as the household structure evolves (Wilson et al. 2015, 2018).

Finally, public subsidies are closely associated with the realisation of renovations. Public subsidies increase the probability of all investigated renovations substantially, ranging from +67% in wall insulation to +98% in cellar insulation. These results underscore the statistical difference between descriptive frequencies and regression coefficients: As an example, just 27.3% of wall insulations received a public subsidy (Table 2), but if calculated as a unique regression effect that controls for the supporting or hindering influence of other parallel events, the impact of public subsidies is much more pronounced (probability +67%, Table 3). However, since temporal precedence of subsidy before renovation cannot be established (see Section 2.2), the high regression effects foremost underline that renovations and subsidies tend to happen in concert. The data do not allow discerning whether the subsidy was a constitutive reason for a renovation, or whether the subsidy provided a windfall profit for households who would have undertaken the renovation anyway. By contrast, private subsidies play a marginal, non-significant role.

Apart from technical failures and subsidies, the regression analysis does not yield any enabling triggers with positive coefficients. Instead, the occurrence of building, circumstantial and household events tends to restrict renovations. Most effects of critical events on renovations shown in Table 3 are weak and do not reach statistical significance; however, size and sign of these non-significant effects largely conform with the significant effects.

Table 3. Regression of renovation occurrence on critical events.

	Wall insulation			Windows			Heating system			Roof insulation			Cellar insulation			PV or solar heating		
	B	e		B	e		B	e		B	e		B	e		B	e	
Constant	0.37	0.03	**	0.34	0.03	**	0.28	0.03	**	0.13	0.02	**	0.04	0.01	**	0.08	0.01	**
Breakdown heating	-0.08	0.04	**	-0.09	0.04	**	0.22	0.04	**	-0.06	0.02	**	-0.01	0.01		-0.02	0.02	
Rupture piping	-0.03	0.05		-0.11	0.04	**	-0.11	0.04	**	-0.08	0.03	**	0.01	0.02		-0.03	0.02	*
Roof damage	0.04	0.05		-0.05	0.04		-0.11	0.04	**	0.11	0.03	**	0.00	0.02		-0.04	0.02	*
Window damage	-0.04	0.05		0.24	0.05	**	0.00	0.05		-0.02	0.03		0.01	0.02		-0.03	0.02	
Availability large sum	-0.03	0.04		0.02	0.04		-0.08	0.04	**	-0.02	0.02		-0.01	0.01		0.01	0.02	
Availability personal time	0.00	0.05		-0.09	0.05	**	-0.02	0.05		-0.02	0.03		-0.03	0.02		-0.04	0.02	*
Disability	-0.01	0.09		-0.17	0.08	**	-0.06	0.08		0.03	0.05		-0.02	0.03		0.02	0.04	
Birth child	0.01	0.05		-0.08	0.04	*	0.01	0.04		-0.06	0.03	*	-0.02	0.02		-0.02	0.02	
Moving in adult	-0.01	0.06		-0.02	0.05		-0.06	0.05		-0.01	0.03		0.02	0.02		-0.02	0.02	
Moving out / death adult	-0.11	0.05	**	-0.08	0.05		0.02	0.05		0.00	0.03		-0.03	0.02	*	-0.04	0.02	**
Subsidy public	0.67	0.06	**	0.71	0.05	**	0.70	0.05	**	0.89	0.06	**	0.98	0.04	**	0.95	0.03	**
Subsidy private	-0.03	0.19		0.06	0.41		0.03	0.18		0.08	0.28					-0.02	0.08	
F	12.5		**	21.9		**	24.9		**	21.4		**	54.5		**	91.6		**
R^2 (in %)	20.2			31.0			33.6			29.9			49.7			64.5		

*B=unstandardized regression coefficient. e=standard error of regression coefficient. * p<.10, ** p<.05. Occurrence of a renovation coded as dummy variable, 1=occurred, 0=did not occur. n(wall insulation)=601, n(windows)=597, n(heating)=604, n(roof insulation)=615, n(cellar insulation)=619, n(PV solar)=616.*

3.3 Critical events as accelerators of renovations

An accelerator effect appears if a renovation is implemented more swiftly if preceded by a critical event. In the regression on pace of implementation, small subsamples render many predictors statistically non-significant; moreover, little explained variance (R^2) indicates that the included critical event dummy variables do not suffice to capture the full scope of factors underlying renovation pace. Nevertheless, systematic comparison across renovations and implementation phases offers interesting insights. Tables 4-9 give the regression results for the investigated renovations.

