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Shall I open the window? An experiment on effort and habits in thermal-comfort adjustment practices

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Abstract

Energy retrofits of residential dwellings, *ceteris paribus*, result in a new socio-technical system characterized by higher room temperatures. In the new environment, individuals might change their type of interaction with the building and exert a certain level of effort to adapt to the new comfort situation depending on their previous practices. In this paper, by means of a Discrete Choice Experiment conducted among 3,161 tenants and owner-occupiers in Germany, we investigate preferences for practices implemented to adjust thermal comfort in retrofitted buildings, thus attempting to reconcile rational choice with social practice theories. We focus on effort and habits but our models also account for the type of control over the room temperature, adjustment time, and clothing. Our results show that in the presence of an obstruction, like potted plants or other decorative paraphernalia, in the proximity of the interaction point with the system, respondents dislike exerting effort to fully open the window but would still make the effort to switch off the heating system. Moreover, respondents with more environmentally-friendly heating and ventilation habits particularly dislike tilting the windows rather than opening them wide; however, after the retrofit they tend to prefer wearing lighter clothes at home. By quantitatively measuring the impact of each factor in the decision-making process, we contribute to the ongoing rebound debate in the energy economics and social psychology literature alike.

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1 Introduction

In Germany policy-makers are not achieving the results expected by the implementation of energy-saving policies in buildings (Galvin, 2015). This calls for the need to closely look into possible explanation for this phenomenon. By affecting the physics of the building, the implementation of deep thermal retrofits leads to a higher indoor temperature, *ceteris paribus*. In a study of the households in Germany, Galassi and Madlener (2016) show that only about 33% of the individuals living in residential buildings would actually feel more comfortable in a warmer indoor environment in winter. The question arises with regard to which actions the non-comfortable individuals would take to bring indoor comfort back to levels prevailing prior to retrofitting and how environmentally-friendly these actions are. Such actions concern operating the windows and the heating system in a way that might involve a rearrangement of the old ventilation and heating habits, i.e. a change in the practice of operating the system in an attempt to deal with the socio-technical mismatch (MacKenzie and Wajcman, eds, 1999; Galvin and Sunikka-Blank, 2013) brought about by the new technology. In a study investigating social-housing tenants' reflections on a new technology, Brown et al. (2014) point out that often new technologies are in conflict with deeply rooted energy-use-related practices. For instance, the practices of heating and ventilating might be disrupted by the installation of an automatic heating and ventilation system, which makes it hard for the occupant to manually adjust comfort to the preferred level.[1] Although to an external viewer some adaptation strategies might seem irrational, the actions undertaken by occupants to adjust thermal comfort are surely not random (Polinder et al., 2013). It follows that, as Milne and Boardman (2000) stress, the type of retrofit measure has an impact not just on the level of comfort achieved but also on a household's subsequent adaptation strategy: when feeling too warm after the retrofit some individuals might try to reduce the radiant temperature by turning down the thermostat, while others might adapt to the new condition by wearing lighter clothing. The type of adaptation strategy will eventually also affect the

[1] We refer to Maréchal and Holzemer (2015) for an extensive review of energy-related household practices.

demand for energy services [2], which indicates the importance of investigating this topic in the light of energy and/or climate policy concerns. Adjustment strategies – such as a reduction of thermostat temperatures or of heating times – lead to no increase in the demand for energy services and energy consumption, whereas an increase in ventilation does lead to higher energy consumption and therefore also to a rebound effect.[3] As stressed in Galvin (2015) and Milne and Boardman (2000), besides the classic price effect, possible sources of rebound effects are the increase in thermal comfort (comfort-taking effect), an unplanned change in lifestyles, the occupants failing to properly operate the new system, also known as the human-technology interface problem, and, most importantly, a failure in the system to satisfy occupants' needs in light of their habits and practices.

An important caveat is that when implementing one adjustment strategy or the other, individuals maximize their utility given their habits and the amount of effort they are willing to invest in the accomplishment of the practice. Notwithstanding, in the field of economics, there are few empirical studies investigating habits in relation to energy consumption. These mainly focus on the circumstances under which it is possible to change a habitual behavior to turn individuals into more sustainable energy users (see e.g. Maréchal, 2010). However, besides the work of Corradi et al. (2013) on cognitive effort and energy consumption, to the best of our knowledge no economic study has been produced on the impact of effort on energy usage. Considering the scarce research of quantitative nature in this field and given that no economic theory can, alone, explain the behavior of occupants in retrofitted dwellings, we turn to social psychology theory – and social practice theory in particular – which we hereby attempt to reconcile with the rational choice theory.

