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Dorothée Charlier and Adan L. Martinez-Cruz

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Department of Economics, Umeå University, S-901 87, Umeå, Sweden

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Do habitual energy saving behaviors of household heads impact energy consumption in their own dwelling? An exploration in the French residential sector

By:

Dorothée Charlier [a]

Adan L. Martinez-Cruz [b, c, d]

[a] Institut de Management,
Université Savoie Mont-Blanc
dorothee.charlier@univ-smb.fr

[b] Department of Forest Economics
& Centre for Environmental and Resource Economics (CERE),
Swedish University of Agricultural Sciences (SLU),
Sweden
adan.martinez.cruz@slu.se

[c] Centre for Energy Policy and Economics (CEPE),
ETH-Zurich,
Switzerland

[c] Department of Economics
Centro de Investigacion y Docencia Economicas,
Mexico

Abstract:

This paper investigates whether habitual energy saving behaviors of a household head impact actual energy consumption in his/her own dwelling. In doing so, this paper compares actual energy consumption across French households that, with exception of household heads' energy saving behaviors, are similar in observables –including household composition and dwellings' energy efficiency. Comparisons are carried out within three subsets of households, based on renovation status of dwellings –i) no renovation; ii) with renovations tackling health- and/or energy-related issues; and iii) with renovations aiming to increase thermal comfort. No differences in actual energy consumption are documented across the three subsamples. We interpret this result as suggesting that habitual energy saving behaviors of household heads may not compensate energy intensive behaviors of other household members and, consequently, may produce no discernible impact on their own dwelling's energy consumption. This result highlights the potential for misleading conclusions when imputing the energy saving behaviors of the household head to the entire household –a conventional practice in a number of literatures. The French residential sector is taken as study case due to the uniqueness and richness of data collected by PHEBUS –the Performances of Housing, Energy Equipment, Needs and Uses of Energy Survey.

JEL Classification: Q41; Q49

Keywords: Habitual energy saving behaviors; household head's preferences; energy performance gap; French residential sector; propensity score matching.

1. Introduction

During the last couple of decades, the building sector has experienced a steady decrease in energy requirements due to the use of insulation and more efficient heating and ventilation systems (Guerra Santin, 2013). However, a wide variation in energy consumption is still observed among buildings that theoretically should experience similar consumption –ranging from 1.2 to 2.8 times when comparing identical buildings (Schakib-Ekbatan et al., 2015), with some studies reporting actual energy consumption reaching as much as 2.5 times the predicted or simulated one (Zou et al., 2018).

While extensively discussed in the engineering literature,[1] this *energy performance gap* has somehow been overlooked by economists who may argue that this gap is embedded into the *energy efficiency gap*.[2] However, what seems to be behind the energy performance gap is not that consumers are failing to carry out energy saving investments but instead that they are missing out on the savings of such investments –implying that an energy performance gap may remain even if the energy efficiency gap is closed. An illustrative example has recently been documented by Davis et al. (2019) who, based on a quasi-experimental setting, report null impacts on electricity use and thermal comfort from energy efficient upgrades to houses located in North-east Mexico. In contrast to these null effects, engineering estimates had predicted a decrease in electricity use of up to 26%.

Economists may also suspect a rebound effect behind the energy performance gap. The existence of a rebound effect implies that consumers do not miss out on their savings but rather decide to re-optimize their consumption. Although there is evidence of a rebound effect in the residential sector (e.g. Aydin et al., 2017; Hediger et al., 2018), some authors have argued that it has been overplayed (Gillingham et al., 2013).

Habitual energy saving behaviors have also been argued to impact the energy performance gap. These behaviors refer to everyday actions that directly influence energy use at either no or minimal structural changes on dwellings –e.g. thermostat setting, closing off of unused rooms, window closure when heating is on (Barr et al., 2005). The literature on energy saving behaviors has focused on characterizing energy savers across a wide range of contexts (e.g.

[1] See Zou et al. (2018) for a review focusing on 227 studies published during the previous decade.