Regarding building events, perhaps most striking is the absence of an accelerator effect of technical failure on renovating the failing building component. In contrast to their clear trigger effect, breakdown of the heating system, roof damage and window damage are unrelated to the duration of the associated renovations of changing the heating system, roof insulation or retrofitting windows. Instead, building events decelerate the planning and preparation phases of selected non-associated renovations by approx. 0.5-0.7 years (e.g. blockage or rupture in piping delays planning of a new heating system by 0.48 years, and delays preparation of roof insulation by 0.62 years). Window damage seems to lead to even longer delays of the planning phase, by 0.70 years in roof insulation and 1.70 years in photovoltaics or solar heating. Presumably, coping with immediate technical defects leads to postponement of design and feasibility inquiries regarding other renovations. Only for two renovations an accelerator effect is observed: Roof damage speeds up planning of the heating system by 0.63 years, presumably because reconstructing the building envelope makes households move up the question of re-dimensioning thermal input on their agenda. Breakdown of the heating system speeds up the preparation of cellar insulation by 1.83 years, presumably because technical works in the heater room provide an opportunity for refurbishing the entire basement.

Circumstantial events only affect the duration of implementation of photovoltaics or solar heating. Similar to their barrier effect of making renovations less likely, implementation takes longer in the light of circumstantial events. Availability of a large sum of money slows down the planning phase of photovoltaics or solar heating by 0.94 years; disability slows down the total implementation phase of photovoltaics or solar heating by 1.57 years.

If critical household events occur, renovations tend to take up to one year longer. The birth of a child prolongs the planning phase of wall insulation by 0.42 years, the construction phase of windows by 0.22 years, and the preparation phase of cellar insulation by 1.51 years. Moving in of an adult extends the preparation phase of changing the heating system by 0.61 years, and the planning and construction phases of roof insulation by 0.95 and 0.78 years, respectively. Moving out or death of an adult extends the preparation phases of window and roof renovations by 0.30 and 0.41 years, respectively.

Public subsidies have divergent effects – on the one hand, they act as decelerators of renovations, by slowing down the construction phase of wall insulation by 0.24 years and the planning phase of photovoltaics or solar heating by 0.55 years; on the other hand, they act as accelerators by decreasing the total time it takes for implementing a windows renovation by 0.41 years. However, these effects emerge too sporadic as to support the overall stereotype of handling subsidies as a protracted, time-consuming process of paperwork and waiting for approval. Possibly, applying for a subsidy requires additional deliberation during the precursory stages of implementation, but as soon as funding is confirmed, construction may proceed swiftly. Private subsidies are relevant only in wall insulation, where they exhibit a counter-directional effect: extending the planning and preparation phase (by 1.11 and 0.70 years) is balanced by shortening the construction phase (by 0.75 years), resulting in a net delay of 1.30 years if the wall insulation draws on a private subsidy.

In contrast to the results on trigger effects, technical failures do not speed up the renovation of the failing building component. However, also contrary to trigger effects, some technical failures carry over to other renovations by decelerating their planning and preparation phases. The decelerator effect also applies to circumstantial and household events. Additional resources or changes in household structure do not encourage homeowners to commence renovations earlier; instead, these events rather have the counter-intuitive effect of delaying renovations to a later date.

Table 4. Regression of renovation pace on critical events, wall insulation.

	Planning phase			Preparation phase			Construction phase			Total implementation phase		
	B	e		B	e		B	e		B	e	
Constant	0.62	0.16	**	0.31	0.09	**	0.32	0.09	**	1.27	0.19	**
Breakdown heating	-0.05	0.23		0.09	0.14		-0.02	0.14		0.08	0.27	
Rupture piping	0.13	0.23		0.05	0.15		0.21	0.15		0.46	0.28	
Roof damage	0.04	0.24		0.00	0.15		-0.13	0.15		-0.04	0.28	
Window damage	0.01	0.28		-0.02	0.17		0.04	0.18		-0.23	0.34	
Availability large sum	0.02	0.22		0.13	0.13		0.13	0.13		0.34	0.26	
Availability personal time	0.20	0.25		0.24	0.16		0.05	0.16		0.44	0.30	
Disability	0.33	0.42		-0.41	0.28		-0.26	0.28		-0.24	0.51	
Birth child	0.42	0.23	*	-0.05	0.14		0.18	0.14		0.53	0.28	*
Moving in adult	0.14	0.27		0.27	0.17		-0.05	0.17		0.28	0.32	
Moving out / death adult	0.54	0.33		-0.26	0.20		0.28	0.20		0.38	0.39	
Subsidy public	0.23	0.22		-0.20	0.14		0.24	0.13	*	0.06	0.27	
Subsidy private	1.11	0.60	*	0.70	0.39	*	-0.75	0.40	*	1.30	0.72	*
F	1.26			1.04			1.46			1.51		
R^2 (in %)	8.1			5.9			7.7			9.5		