According to Schatzkian social practice theory (Schatzki, 1997), practice is defined as

[2]Energy services are hereby defined as the "benefits that people derive from consuming energy" (Galvin, 2015)

[3]Following the definition of direct rebound effect contained in Sorrell and Dimitropoulos (2008), we identify rebound effect in residential buildings as an increase in the demand for energy services resulting from the implementation of energy-efficient measures aimed at improving the building. This increased consumption offsets the energy savings that might otherwise take place; therefore, the rebound effect is often quantitatively measured as $RE = 1 - \frac{actual \quad energy \quad savings}{expected \quad energy \quad savings}$. The increase in the demand for energy services can be intentional or unintentional. In the case of respondents feeling too warm and wanting to bring the temperature down, rebound effect might originate from a change in ventilation patterns or clothing habits (Galvin, 2015).

an action that repeats itself due to a structure identified by three elements: practical understanding, explicit rules, and teleoaffectivity. Building on Bourdieu's notion of *habitus*, practical understanding refers to the ensemble of knowledge, skills, and principles that guides human action but is impossible to be verbally or explicitly described in full detail. For Schatzki rules are codifications and, as such, can be written down or explicitly communicated. Schatzki's concept of teleoaffectivity refers to a person's wish or need that leads them to act out a given practice. It involves both an emotional and a rational dimension, in a logic of capital maximization that resembles the classical utility maximization problem. We argue that the notion of teleoaffectivity, as defined by Schatzki, is a useful construct for capturing the elements motivating an individual's action, responsible for the maximization of the utility based on a set of items that matter to the actor, in a process that takes place despite the unconsciousness of habits. As such, teleoaffectivity – in this context identified with the wish and need to improve indoor thermal-comfort conditions which motivate the individual to act – is the element enabling the rational investigation of what would otherwise be classified as an unconscious habit. Seen under the Schatzkian light, habits have a rational component, too, which validates the usage of rational choice theory to investigate them. Practices are also entities varying over time, which are subjected to the impact of environmental factors. For example, the installation of a new heating system or insulated walls will have an impact on a household's ventilation and heating practices. This is also reflected in a more recent work by Schatzki (2010) in his concept of "material arrangements", which explores the relationship between material infrastructure and human practices. In fact, reality shows that individuals (households) do not necessarily act in the way policymakers intended they should or assumed they would, because new technologies and evolving infrastructure co-shape their practices (Strengers, 2012) and, as such, also their demand for energy (Røpke, 2009; Gram-Hanssen, 2014; Walker et al., 2014). Thus, from a policy-maker perspective, it is important to investigate how practices change in response to thermal upgrades, and to account for those changes during the phase of design of the measure (Vlasova and Gram-Hanssen, 2014).

Despite extensive research on household preferences for energy-saving measures in residential buildings (see e.g. Poortinga et al., 2003; Jaccard and Dennis, 2006; Kwak et al., 2010; Achtnicht, 2011; Alberini et al., 2013), there seems to be a severe lack of quantitative studies addressing the way that changes in the socio-technical system affect how individuals interact with the new environment to adjust comfort to their preferred levels. By focusing on Germany – where the government has introduced relatively stringent standards for the retrofit of the existing building stock through the *Energieeinsparversordnung* (EnEV, 2009) – we conduct a Discrete Choice Experiment (DCE) among an extensive sample of tenants and owner-occupiers living in either retrofitted or non-retrofitted dwellings. Given the high variety of retrofit options, we propose the DCE to be the most suitable methodology for capturing the impact of a deep thermal retrofit on comfort-adjustment practices. This study builds on Schatzkian social practice theory applied to ventilation practices as framed in Galvin (2013), expanded to include heating interaction practices with the twofold aim of (i) investigating which actions are undertaken to adjust to an increase in indoor temperature; and (ii) explaining the heterogeneity in the preferences for adjustment strategies by controlling for the role of previous, pre-retrofit practices and habits. Therefore, in what follows we consider any thermal adjustment strategy to be a practice.

Besides Schatzkian social practice theory, we draw from additional literature (revised below) to inform the attributes of our DCE. For instance, Walker et al. (2014) find that in interacting with the new system, respondents will do whatever allows them to adjust comfort in the quickest possible way. By introducing responsiveness of the heating system as an attribute in their DCE, a study by Jaccard and Dennis (2006) comes to the conclusion that waiting time is an important aspect when deciding which action to undertake. Leaman (2008) reports the same finding. Previous research in the field has also found energy-saving behavior (e.g. switching off the heating system instead of opening the window) to depend on cognitive effort (Corradi et al., 2013). Overall, however, it remains unclear how socio-technical considerations can lead to retrofit solutions that suit the occupants better (Tweed, 2013).

Results, consistent across the estimation of two econometric models, reveal (*inter alia*) that respondents positively value fully opening the window and switching off the heating system rather than tilting the windows vertically 5-10 degrees or wearing lighter clothes.

Particularly averse to tilting the windows are "well-behaving" respondents who, however, also show a preference for wearing lighter clothes at home.