[2] The energy efficiency gap refers to the failure of consumers to make energy saving investments that have positive net present value which leads to a slower diffusion of energy-efficient products than would be expected if all positive net present value investments were made (Gillingham and Palmer, 2014).

Belaid and Garcia, 2016; Nauges and Wheeler, 2017; Quaglione et al., 2017; Wang et al., 2018).

Fewer studies have documented impacts from habitual energy behaviors on actual energy consumption, with mixed results. For instance, Davis et al. (2019) documents that part of the explanation for the null effects in North-east Mexico is that most households in their study kept the habit of opening windows on hot days, nullifying the thermal benefits of roof and wall insulation. Analyzing panel data on Dutch households and measuring energy saving behaviors as the propensity to decrease the temperature at night via thermostat settings, Brounen et al. (2013) document lower energy expenditures in households where respondents carry out energy saving behaviors. Focusing on a cross-section dataset collected in Hungary and carrying analysis at the individual level, Tabi (2013) documents no differences on stated energy consumption and estimated CO2 emissions across degrees of energy saving behaviors.

In this context, this paper implements a comparison of actual energy consumption across French households that, with exception of household heads' energy saving behaviors, are as similar as possible in observables –including household composition and dwellings' energy efficiency. In addition, because differences in energy consumption does not necessarily translate into differences in CO_2 emissions (Palmer and Walls, 2015), this paper also compares estimated CO_2 emissions. Comparisons are carried out within three subsets of households, based on renovation status of dwellings –i) no renovation; ii) with renovations tackling health- and/or energy-related issues; and iii) with renovations aiming to increase thermal comfort. We observe no differences –neither in actual energy consumption nor in estimated CO_2 emissions. This lack of differences holds across the three subsets of households.

We interpret the lack of differences as suggesting that habitual energy saving behaviors of household heads may not compensate energy intensive behaviors of other household members and, consequently, may produce no discernible impact on their own dwelling's energy consumption. The lack of differences across renovated and not renovated dwellings imply that the null effect is not driven by the energy efficiency of the dwelling. The results in this paper suggest that a policy aiming to close the energy performance gap via changes in energy saving behaviors should make sure to target all members in the household –not only the head of the household.

This paper also brings to the discussion the potential for misleading conclusions when energy behaviors of respondents –usually household heads— are used to make inferences about energy consumption at the household level. Although this is conventional practice in the energy economics literature, engineering and psychological literatures provide evidence of intra-household heterogeneity in preferences for thermal comfort and the associated energy saving behaviors –which make it problematic to impute one respondent's answers to the household. For instance, Karjalainen (2007) documents gender differences in thermal comfort and use of thermostats that hold across three thermal environments –homes, offices and a university. This intra-household heterogeneity has been documented in several countries located in different continents and not only across gender but also across age and personal control of temperature (e.g. Enzler et al., 2019; Hwang et al., 2009; Luo et al., 2014; Tweed et al., 2015; Wang et al., 2018).

Taking as departure point the documented intra-household heterogeneity in both preferences for thermal comfort and the corresponding energy saving behaviors, the identification strategy in this paper relies on distinguishing between preferences of a household head and preferences of the rest of household members. This distinction seems unnecessary when it comes to energy expenses or dwelling characteristics but in this case it provides the justification to conceptualize preferences on energy savings of the household head as randomly assigned to the rest of the members in the household –resembling a discontinuity or a quasi-experiment.[3] Under such conceptualization, this paper first confirms that French household heads preferring energy savings over thermal comfort also report a higher rate of energy saving behaviors. Then propensity score matching techniques are used to pair households in observables, with exception of the household heads' preferences for energy savings.

The empirical analysis in this paper takes advantage of unique data collected through PHEBUS –the Performances of Housing, Energy Equipment, Needs and Uses of Energy Survey. This survey is particularly useful for our purposes because it not only collects information about patterns of energy consumption via a face-to-face interview to the household head of the dwelling, but it also includes the results of an energy audit that reports

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[3] Equivalently, another way of conceptualizing our exercise is that we carry out an impact evaluation of how effectively the preferences of a household head are passed along to the rest of the household members.

the dwelling's actual energy consumption. Both types of information allow us to identify households with similar household composition and dwelling characteristics and energy performance.