*B=unstandardized regression coefficient. e=standard error of regression coefficient. * p<.10, ** p<.05. Duration of the respective implementation phases given in years. n(wall insulation)=185-222.*

Table 5. Regression of renovation pace on critical events, windows.

	Planning phase			Preparation phase			Construction phase			Total implementation phase		
	B	e		B	e		B	e		B	e	
Constant	0.47	0.13	**	0.27	0.07	**	0.13	0.07	**	0.82	0.17	**
Breakdown heating	0.66	0.19	**	0.03	0.11		0.23	0.11	**	1.00	0.25	**
Rupture piping	0.18	0.24		0.08	0.15		0.02	0.15		0.31	0.32	
Roof damage	0.09	0.22		0.02	0.13		0.15	0.13		0.31	0.29	
Window damage	-0.02	0.19		-0.02	0.12		-0.03	0.12		-0.08	0.26	
Availability large sum	0.09	0.18		0.05	0.10		0.08	0.10		0.24	0.23	
Availability personal time	0.09	0.25		-0.20	0.15		0.04	0.15		-0.07	0.33	
Disability	0.55	0.51		0.16	0.32		0.13	0.32		0.86	0.68	
Birth child	0.17	0.20		-0.12	0.12		0.22	0.12	*	0.32	0.26	
Moving in adult	-0.18	0.23		0.17	0.14		0.06	0.14		0.03	0.30	
Moving out / death adult	-0.24	0.24		0.30	0.15	**	0.03	0.15		0.13	0.32	
Subsidy public	-0.19	0.17		-0.08	0.10		-0.11	0.10		-0.41	0.22	*
Subsidy private	-1.02	1.09		0.15	0.67		-0.43	0.67		-1.38	1.44	
F	1.45			0.85			1.09			2.23		**
R^2 (in %)	10.0			5.5			6.5			14.5		

*B=unstandardized regression coefficient. e=standard error of regression coefficient. * p<.10, ** p<.05. Duration of the respective implementation phases given in years. n(windows)=169-201.*

Table 6. Regression of renovation pace on critical events, heating system.

	Planning phase			Preparation phase			Construction phase			Total implementation phase		
	B	e		B	e		B	e		B	e	
Constant	0.59	0.15	**	0.33	0.11	**	0.08	0.09	**	1.00	0.20	**
Breakdown heating	-0.08	0.17		-0.18	0.13		0.13	0.10		-0.16	0.22	
Rupture piping	0.48	0.25	*	0.07	0.19		0.12	0.15		0.63	0.33	*
Roof damage	-0.63	0.26	**	0.33	0.20		0.16	0.17		-0.13	0.35	
Window damage	0.09	0.28		-0.05	0.22		-0.05	0.18		-0.01	0.37	
Availability large sum	0.07	0.20		0.08	0.15		0.20	0.12		0.40	0.26	
Availability personal time	-0.06	0.25		-0.03	0.18		0.16	0.14		0.11	0.33	
Disability	-0.45	0.46		0.42	0.34		0.08	0.28		-0.01	0.61	
Birth child	0.05	0.20		-0.10	0.15		0.16	0.12		0.07	0.26	
Moving in adult	-0.08	0.29		0.61	0.22	**	-0.19	0.18		0.36	0.38	
Moving out / death adult	0.35	0.23		-0.05	0.17		-0.10	0.14		0.22	0.30	
Subsidy public	0.08	0.18		-0.04	0.13		0.06	0.11		0.08	0.23	
Subsidy private	0.83	0.81		0.11	0.51		0.02	0.34		1.33	1.06	
F	1.50			1.63		*	0.96			1.19		
R^2 (in %)	9.7			9.6			5.5			7.8		

*B=unstandardized regression coefficient. e=standard error of regression coefficient. * p<.10, ** p<.05. Duration of the respective implementation phases given in years. n(heating system)=180-212.*

Table 7. Regression of renovation pace on critical events, roof insulation.