The remainder of this paper is organized as follows. Section 2 explains the methodology applied to obtain our estimations, emphasizing the construction of the research hypotheses, the design of the DCE, and the econometric models used to obtain the estimation results. Section 3 reports the empirical results, including dealing with the issue of unobserved heterogeneity and introducing past habits into the analysis. Section 4 concludes.

2 Methodology

2.1 Research hypotheses

With the purpose of better understanding comfort dynamics in deeply-retrofitted residential buildings, of better informing our research hypothesis, and of improving the wording of our DCE attributes, we initially conducted semi-structured qualitative interviews among 12 tenant households living in buildings retrofitted according to passive house standards in Germany. Across the 12 households, clothing was mentioned several times as an adjustment measure, especially when the temperature in the apartment was perceived to be too cold. The interviewees were also asked to express themselves on system adjustment times. They considered as "a lot" and "fine" waiting times ranging from one to three hours and of 10-15 minutes, respectively. A system that takes 30 minutes to bring the dwelling to a comfortable temperature was considered to be "not quick". In relation to the system control through thermostats, it seemed that thermostats were "either too imprecise or responded too late" or "difficult to deal with". Moreover, thermostats were not easy to program and, although they allowed a wide degree of flexibility in temperatures across different rooms, programming them was time-consuming; in fact one respondent claimed that it needed "5-6 minutes to switch off the heating in every room". Respondents' idea of a well-functioning heating technology is that of a system which reacts fast and is easy to control; radiators seemed to be appreciated because of their manual-valve regulation and short response times but floor heating was praised in some instances, too.

Insulation was perceived to be “not necessary”, or even “bad” in some cases while in others it was labeled as a “very good” measure. Moreover, respondents complained that insulation led to the development of dust or significantly reduced the square meters of floor area to a point where their window opening habits were also affected. Most interestingly, these interviews also provided us with insights on what room is heated when individuals are at home. It turned out that the living room is the area most often heated up. Additional details about the interviews can be found in Galassi and Madlener (2016).

Against the background of the studies reviewed above and the findings of the qualitative interviews, we formulated the following research hypotheses:

- **Hypothesis 1**: Respondents attach a positive value to the practice of regulating the temperature by tilting the window and turning down the heating;
- **Hypothesis 2**: Respondents find short indoor comfort adjustment times desirable;
- **Hypothesis 3**: In choosing their interaction point, respondents are negatively affected by the presence of obstructions and/or the practice of keeping potted plants and paraphernalia in its proximity; more precisely, they will choose the adjustment solution that minimizes their level of effort, given their practices;
- **Hypothesis 4**: Respondents attach greater value to higher energy savings, *ceteris paribus*;
- **Hypothesis 5**: Respondents are keen on wearing lighter clothes at home when feeling warm;
- **Hypothesis 6**: Respondents attach higher value to lower energy savings, provided that windows can be tilted or lighter clothes be worn.

2.2 The sample

The DCE was conducted in winter 2015/2016, and it was part of a broader survey carried out using the computer-assisted web interviewing (CAWI) technique and designed according to the guidelines in Dillman et al. (2009). As in Galassi and Madlener (2016), our dataset is constituted by 3,161 owner-occupiers and tenants in Germany sampled from the online panel "Respondi". Respondents were screened out to ensure that any individuals not involved in the household decision-making process on energy-related matters, individuals sharing a flat with people other than their relatives, as well as individuals who were subtenants would be excluded from the sample. The tenancy rate was 59.60%, with 46% of the respondents represented by women. The average age was 45 years (varying in the range 18-80 years). The biggest share of respondents comes from the federal state of North-Rhine Westphalia (22%), by far the largest state, followed by Bavaria (15%) and Baden-Württemberg (11%). When it comes to education, approx. 26% of the individuals hold a university degree, while approx. 36% attended school until the 10^{th} grade. Moreover, approx. 52% of respondents declared to dispose of a net household income of <2,600 €/month. In addition to that, the share of indoor smokers and owners of pets was 19.42% and 40%, respectively. Finally, environmental concern among the respondents was measured through the New Ecological Paradigm (NEP) scale (Dunlap and Van Liere, 1978; Dunlap et al., 2000), with a mean value of 56.29 and a standard deviation of 8.23. Respondents reporting an above-average score were considered to be "green".

When it comes to the housing situation, 53.37% of the respondents live in a multi-family dwelling, whereas the share of individuals living in a single-family house is 19.30%. The majority of the dwellings has a floor area of less than 80 m^2.

For what concerns the quality of the building stock, a retrofit measure has been implemented in the past 10 years in about 30.5% of the cases, while in approx. 29% of the instances, such measures were implemented more than 10 years ago. Among those who have implemented a retrofit measure within the last 10 years, 61.34% have at least changed the windows, 43.22% have at least changed the doors, while only 41.01%, 38.32%, and 24.90% have insulated the ceilings, external walls, and floors, respectively.

