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Tackling the interplay of occupants' heating practices and building physics: Insights from a German mixed methods study

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A B S T R A C T

The European Union seeks to reduce CO_2 emissions in the residential sector by introducing ever stricter energy efficiency standards for newly constructed projects and energy-oriented modernisations. Despite these regulatory efforts, the actual energy consumption significantly deviates from these ambitious goals. Based on this observation it will be argued that it is possible to explain this deviation by putting the focus on users' practices rather than solely focusing on building physics. In order to determine the impact of building physics and user behaviour on heating energy consumption separately, a mixed methods approach was developed. Actual heat energy consumption data of flats in two German refurbishment areas was collected and semi-standardized interviews with the inhabitants of 80 of these households were conducted. We use qualitative data to identify households' practices related to energy consumption and measure the relative impact of these practices with quantitative data. Aside from the building physics, we can observe that preferences for thermal comfort as well as ventilation practices have the strongest influence on households' heating energy consumption after retrofitting. Based on these findings, it is argued that future policy measures should focus on user-technology interface design rather than solely focusing on ever stricter efficiency standards.

1. Introduction

The European Union's "2020 climate & energy package" [1] aims to reduce greenhouse gas emissions by 20% compared to 1990 by raising the share of renewables to 20% and improving energy efficiency by 20%. One of the measures of the "Energy Efficiency Directive" is an annual rate of 3% in energy efficient building renovations. Efficiency measures in the residential sector seek to reduce heating related energy consumption as it accounts for up to 67% of the households' total energy demand in Germany [2]. However, planned reductions of energy efficient renovations are often not achieved and the existing literature points to a large variance in heating energy consumption of households [3]. Social sciences usually have a strong focus on the influence of socio-demographic factors as well as households practices on heating energy consumption, while building physics are not taken into account [4–6]. Considering both, sociodemographic as well as building physic factors and their inherent dynamics, can reveal important aspects about heating energy consumption, helping to reach reduction targets. Deducing that "efficiency first" by itself will not be sufficient in achieving planned reductions in greenhouse gas emissions, we aim to add to the existing research by explaining household's energy consumption with regard to the building physics. We present findings from our case study, which was conducted in buildings of two refurbishment areas in Germany, where households' energy consumption was approached through a mixed methods design, combining quantitative data on building physics and actual consumption according to energy bills, with qualitative data on consumption behaviour based on semi-standardized interviews. Considering that heating is usually carried out without much reflection by households, we use the framework of practice theory, which will be explained in Section 2. Following a description of our data and methods in Section 3, Section 4.1 presents practices related to households' heating consumption derived from the interviews. In Section 4.2, bearing the building physics in mind, we then proceed to quantify the impact of these practices prior and after retrofitting. In Section 5, we will discuss our findings, and derive policy implications in Section 6.

2. Conceptual framework

In order to account for households' practices as well as the influence of building physics on energy consumption, two important aspects must be considered. First, a practice theory framework is used to analyze

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households' practices. Second, in order to properly account for building physics, the difference between the heating energy demand and actual energy consumption according to bills has to be explained.

Practice theory has already been successfully applied to studies of consumption [7,8] and enjoys great popularity in studies on energy consumption. There is a wide range of empirical research, for example explaining energy consumption in different cultural backgrounds [9], the use of air conditioning [10], stand-by consumption of electrical devices [11], electricity consumption [12], transportation [13], heating energy consumption [4,14], ventilation [15] and energy retrofits [16]. Practice theory not only challenges the image of actors making conscious rational decisions by pointing to the importance of routinized behaviour and (implicit) knowledge [17], it also focuses on "settings", such as historically grown infrastructures, specific norms and beliefs, interconnections with other practices, as well as regulations that influence certain practices [18,7]. Furthermore, Reckwitz emphasizes, that without "things", many practices would not be possible [19]. The practice of driving a car is not possible without a car, it cannot be analysed without taking the material side into account: which requirements do practioners face? Which knowledge and physical movements are required?

Our analyses is based on the components of practices as described by Shove and Pantzar [20]: meanings, competences and material arrangements. *Meanings* describe households making sense of what they do and why they do it. They include beliefs, attitudes, and understandings related to home and heating, such as feeling cosy at home or saving energy due to financial reasons. Practices rely on specific *competences*, for instance the (informal or explicit) know-how about the heating system/thermostats or information on how to ventilate correctly. The third element are *material arrangements*, things, such as the technology involved in heating practices and building physics, e.g. thermal insulation or heating systems. As explained above, practices depend on specific settings and arrangements. This is of particular interest when observing practices of energy consumption: a change in material arrangements, energy efficiency renovation for instance, can lead to (unintended) changes, e.g. the "rebound effect".[1] These changes in "elements" [20], such as the shift from automatic to manual transmission in cars, might result in a situation, in which common practices do no longer fit the specific setting [21]. Thus, if elements disappear or change, practices might disappear or change, and vice versa.