	Planning phase			Preparation phase			Construction phase			Total implementation phase		
	B	e		B	e		B	e		B	e	
Constant	0.66	0.20	**	0.05	0.09	**	0.29	0.17	**	0.90	0.22	**
Breakdown heating	-0.17	0.40		0.01	0.18		0.16	0.32		0.05	0.43	
Rupture piping	0.84	0.72		0.62	0.35	*	-0.66	0.64		0.94	0.78	
Roof damage	-0.14	0.27		0.10	0.13		0.19	0.23		-0.06	0.29	
Window damage	0.70	0.48		0.22	0.23		0.35	0.42		1.49	0.51	**
Availability large sum	-0.36	0.36		-0.08	0.17		-0.19	0.31		-0.46	0.39	
Availability personal time	-0.05	0.41		-0.06	0.20		0.43	0.34		0.10	0.44	
Disability	0.48	0.64		-0.23	0.31		-0.55	0.57		0.31	0.69	
Birth child	-0.02	0.36		-0.05	0.17		0.10	0.30		0.28	0.38	
Moving in adult	0.95	0.47	**	-0.25	0.21		0.78	0.36	**	0.48	0.51	
Moving out / death adult	0.12	0.35		0.41	0.17	**	-0.23	0.30		0.39	0.38	
Subsidy public	-0.13	0.31		-0.03	0.14		-0.20	0.26		-0.17	0.33	
Subsidy private	-0.87	1.23		-0.46	0.61		1.23	1.11		-0.59	1.33	
F	1.30			1.27			0.96			1.67		
R^2 (in %)	24.6			21.7			16.5			29.4		

*B=unstandardized regression coefficient. e=standard error of regression coefficient. * p<.10, ** p<.05. Duration of the respective implementation phases given in years. n(roof insulation)=60-70.*

Table 8. Regression of renovation pace on critical events, cellar insulation.

	Planning phase			Preparation phase			Construction phase			Total implementation phase		
	B	e		B	e		B	e		B	e	
Constant	0.63	0.34	*	0.45	0.38		0.05	0.27		1.12	0.56	*
Breakdown heating	-0.40	0.59		-1.83	0.66	**	0.37	0.47		-1.86	0.97	*
Rupture piping	0.19	0.67		2.14	0.74	**	-0.20	0.53		2.13	1.10	*
Roof damage	-0.55	0.67		0.47	0.75		0.12	0.53		0.04	1.10	
Window damage	0.03	0.62		-0.57	0.69		-0.18	0.50		-0.72	1.03	
Availability large sum	0.14	0.50		-0.16	0.56		0.04	0.40		0.02	0.83	
Availability personal time	-0.14	0.66		-0.48	0.73		-0.01	0.52		-0.64	1.08	
Disability												
Birth child	0.74	0.65		1.51	0.72	*	0.16	0.52		2.41	1.06	**
Moving in adult	-0.14	0.61		-0.50	0.68		0.49	0.49		-0.15	1.01	
Moving out / death adult												
Subsidy public	0.01	0.43		0.53	0.48		0.19	0.34		0.73	0.70	
Subsidy private												
F	0.49			2.57		**	0.27			1.99		
R^2 (in %)	19.7			56.3			11.9			49.9		

*B=unstandardized regression coefficient. e=standard error of regression coefficient. * p<.10, ** p<.05. Duration of the respective implementation phases given in years. n(cellar insulation)=27.*

Table 9. Regression of renovation pace on critical events, PV or solar heating.