When it comes to heating, cooling, and ventilation practices, approx. 22% of the respondents keep the temperature below 19 °C, the standard temperature for Germany, approx. 72% turns the heating down when feeling too warm, approx. 23% of the respondents make themselves warmer without increasing the use of the heating or they do not make themselves warmer at all when feeling cold, and 89% of the respondent practice shock ventilation (*Stoßlüftung*[4]).

2.3 The design of the Discrete Choice Experiment

The design of the DCE was computer-generated using the Sawtooth Software®. We chose the "balanced overlap" design based on the D-efficiency as well as the values taken on by the standard errors for interaction terms obtained from simulated data of dummy respondents. The DCE consists of six choice cards as depicted in Figure 1 where the attributes vary randomly, and two identical holdouts to check for the reliability of respondents.

Imagine you lived in an old house that has been comprehensively retrofitted with insulated walls, ceiling/roof, and windows as well as with an energy-saving heating system. In comparison to the non-retrofitted house you can now not only achieve higher indoor temperatures but also significant energy-cost savings. Further imagine that you find the temperature <u>in your living room on a winter day</u> too warm, which alternative would you choose to achieve the desired indoor temperature?

Note: There can be alternatives that seem to be unrealistic. Do not let this bother you and consider the alternative as possible.

	Alternative A	*Alternative B*
Temperature adjustment measure	**I do not adjust anything**	**I turn down the heating**
Adjustment time to the desired comfort	**60 minutes to achieve the desired comfort**	**30 minutes to achieve the desired comfort**
Presence of obstructions in proximity of the interaction point	**None: it is possible to fully open the window and turn the heating down**	**It is not easy to turn the heating down**
Monthly energy savings	**€22**	**€44**
Clothing	**I wear something lighter**	**I do not change my clothes**
YOUR CHOICE	○	○

Figure 1: Example of a choice card, translated from the German language

In each choice card respondents chose between two alternatives the one that best identifies their comfort-adjustment strategy. We are aware of the fact that usually DCEs offer respondents the choice to choose none of the previous alternatives. We believe, however, that in a situation in which comfort has been compromised, respondents must act in order to bring

[4] *Stoßlüften* refers to the practice of achieving short and intensive ventilation by fully opening several windows and doors at home simultaneously for a few minutes.

comfort back to a higher level; our alternatives, moreover, already represent the full spectrum of possibilities that individuals have in reality.[5] The original choice of attributes and their levels was largely confirmed and partially improved through the cognitive pretests conducted among a small group of respondents belonging to different socio-demographic groups. This led to the attribute specification contained in Table 1.

Table 1: Attributes and their levels

Attribute	**Level**
A1. Temperature adjustment measure (ADJUST)	1.1 I open the window fully 1.2 I tilt the window 1.3 I open the window fully and turn the heating down 1.4 I turn down the heating 1.5 I do not adjust anything*
A2. Adjustment time (TIME)	2.1 5 minutes to achieve the desired comfort 2.2 30 minutes to achieve the desired comfort* 2.3 60 minutes to achieve the desired comfort
A3. Presence of obstructions in proximity of the interaction point (OBST)	3.1 None: it is possible to fully open the window and turn the heating down* 3.2 It is not easy to open the window 3.3 It is not easy to turn down the heating
A4. Monthly energy savings (SAV)	4.1 High, customized* 4.2 Low, customized
A5. Clothing (CLOTH)	5.1 I do not change my clothes* 5.2 I wear something lighter

We based the computation of customized energy savings on findings from Galvin (2015). The higher level represents the situation in which no rebound effect occurs and the technical savings from the implementation of the energy efficiency measure are fully appropriated. On the other hand, the lower level represents a situation in which the demand for energy service increases due to a socio-technical mismatch, thus accounting for the presence of a rebound effect (Table 2).

[5] The only unrealistic combination in which A1.5 is shown together with A5.1 in both alternatives of the same choice task only appears in 33 out of the possible 18,966 choice tasks composing the 300 different designs for the 3,161 respondents, which translates into a probability of 0.17%.

Table 2: Customization of the monthly energy savings attribute

Category	Levels	Customized levels (€)
< 40-59 m^2	High	14
	Low	7
60-99 m^2	High	26
	Low	13
100-159 m^2	High	44
	Low	22
>160 m^2	High	66
	Low	33

2.4 The model

The mixed logit model, with attributes' coefficients assumed to follow a multivariate normal distribution, has seen an increase in the number of applications over the last decade, thus becoming a standard in the analysis of choice data. This is mainly due to its ability to relax the Independence from Irrelevant Alternatives (IIA) property of the classical multinomial (also known as conditional) logit model. However, recent studies have raised the question of how much of the heterogeneity captured by this model is due to a *scale effect*, i.e. the level of randomness behind consumers' choices – as embedded in the standard deviation of the error term variance – rather than a *difference in preferences* (known as taste heterogeneity). A new model has therefore gained attention for its ability to allow flexible individual heterogeneity and disentangle one effect from the other: the generalized multinomial logit (G-MNL) model (Fiebig et al., 2010; Greene and Hensher, 2010).