Three features embedded in PHEBUS are essential for the empirical strategy in this paper. First, respondents report whether, when it comes to indoor heating, they prefer thermal comfort or energy savings. Second, respondents report whether they carry out specific habitual energy saving behaviors. Third, respondents were filtered such that only occupants involved in the household energy use decision process could answer the survey. The latter feature is a common filter to increase the chances that household heads respond a survey – and, accordingly, we refer to respondents of PHEBUS as household heads.

The rest of this paper is structured as follows. Section 2 describes three literatures to which this paper relates –including the literature documenting intra-household heterogeneity in preferences for thermal comfort and corresponding energy saving behaviors. Section 3 describes our data –including i) the testing on PHEBUS that French household heads preferring energy savings also report a higher rate of energy saving behaviors; and ii) the report of pre-matched comparisons of energy consumption and estimated CO_2 emissions. Section 4 provides further justification of our identification strategy. Section 5 reports results from the comparisons across matched samples. Section 6 concludes and discusses the implications.

2. Related literature

This paper intersects three streams of literatures. One literature has focused on the factors behind the energy performance gap –in particular, we describe the stream that has dealt with habitual energy saving behaviors. A second literature documents the intra-household heterogeneity in energy saving behaviors associated to preferences for thermal comfort. A third literature focuses on the determinants of energy consumption in the French residential sector –in particular, the studies that have previously analyzed PHEBUS.

2.1. Occupants' behaviors and energy performance gap

Differences between predicted and actual energy arise from a prediction based on parameters that assume unrealistic range of values (Daniel et al., 2015). One of such parameters refers to occupants' interaction with their dwelling. For instance, engineering models may not consider that occupants usually re-optimize consumption once a dwelling has become energy efficient which leaves the door open for the possibility of an increase in actual energy consumption – which is known as rebound effect. There is a large literature documenting this effect. Gillingham et al. (2016) provides a critical overview of the rebound effect and its relative magnitude.

This paper is more concern with *habitual actions to save energy*. These actions refer to everyday behaviors that directly impact energy use at either no or minimal structural adjustment. These behaviors are habitual in the sense that are part of an individual's lifestyle. A non-exhaustive list of habitual energy saving behaviors include thermostat setting, closing off of unused rooms, altering room use, window closure when heating is on, using a clothes line rather than a tumble drier, putting a full load of washing on rather than a half load, and the amount of maintenance undertaken on existing appliances (such as boilers, fires and washing machines) to ensure their best energy efficiency (Barr et al., 2005).

In contrast to behaviors driven by a rebound effect, habitual actions are done *without thinking*. Taking opening of windows as an example, assume two individuals in a recently renovated dwelling. To better take advantage of the new heating system, both receive the suggestion to keep windows closed when the heating is running. One of them keeps windows closed because even before the renovation, she was in the habit of not opening the windows. The second individual keeps windows closed because she wants to save on energy bills to buy a new efficient car. The latter person is re-optimizing and adjusting his behavior accordingly. The former person is carrying on her habitual behavior.

There is an ample literature documenting characteristics of habitual energy savers across a wide range of contexts, including major cities in Asia (Hori et al., 2013), urban China (Wang et al., 2018; Wang et al., 2018), OECD countries in general (Nauges and Wheeler, 2017), Italy (Quaglione et al., 2017), Sweden (Ek and Soderholm, 2010; Martinsson et al., 2011), France (Belaid and Garcia, 2016), and a medium-size city in UK (Barr et al., 2005).

With mixed results, fewer studies have focused on whether habitual energy saving behaviors impact actual energy consumption in the residential sector. Brounen et al. (2013) analyze panel data on Dutch households and measure energy saving behavior by the respondent's choice of thermal comfort via thermostat settings –the propensity to lower temperature during the night. They document that respondents with higher incomes choose higher comfort levels, and age is negatively related to lowering the temperature at night. When modeling actual household energy consumption, they find that households where respondents choose lower temperatures at night face lower energy expenditures.