In order to take the material arrangements, i.e. building physics, into account, we refer to the concept of energy performance rating (EPR) [22]. The EPR is calculated by including factors such as building age and size, heat loss through outer surface area etc. [23]. The measure represents the "expected" energy consumption a building is supposed to have according to standardized calculations [24]. Among other things, the EPR is used to assess the performance of a renovation measurement, calculating the expected energy consumption of a building prior and after retrofitting. Usually, the user's behaviour is held constant and based on assumptions rather than actual observations [25]. This leads to a situation, in which the EPR differs from the actual heating energy consumption according to bills. In the following analysis we will therefore refer to the EPR as *"energy demand"*, whereas the term *"energy consumption"* stands for the actual energy consumption of households – influenced by their behaviour.

Investigations of the actual energy consumption after retrofitting show, that savings are often lower than predicted. This effect is usually described as the "rebound effect". However, as elaborated by Sunikka-Blank and Galvin [24], another reason for lower reductions is the calculation method, which does not take the actual consumption before retrofitting into account. Possible savings are not as high as expected, because users in non-renovated buildings often consume up to 30% less than anticipated, which is referred to as the "prebound effect" [21]. Merely calculating an energy demand while holding users' behaviour fixed does not sufficiently explain the actual energy consumption. Nonetheless, building physics have a high influence on energy consumption. For instance, a flat situated at the corner of a building has a very large wall surface area through which heat diffuses into the atmosphere. Consequently, more heating energy is needed to heat up such a flat compared to a flat situated in the middle of an apartment building with less outer surface area. In order to figure out which part of consumption is accounted for by behaviour and which by building physics, a flat-specific heating energy demand needs to be taken into account (c.f. Chapter 3). Even though a broad range of literature focusing on the relation between heating energy consumption and socio-demographics such as household size [26], household income [27] and education [28] exists, to our knowledge literature explaining the impact of households' heating practices while controlling for the heating demand of the households' flats is rare. Hence, we aim to explore household's practices influencing energy consumption and measure their impact by using a mixed methods approach, combining quantitative data on building physics as well as consumption data according to bills with qualitative interviews from two refurbishment areas.

3. Data & methods

In order to explain the variance of heating energy consumption practices, but also measure their impact, we have to analytically discern the amount of consumption caused by building physics and the consumption influenced by household's behavioural patterns. In other words, measuring the impact of household's consumption practices requires information about the flat-specific energy demand. This demand depends on several factors: number and quality of windows, wall surface area, position of the apartment in the building (ground, middle or top floor), and its thermal insulation properties. Based on this information, the consumption patterns of the household can be analysed independent from the building physics.

We were able to record data on households' heating energy consumption in combination with the heating demand according to building physics in apartment buildings subject to energetic retrofitting in the cities of Ulm and Munich, both situated in the south-eastern part of Germany (Table 1). Each building includes multiple apartments and is managed by a social housing association. With the support of the housing associations and after gaining permission from the households, we were able to collect the actual heating energy consumption according to bills for each household and anonymised it. In the city of Ulm we collected consumption data before and after retrofitting. From a total of 184 flats in the buildings in Ulm prior to the retrofit, 177 households agreed to pass on their bills. In the course of the retrofit, some flats were merged, resulting in fewer flats after retrofitting. Drop-outs only occurred when households relocated due to this measure or private reasons. For the 33 apartments in Munich we only have consumption data after the retrofitting for 31 households, because the buildings did not have central heating prior the retrofit. Therefore our data includes a higher number of observations after the retrofit. The total heating energy consumption according to the bills for each household was converted into heating energy consumption per square metre and year (kWh/m^2/a) and adjusted with local temperature correction factors.

Since the households live in different flats (size, wall surface etc.), their consumption differs due to the buildings physics. Therefore our research group developed a tool to account for a flat-specific heating demand according to building physics (with the user's behaviour held constant, similar as for the EPR for buildings) [29].[2] We used architects'

[1] The rebound effect states, that energy consumption increases after an improvement in energy efficiency of buildings and appliances [50,67,68].

[2] Further information is available in our working paper [29]. Calculations and theoretical assumptions for this calculator have been drawn from an already existing tool for buildings issued by the German IWU [69].