The G-MNL model is a combination of the mixed logit and scale MNL models (Keane, 2006). Following the notation in Fiebig et al. (2010), we use our choice data to estimate the G-MNL in the framework of random utility theory (McFadden, 1974). The utility of person $n \in \{1, ..., N\}$ from choosing the alternative $j \in \{1, ..., J\}$ in the choice task $t \in \{1, ..., T\}$ can be expressed as:

$$U_{njt} = [\sigma_n \beta + \gamma \eta_n + (1 - \gamma)\sigma_n \eta_n]\, x_{njt} + \varepsilon_{njt}, \qquad (1)$$

where x_{njt} is a constant vector with the attribute levels of alternative j, σ_n is the individual scaling parameter, β is the vector of the average attribute utilities, η_n is the vector of individual deviations from β such that $\eta_n \sim MVN(0, \Sigma)$, ε_{njt} is the i.i.d. error term, and $\gamma \in [0, 1]$ is a parameter that determines the relationship between the variance of unexplained taste heterogeneity and the scale, thus specifying the way in which the mixed logit and scale MNL models are nested. By setting $\gamma = 1$ in equation (1) one obtains the G-MNL-II model

$$U_{njt} = \sigma_n(\beta + \eta_n)x_{njt} + \varepsilon_{njt}, \qquad (2)$$

where the standard deviation of the unexplained taste heterogeneity parameter η_n is proportional to σ_n and individual utilities can thus be rewritten as:

$$\beta_n = \sigma_n \beta + \eta_n^*. \qquad (3)$$

Most importantly, the random parameter σ_n is assumed to be log-normally distributed $\sigma_n \sim LN(\overline{\sigma} + \theta z_n, \tau^2)$ with $\overline{\sigma}$ being a normalizing constant and θz_n a vector of respondents' characteristics (Fiebig et al., 2010; Gu et al., 2013). In other terms, it depends on the value taken on by τ whether scale heterogeneity is present or not, with greater values of τ meaning larger scale heterogeneity, while the socio-demographic variables can be used to explain such scale variability across people (vector θ).

Given the standard logit form of the choice probability

$$Pr(y_{nt} = j|\beta_n) = \frac{exp(\beta_n' x_{njt})}{\sum\limits_{j=1}^{J} exp(\beta_n' x_{nkt})}, \qquad (4)$$

following Fiebig et al. (2010) and Gu et al. (2013) the likelihood function for G-MNL-II can be written as:

$$LL(\beta, \tau, \theta, \Sigma) = \sum_{n=1}^{N} \left\{ \int \prod_{t=1}^{T} \prod_{j=1}^{J} Pr(y_{nt} = j|\beta_n)^{y_{njt}} p(\beta_n|\beta, \tau, \theta, \Sigma) d\beta_n \right\}, \qquad (5)$$

which can only be solved with simulation, with a simulated log-likelihood

$$SLL(\beta, \tau, \theta, \Sigma) = \sum_{n=1}^{N} \left\{ \frac{1}{R} \sum_{r=1}^{R} \prod_{t=1}^{T} \prod_{j=1}^{J} Pr(y_{nt} = j | \beta_n^{[r]})^{y_{njt}} \right\}, \tag{6}$$

$$\beta_n^{[r]} = \sigma_n^{[r]} \beta + \sigma_n^{[r]} \eta_n^{[r]}, \tag{7}$$

$$\beta_n^{[r]} = exp(\overline{\sigma} + \theta z_n) + \tau \nu^{[r]}, \tag{8}$$

where $[r]$ indicates a vector generated using Halton draws (and pseudo random draws, in the case of $\nu^{[r]}$) and $\overline{\sigma}$ is set to $-ln\{\frac{1}{N}\sum_{i=1}^{N} exp(\tau)\nu_i^{[r]}\}$.

Estimations were conducted using the *mixlogit* (Hole, 2007) and *gmnl* (Gu et al., 2013) commands in Stata® v.14, setting 500 Halton draws and burning 45 initial iterations (Hensher and Greene, 2003). In addition, standard errors for the G-MNL-II model are robust and clustered at the individual level.