Focusing on a cross-section dataset collected Hungary and carrying analysis at the individual level, Tabi (2013) documents no differences on stated energy consumption and estimated CO2 emissions across degrees of energy saving behaviors. Four profiles were identified based on environmental actions carried out by respondents. Two clusters describe individuals undertaking energy saving behaviors: energy savers and supergreens. Supergreens are willing to reduce energy consumption and travel in a more environmentally friendly ways instead of using cars. Accordingly, supergreens have the lowest carbon emissions for car use. However, their emissions due to energy consumption for heating and electricity are similar to the browns', and in some cases, total emissions from supergreens exceed emissions from browns.

2.2. Intra-household heterogeneity in preferences for thermal comfort and associated energy saving behaviors

Both engineering and psychological literatures provide evidence of intra-household heterogeneity in both preferences for thermal comforts and energy saving behaviors associated to such preferences. For instance, an issue discussed in engineering studies is how to deal with higher levels of thermal discomfort reported by older people in comparison to younger co-occupants (van Hoof et al., 2017). Focusing on study cases across UK, Tweed et al. (2015) document that older occupants reporting thermal discomfort pursue satisfactory thermal conditions through measures that produce spatial variation in temperature which ultimately impacts a household's actual energy consumption.

Focusing on Finland, Karjalainen (2007) documents gender differences in thermal comfort that hold across three thermal environments –homes, offices and a university. In comparison to males, females are less satisfied with room temperatures, prefer higher room temperatures, and feel both uncomfortably cold and uncomfortably hot more often. Although females are more critical of their thermal environments, males use thermostats in houses more often than females. This result points out to a potential gender difference in the contribution to actual energy consumption. Consistently, Enzler et al. (2019) report that, in a sample of households located in the German-speaking part of Switzerland, females use about 23% less electricity than their male co-occupants.

Intra-household heterogeneity in preferences for thermal comfort and energy savings have also been linked to the personal control that occupants have over the temperature they experience. Occupants with more personal control on room temperature have stronger preferences for energy savings and tend to accept wider ranges of indoor thermal environments, with the consequential impact on actual energy consumption (Wang et al., 2018). This link has been documented in climates ranging from China in winter (Luo et al., 2014) to hot-humid Taiwan (Hwang et al., 2009).

2.3. Energy consumption in the French residential sector

There is a number of studies documenting energy consumption in the French residential sector. A non-exhaustive list of issues covered by these studies includes i) the high degree of capital constraint faced by lower income households when it comes to daily energy consumption and appliance purchasing behavior (Cayla et al., 2011); ii) the lack of changes in fuelwood demand due to changes in price unless wood represents the main source of energy for heating –which is the case mostly for lower income households (Couture et al., 2012); iii) the different bundles of policies that would help in reaching the French energy consumption goals in 2050 (Charlier and Risch, 2012; Charlier et al., 2018); iv) the presence of free-riding when taking advantage of the tax credits for home insulation introduced in 2005 (Nauleau, 2014); v) the underinvestment in energy efficiency under a split incentive scheme and how a tax credit for dwelling renovation is unsuccessful to solve this underinvestment (Charlier, 2015); vi) the relative importance of occupants' characteristics with respect to physical dwelling characteristics in explaining household energy consumption (Belaid, 2016); vii) the construction of a typology of households based on energy consumption patterns (Hache et al., 2017); and viii) the proposal and testing of an indicator of energy poverty (Charlier and Legendre, 2019).

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Among the studies analyzing PHEBUS, Belaid and Garcia (2016) explore the factors influencing energy saving behaviors in the residential sector. In a first step, they create an indicator of energy saving behaviors that, in a second step, becomes the explained variable in an ordinal least square regression. Five variables are found to positively explain the energy saving behaviors: energy price, household income, education, age of head of household and dwelling energy performance.