	Planning phase			Preparation phase			Construction phase			Total implementation phase		
	B	e		B	e		B	e		B	e	
Constant	-0.09	0.28		0.23	0.17		0.06	0.09		0.09	0.33	
Breakdown heating	0.56	0.49		-0.16	0.29		-0.12	0.13		0.44	0.58	
Rupture piping	-0.16	0.58		0.27	0.27		0.36	0.14	**	0.08	0.68	
Roof damage	-0.54	0.62		-0.41	0.41		-0.18	0.18		-1.18	0.73	
Window damage	1.70	0.54	**	0.07	0.36		0.30	0.19		2.07	0.63	**
Availability large sum	0.94	0.37	**	-0.12	0.21		-0.04	0.10		1.04	0.44	**
Availability personal time	-0.43	0.50		-0.15	0.30		-0.48	0.16	**	-0.93	0.58	
Disability	0.70	0.59		0.59	0.39		0.41	0.20	*	1.57	0.69	**
Birth child	-0.43	0.39		0.11	0.23		0.09	0.12		-0.33	0.45	
Moving in adult	0.56	0.52		0.19	0.34		0.01	0.18		0.83	0.60	
Moving out / death adult	0.15	0.62		0.30	0.31		0.02	0.16		1.02	0.72	
Subsidy public	0.55	0.32	*	-0.07	0.20		0.10	0.10		0.63	0.37	
Subsidy private	0.12	0.74		0.33	0.34		-0.24	0.18		0.87	0.86	
F	1.91		*	0.60			1.89		*	2.68		**
R^2 (in %)	41.7			15.0			33.0			50.1		

*B=unstandardized regression coefficient. e=standard error of regression coefficient. * p<.10, ** p<.05. Duration of the respective implementation phases given in years. n(PV solar)=44-58.*

4 Discussion and conclusions

An online survey of Austrian homeowners reconstructed individual timelines of critical events and renovations. The temporal sequence of calendar dates enables to extract events that preceded a specific renovation; multiple regression analysis estimates the unique impacts of events on renovations. The range of critical events investigated includes technical failures, changes in household resources and capacities, changes in the composition of household members, as well as the use of subsidies for the renovation.

Trigger effects are confirmed only for technical defects of the heating system, roof or windows; these defects instigate a subsequent renovation of this particular building component. By contrast, other critical events show barrier effects (that is to say, negative trigger effects). Technical failures make the occurrence of renovations of other building components less likely; availability of additional household capacities and changes in the family structure similarly inhibit the realisation of renovations.

Accelerator effects emerge rarely and apply only when selected technical failures speed up the implementation of other, related building components. Instead, critical events mainly delay the planning (the period from considering the renovation for the first time to concluding planning) and preparation (the ensuing stage up to commencement of construction work) phases of the implementation process.

Taken together, these results underscore the need for a differential perspective, as trigger and accelerator effects do not emerge consistently across different critical events and renovations. This puts into question the common view of critical events as windows of opportunity, when a momentary disruption of everyday routines supposedly facilitates investment choices which would not be taken in the regular course of family life. Such windows seem to open only in regards to replacing a broken building component. In all other instances, critical events apparently preclude or protract the implementation of renovations.

Policy efforts for promoting energy efficiency in buildings should attempt to approach homeowners at the moment in time when they experience technical failures and near-failures. These policy efforts should be wary of negative carry-over effects hindering or delaying renovation of other, non-affected building components. Alternatively, policies could strive to mitigate decelerator effects to ensure swift completion of renovation, for instance by providing technical consulting to families after birth of a child.

Public subsidies are closely associated with the realisation of renovations. While only about a third of renovations received a subsidy, subsidies substantially increase the probability of a renovation. There is no clear indication that the subsidy paperwork would slow down the implementation process. Subsidies seem fairly effective in supporting renovation; however, for lack of time data the present study could not operationalise subsidies in a strict sense as critical events.

The survey method of reconstructing household timelines offers a practical alternative to costly repeated survey waves. Renovation activities are hard to capture in longitudinal surveys as they happen rarely and unfold over prolonged time periods. A longitudinal survey would struggle with aligning the timing of survey waves to the high inter-household variance in occurrence and pace of renovations. The present study takes a deliberately narrow view on the renovation considerations of homeowners by centring on the impact of critical events. Obviously, numerous other factors besides critical events are also relevant in renovation decisions. This reflects on the low explained variance of the regression analyses; however, R^2 is generally impeded by the naturally low variance of the dichotomous predictor variables. Furthermore, renovations of different components of the same building do not occur in a disconnected manner, but may follow up and enable each other over the years. Future analyses of the present dataset will therefore elaborate temporal sequences of renovations and how they promote or prevent each other.

Acknowledgements

This research received financial support from the Austrian Climate and Energy Fund and was carried out within the ACRP program (project number: B670150).

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