3 Results

In this section we report results from both the mixed logit and G-MNL-II models. Log-odds are presented in Table 3, where levels enter as dummy-coded. Results are largely consistent in sign and level of significance across models 1 and 2. It can be seen that respondents attach a positive value to opening the window fully. Preferences over tilted windows vary widely across the respondents but overall we cannot claim that respondents would tilt the window to adjust comfort. Positively valued are also the two measures involving switching off the heating system. Overall, these findings provide mixed evidence in favor of hypothesis 1. Adjustment times also come with the expected sign: 5 minutes is valued positively while 60 minutes is valued negatively, thus confirming hypothesis 2. When it comes to the presence of obstructions (as in hypothesis 3), it can be seen that the presence of potted plants or other decorative paraphernalia in the proximity of the interaction point does indeed represent a negative limit to the choice of the adjustment strategy, with negative signs of "Obst. window" and "Obst. heating". Hypothesis 4 is also confirmed by the negative sign of "Lower savings", whereas hypothesis 5 cannot be confirmed in light of the heterogeneous (but insignificantly different from zero) preferences for "Lighter clothes". It is also worth noticing that a comparison of the mixed logit and G-MNL-II models based on AIC and BIC lead the researcher to prefer the latter to the former model; in fact, τ – the scale parameter – is positive and significant, thus suggesting the presence of scale next to taste heterogeneity. Although in this work we do aim at measuring rebound effect, we are still interested in capturing those behaviors that might be responsible for it, i.e. tilting the windows and putting on lighter clothes as long as higher energy savings can still be achieved in doing that.

Table 3: Estimation results mixed logit and G-MNL-II (Scaled mixed logit)

Variable	**Model 1 Mixed logit**		**Model 2 G-MNL-II**	
	Mean	S.D.	Mean	S.D.
Window fully open	.211***	.396*	.665*	.610*
	(.050)	(.177)	(.266)	(.271)
Window tilted	.013	.733***	.055	1.937**
	(.050)	(.111)	(.153)	(.720)
Window fully open+heating off	.733***	.623***	2.503**	2.194**
	(.054)	(.129)	(.957)	(.833)
Heating off	.655***	.664***	2.258*	1.811*
	(.054)	(.117)	(.888)	(.738)
5 mins	.427***	.891***	1.512*	2.352**
	(.041)	(.071)	(.612)	(.829)
60 mins	-.442***	.763***	-1.529**	2.470**
	(.040)	(.078)	(.580)	(.946)
Obst. window	-.803***	.660***	-2.768**	1.904**
	(.044)	(.081)	(1.045)	(.738)
Obst. heating	-.792***	.631***	-2.771**	1.750**
	(.043)	(.080)	(1.059)	(.655)
Lower savings	-.485***	1.946***	-1.681**	6.267**
	(.047)	(.076)	(.650)	(2.327)
Lighter clothes	.031	.700***	.080	2.092**
	(.029)	(.059)	(.101)	(.776)
τ			1.629***	
			(.281)	
N°Obs.	37,932		37,932	
N° Resp.	3,161		3,161	
AIC	23142.15		23091.24	
BIC	23313.02		23270.65	

*** = p<0.001; ** = p<0.01; * = p<0.05
Standard errors in parentheses
BIC computed on 37,932 observations

Therefore, in an attempt to verify hypothesis 6 and also the presence of rebound effect, we included in the estimation several interaction terms across the attributes indicating savings, the presence of obstructions, adjustment measures, and clothing (all entering the model as fixed variables). Results are reported for models 3 and 4 in Table 4, where it can be seen that almost none of the interaction terms is significant. Therefore, we reject hypothesis 6 that respondents attach a higher value to lower energy savings provided that windows can be tilted or lighter clothes be worn. Exceptions are represented by the presence of obstructions in front of the heating-system interaction point and the adjustment measure "Window fully open+heating off", which enters the model positively. This indicates that in the presence of obstructions in front of the heating systems, individuals would still exert effort to switch off the heating system, but they would also open the windows widely.

Table 4: Estimation results mixed logit and G-MNL-II (Scaled mixed logit) with interaction terms

Variable	**Model 3 Mixed logit**	**Model 4 G-MNL-II**
sav2_adjust1	.089	.102
	(.104)	(.119)
sav2_adjust2	-.051	-.015
	(.107)	(.120)
sav2_adjust3	.119	.175
	(.104)	(.117)
sav2_adjust4	-.004	.031
	(.106)	(.118)
sav2_cloth2	.110	.148
	(.070)	(.079)
obst2_adjust1	.095	.060
	(.132)	(.149)
obst2_adjust2	-.006	-.014
	(.136)	(.150)
obst2_adjust3	.262*	.183
	(.132)	(.150)
obst2_adjust4	.144	.156
	(.135)	(.153)
obst3_adjust1	.246	.262
	(.134)	(.153)
obst3_adjust2	.040	.049
	(.133)	(.150)
obst3_adjust3	.414**	.416**
	(.134)	(.153)
obst3_adjust4	.185	.222
	(.135)	(.152)
cloth2_adjust1	-.040	-.035
	(.109)	(.124)
cloth2_adjust2	-.035	-.067
	(.110)	(.126)
cloth2_adjust3	-.129	-.175
	(.109)	(.123)
cloth2_adjust4	.152	.163
	(.111)	(.126)
τ		.856***
		(.090)
N°Obs.	37,932	37,932
N°Resp.	3,161	3,161
AIC	23,150.36	23,260.1
BIC	23,466.47	23,584.76

*** = p<0.001; ** = p<0.01; * = p<0.05
Standard errors in parentheses
BIC computed on 37,932 observations

Moreover, the positive and significant interaction term between turning down the heating and the presence of obstructions in front of the windows further confirms hypothesis 3. However, the presence of an obstacle in front of the heating system does not reduce the incentive to interact with this system.