Belaid (2017) implements a structural equation model on PHEBUS data to tease out the effects from dwelling characteristics and household attributes on residential energy use. He concludes that the direct effect of household-related attributes –among which energy saving behaviors are included—on residential energy demand is lower than the corresponding effect from the dwelling attributes but, when considering the indirect effect of household factors on energy use, the total impact of household-related attributes on the French residential energy consumption is just slightly lower than that of dwelling characteristics.

The study by Bakaloglou and Charlier (2019) is the closest to this paper because they analyze PHEBUS data to document the contribution of energy saving behaviors to energy consumption. They estimate a discrete-continuous model to examine simultaneously whether preferences for thermal comfort impact the energy efficiency of the dwelling and the final energy consumption. Their main result implies that households preferring thermal comfort over energy savings consume around 10% more energy than similar houses.

3. Preference for thermal comfort and habitual energy-saving behaviors in PHEBUS

3.1. PHEBUS

We analyze the data collected through the 2012 Performances of Housing, Energy Equipment, Needs and Uses of Energy (PHEBUS) survey.[4] PHEBUS was conducted from April to October 2012, and consists of two modules that were implemented separately. The first module gathers household level information through a face-to-face interview to household heads. The second module collects dwelling level energy performance via an energy audit. While the first module was implemented on household heads of 5,405 dwellings, the energy audit was carried out on only 2,385 of those dwellings. Given that the results of the energy audit are essential to the empirical strategy in this paper, we focus our analysis on the dwellings for which an energy audit was carried out –once missing values have been excluded, our sample contains information for 2,243 dwellings.

[4] PHEBUS is available upon request to the Service of Observations and Statistics which is part of the French Ministry of Sustainable Development and Ecology.

3.2. Preference for thermal comfort and energy-saving behaviors

By means of a face-to-face module, PHEBUS gathers household heads' preferences for indoor thermal comfort and their habitual energy saving behaviors. Respondents report whether, when it comes to indoor heating, they prefer thermal comfort or energy savings. Table 1 reports the distribution of preferences for thermal comfort for the entire sample under study and for the subsamples of interest –based on unmatched samples. According to the first row in table 1, thermal comfort is preferred by around 42% of the household heads in our sample –i.e. 935 out of the 2,243. The preferences for thermal comfort may vary with the conditions of the dwelling –i.e. renovation of a dwelling may be associated with the willingness to trade thermal comfort for energy savings. To gain insights on this possibility, the second and third rows of table 1 report the number of respondents that prefer thermal comfort conditional on living in a dwelling that has been renovated. Somehow surprisingly, the percentage of household heads preferring thermal comfort remain around 42% regardless the renovation conditions of the dwelling.

The last three rows of table 1 focus on subsamples of respondents that live in renovated dwellings, and report the number of household heads preferring thermal comfort conditional on the reasons for renovation. Three categories of renovation reasons are considered –for replacement, protection and health-related reasons; for energy-related reasons; and for thermal comfort and other reasons.[5] The pattern is consistent with the previous percentages –regardless the reason for renovation, the percentage of respondents preferring thermal comfort ranges from 39% to 42%.

Indeed, declaring that energy savings are preferred over thermal comfort does not necessarily translates into habitual energy saving behaviors. PHEBUS also collects information on these behaviors. Thus, we corroborate that respondents preferring energy savings declare a higher rate of habitual energy saving behaviors than respondents preferring thermal comfort.

Table 2 reports the percentage of respondents that carry out habitual energy saving behaviors. Following previous studies (e.g. Belaid and Garcia, 2016), energy saving behaviors are measured by whether the household head reports that i) during the winter previous to the survey, he/she was in the habit of regularly lowering the temperature or turning off the heating in the bedrooms during daylight time or at night; ii) during the heating period

[5] PHEBUS pools the thermal comfort with the general *other reasons* category.

previous to the survey, he/she turned off the heating when the dwelling was unoccupied; and iii) when opening a window to ventilate a room, he/she turns down or off the heating of the room.

The percentage of household heads performing a habitual energy saving behavior is calculated for both the group that prefers thermal comfort and for the group that prefers energy savings. Table 2 reports percentages for the entire sample under analysis, and for three sub-samples according to renovation status –no renovation; renovation for energy-related, replacement, protection, and health-related reasons;[6] and renovation for comfort and other reasons.

The numbers in table 2 suggest that a smaller percentage of household heads preferring thermal comfort perform energy saving behaviors. For instance, 27% and 43% of thermal comfort respondents were in the habit of regularly lowering the temperature at, respectively, daylight time and night time. In contrast, 35% and 50% of energy saving respondents report performing this energy saving behavior. A similar pattern is observed when these percentages are calculated for each renovation status subsample. For instance, the percentage of thermal comfort respondents lowering the temperature at daylight time ranges from 26% to 28%, and the percentage of energy saving respondents ranges from 34% to 38%. Also, the percentage of thermal comfort respondents lowering the temperature at night time ranges from 41% to 46%, and the percentage of energy saving respondents doing so ranges from 46% to 54%. Importantly, the differences in these percentages are statistically different at least at the 90% level of confidence.

Similarly, a smaller percentage of thermal comfort respondents turn off the heat when the dwelling is unoccupied –9% versus 13%, for the entire sample. Similar numbers, with the corresponding statistical difference, are observed for the two subsamples of respondents occupying renovated dwellings. For the subsample of respondents occupying unrenovated dwellings, the percentages do not statistically differ from each other –11% versus 12%.

[6] We have pooled observations with renovation for energy-related reasons together with observations with renovation for replacement, protection, and health-related reasons. We have done so to gain variation in the variables that later will inform the propensity score used to match observations with preferences for thermal comfort and observations with preferences for energy savings.

The last energy saving behavior reported in table 2 refers to whether respondents turn down or off the heating of the room when opening the window. Similar to the previous two energy saving behaviors, a smaller percentage of thermal comfort respondents *always* perform this energy saving behavior –33% versus 42%, with very similar percentages across the renovation status subsamples. However, when it comes to performing *sometimes* this energy saving behavior, the percentages are not statistically different across preferences and subsamples.

The implication from the comparisons presented in table 2 is that a larger proportion of household heads reporting a preference for energy savings do perform habitual energy saving behaviors in comparison to the respondents that prefer thermal comfort. Thus, we conclude that preferences for energy savings translate into habitual energy saving behaviors in the French residential sector.

3.3. Energy consumption

3.3.1. Estimates of energy consumption and energy efficiency of the dwelling

An energy audit with a 10-year validity period was offered free of charge as an incentive to participate in PHEBUS. The audit works as an incentive because it has been mandatory since November 2006 for dwellings for sale, and since July 2007 for dwellings for leasing. Since January 2011, real estate agencies are obliged to display the results of the audits of their dwellings.

The energy audit provides an engineerial estimate of the energy consumption of a dwelling. Estimation of energy consumption is based on the characteristics of the building, average weather conditions of the dwelling's location, and appliances used by the occupants. The information from the energy audit is used to assign a dwelling to an energy efficiency category that goes from A to G –with A being the most efficient dwellings, and G being the least efficient ones. Further details are provided in appendix A.

We inform our matching strategy with the energy efficiency category that results from the energy audit. In this way, we account for dwelling characteristics that otherwise are extremely difficult to capture –obsolescence of the housing stock, heating system performance, previous renovations— and appliances at the dwelling.

3.3.2. Actual energy consumption

Actual energy consumption is directly provided in PHEBUS database. Information collected is based on households' detailed invoice and is available for each type of fuel in kilowatt hours and also converted into ton oil equivalent. Actual energy consumption is expressed in kilowatt-hours per square meter and it is based on energy bills for the year 2012. Actual energy consumption measurement includes all energy consumption, regardless of the energy uses.