Table 5: Estimation results mixed logit and G-MNL-II (Scaled mixed logit) with selected socio-demographics

Variable	**Model 5 Mixed logit** Mean	S.D.	**Model 6 G-MNL-II** Mean	S.D.
Obst_win*Win+heat	.216* (.104)			
Obst_heat*Win+heat	.289** (.106)		.265 (.153)	
Older*Win+heat	.281*** (.085)		.510** (.166)	
Older*Heating off	.429*** (.087)		.749*** (.188)	
Older*Obst_win	-.285*** (.076)		.460*** (.140)	
Older*Obst_heat	-.281*** (.076)		-.437** (.138)	
Fem*Obst_win	-.297*** (076)		-.458** (.142)	
Fem*Obst_heat	.162 (.090)		-.409** (.135)	
Fem*Low_sav	-.276*** (.075)			
Green*Win+heat	.155 (.082)		.265 (.145)	
Green*5 mins	.242** (.079)		.407** (.146)	
Green*60 mins	-.170* (.076)		-.203 (.124)	
Green*Obst_win	-.410*** (.077)		-.659*** (.160)	
Green*Obst_heat	-.379*** (.076)		-.615*** (.157)	
Green*Low_sav	-.346*** (.090)		-.600*** (.180)	
Smoke*5 mins	-.304*** (.090)		-.425** (.153)	
Smoke*Low_sav			.392 (.204)	
Pet*Light clothes	.121* (.060)		.198 (.103)	
Behave*Win_tilted			-.483** (.163)	
Behave*Obst_win	-.251** (.086)		-.336** (.146)	
Behave*Obst_heat	-.261** (.084)		-.385** (.147)	
Behave*Low_sav	-.380*** (.100)		-.588** (.183)	
Behave*Light clothes	.222*** (.066)		.324** (.114)	
τ			.980*** (.160)	
N°Obs.	37,932		37,932	
N° Resp.	3,161		3,161	
AIC	22,966.39		22,938.03	
BIC[6]	23,316.68		23,296.86	

*** = p<0.001; ** = p<0.01; * = p<0.05; Standard errors in parentheses

[6]Computed on 37,932 observations.

With the purpose of capturing how practices change with the (hypothetical) implementation of the retrofit measure and explaining unobserved heterogeneity, we interacted selected socio-demographic variables with the attribute levels. As a proxy for practices before the retrofit takes place we constructed the variable "behave" which takes the value of 1 if respondents are considered to show before the retrofit thermal adjustment practices that are relatively environmentally-friendly, and 0 otherwise. This is an indicator composed of four other variables, whose answers were gathered in our survey: a dummy taking the value of 1 if respondents keep the inside temperature at 19 °C or below, a dummy taking the value of 1 if respondents use energy non-intensive measures to warm themselves up when cold, a dummy taking the value of 1 if respondents turn the heating down when feeling too warm, and a dummy taking the value of 1 if respondents "shock-ventilate". Thus, a "well-behaving" respondent is a person scoring the value of 1 in at least three out of the four dummy variables above. Besides the interaction terms that are significant in Table 4, the additional interactions included in models 5 and 6 of Table 5 were selected for being significant at least at the 95% level of confidence, based on preliminary regression results (not reported here) ran using the default value of 50 Halton draws.

At first glance, results seem to be largely consistent across models 5 and 6. When all interaction terms are included, we see that the interactions between the presence of obstructions and the adjustment measure are significant in model 5 but turn insignificant in model 6. Most interestingly, according to model 6, tilting the windows seems to be particularly disliked by well-behaving respondents, whereas the combination "opening the window fully and switching off the heating" is particularly valued by relatively older and environmentally concerned respondents. Moreover, shorter adjustment times are seen positively by greener respondents but negatively by smokers. This finding is intuitively plausible if one thinks that smokers might have a preference (not found in our study) for leaving windows open for a longer period to improve the quality of the indoor air. The difficult operability of windows and heating due to the presence of obstructions is negatively perceived by all socio-demographic groups except smokers. A negative preference for lower savings was registered for females, environmentally concerned individuals, and well-behavers. Finally, wearing lighter clothes is preferred only by well-behaving respondents, which signals a change in the practice of wearing clothes at home in comparison to the practice self-reported to be adopted before the implementation of the retrofit.

Finally, by looking at the cumulative density function of the random parameters from model 2, we deduced the share of respondents preferring each level.[7] Therefore, approx. 89% of the respondents would prefer interacting with both windows and heating at the same time rather than not doing anything, whereas only about 5% of the individuals would tilt the windows. Approx. 74% would wait just 5 minutes rather than 30, whereas approx. 27% of them would be willing to wait 60 minutes. Interestingly, 7.35% and 5.71% of the respondents would positively value the presence of potted plants and decorative paraphernalia in front of the windows and the heating system, respectively. Approx. 39% of the respondents would be willing to sacrifice savings in energy bills while approx. 6% of the respondents would be willing to wear lighter clothes to adjust to their comfort levels.

For what concerns data quality, respondents' were consistent across the two holdouts in 74.44% of the cases. From this share one should subtract the 2.56% of respondents who are straightliners, i.e. they always choose the same alternative regardless of the level variation in the attributes. The meaning of all attributes was clear to about 91% of the respondents. Among those who mentioned that at least one attribute was unclear, the presence of obstructions was the least understood one, followed by the adjustment time, whereas the clearest attribute proved to be clothing. When considering the self-reported attribute "non-attendance", we do not see significant differences across the attributes, non-attendance varying between "often" and "always" in 32% to 36% of the cases.

[7] The shares are given by $\Phi(\frac{\beta}{sd_\beta})*100$.

4 Conclusions

This paper aimed at empirically investigating the practice of adjusting thermal comfort of individuals living in thermally deeply retrofitted dwellings, which is relevant in light of energy and/or climate policy concerns. In doing that, particular attention was given to practices responsible for rebound effects. Results – obtained by means of a DCE across tenants and owner-occupiers in retrofitted and non-retrofitted dwellings – bring no evidence of trickle ventilation being preferred. However, it is clear that the presence of obstructions in front of the windows does require respondents to exert more effort when interacting with the system. Most interestingly, we find no evidence of retrofitting changing window opening practices. Despite the fact that clothing is largely insignificant across the models estimated, there seems to be indeed a change in clothing practices, with well-behaving respondents showing a clear preference for wearing lighter clothes after the retrofit. It might be that results for lighter clothes are insignificant not on account of this level being less preferred, but rather because the practice associated to this attribute is less burdensome and therefore most often overlooked. There is, however, no evidence in the self-reported attribute "non-attendance" pointing in this direction. Overall, of our six hypotheses only hypotheses 2, 3, and 4 are confirmed by our findings.

In terms of Schatzkian social practice theory, results indicate that changes in the material arrangement – as those induced by the introduction of a new technology which modifies the physics of the building – do not necessarily lead to a socio-technical mismatch; in fact, the data does not support hypothesis 6 foreseeing the presence of a rebound effect, as the elicited strategies put in place by the respondents to bring comfort back to the optimal levels are overall rather environmentally friendly. However, there seems to be evidence of a clash between the practice of ventilating and that of having obstructions (e.g. potted plants and other decorative paraphernalia) in the proximity of the windows, a finding in line with Galvin's (2013) study. This points to the need for better investigation of occupants' practices before the retrofit is implemented in order to ensure that after the retrofit the new practices will not run against the old ones and therefore also against the full exploitation of the energy-saving potential, as suggested by Vlasova and Gram-Hanssen (2014).

Although we do not find evidence of any specific practice that might justify the presence of a rebound effect, we cannot totally exclude that rebound effects might have taken place; in fact, as stressed in Galvin (2015), a mere price effect – not object of this work – might still be playing a role inducing respondents to warm up more rooms or to heat their rooms for longer periods. Notwithstanding, we consider our findings important since they overall exclude the hypothesis that a rebound effect is induced by a change towards less environmentally-friendly practices that occur once retrofit is put into place. This finding seems to be in line with the strand of psychological literature for which there are positive behavioral spillovers induced by the (here hypothetical) implementation of the retrofit measure (self-perception theory originally developed by Bem (1972) and applied in Thøgersen, 1999; Thøgersen and Ölander, 2003; Cornelissen et al., 2008). Future research will have to investigate this channel in a more comprehensive way, as well as take the price effect into consideration.

On a methodological note, we can conclude that the generalized logit model produces better estimates than the more frequently used mixed logit model by accounting for scale heterogeneity. This finding suggests the presence of respondents with lexicographic preferences, which may be attributed to the complexity of the task. Moreover, aware of the methodological difficulties of conducting empirical, quantitative studies based on social practice theories (Halkier and Jensen, 2011; Hansen, 2016), we argue that the structural character of such theories is preserved, since inference based on individual data is done by social categories.

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