Actual energy consumption is one outcome variable in our matching strategy. Table 3 reports comparisons of pre-matched means of actual energy consumption. Comparisons are carried out across preferences for thermal comfort for i) the entire sample; ii) the no renovation sample; iii) the sample that renovated for energy-related and replacement reasons; and iv) the sample that renovated for comfort and other reasons. Differences in energy consumption across preferences for thermal comfort are statistically significant at 99% confidence level for three comparisons and at 90% confidence level for one. However, the direction of the differences depends on which sample we focus our attention. For the entire sample and the no renovation sample, the respondents with preference for energy savings spend slightly more energy (around 3 KWh/m^2 and 14KWh/m^2, respectively). For the two samples that have carried out renovations, the respondents with preference for energy savings spend less energy –around 15 KWh/m^2 for the sample with energy-related renovations, and 2 KWh/m^2 for the sample with comfort-related renovations.

Indeed, these statistically significant differences in energy consumption are expected as households with preferences for energy savings more likely carry out energy-related renovations, and consequently decrease their energy consumption –which is what the direction in the difference reflects for the energy-related renovation sample. This is the reason why we carry out a match of households before comparing energy consumptions across preferences for energy savings.

3.4. Estimated CO_2 emissions

We calculate CO_2 emissions (kg/m^2) by applying conversion factors to the actual energy consumption (estimated as explained in section 2.3.2). These conversion factors are applied for each type of fuel. That is, 0.090 for energy consumed through electricity; 0.206, for gas; 0.271, for oil; 0.343, for coal; and 0.0018 for wood (IPPC, 2013).

Our estimates of CO_2 emissions are also an outcome variable in our matching strategy. Table 3 reports comparisons of pre-matched means of CO_2 emissions. Consistent with the comparisons of actual energy consumption across preferences, the group of respondents that prefer energy savings produces more CO_2 emissions for the entire and no renovation samples but produces less CO_2 emissions for the two renovation samples. Similar to the case of energy consumption, these differences in pre-matched means are expected: people carrying out energy-related renovations are more likely committed to decreases their energy consumption and CO_2 emissions –which is what seems to be happening according to table 3.

Results from the comparisons in table 3 indicate that household heads preferring energy savings and occupying a dwelling that has not been renovated do not necessarily spend less energy or produce less CO_2 emissions. It is only within the population that has already carried out a renovation that energy saving preferences translate into less energy consumption and less CO2 emissions.

However, the comparisons presented in table 3 do not take into consideration the socioeconomics of the households and, more importantly, the characteristics of the dwellings. These are factors to control for because energy consumption depends largely on the dwelling's dimension, location and several other characteristics that may drive the results presented in table 3 –therefore, the need to carry out a matching process before reaching conclusions.

4. Identification strategy

The identification strategy in this paper relies on distinguishing between preferences of a household head over thermal comfort and preferences of the rest of household members. This distinction is supported by the evidence pointing out to the intra-household heterogeneity in preferences for thermal comfort and the corresponding energy saving behaviors.

Departing from such distinction, and given that household heads preferring energy savings also report a higher rate of energy saving behaviors, this paper pairs households via propensity score matching techniques, using as *treatment* variable the preferences of household heads on energy savings.

We acknowledge that this matching strategy is unconventional because the treatment variable refers to preferences. Indeed, preferences at the individual level are endogenous to outcome variables at the individual level. However, in the specific context of this paper, the outcome variable is measured at the household level and is only partially influenced by the preferences and actions of the household head.

In practice, the matching strategy in this paper assumes that preferences of household heads can be conceptualized as randomly assigned to the rest of the household members. Because we have shown that household heads reporting preferences for energy savings also report higher rates of energy saving behaviors, this matching strategy allows us to claim causal effects of household heads' energy saving behaviors on household energy consumption. This is the case because this strategy balances the data under analysis. Often, statistical analysis is carried out on imbalanced data. For instance, household heads with preferences for thermal comfort may belong to households and occupy dwellings that systematically differ from the corresponding households and dwellings of household heads preferring energy savings. If meaningful comparisons are to be made, samples need to be balanced on observables which is reached via propensity score matching. Matching minimizes the variation of confounding variables by balancing the sample with respect to key factors that may influence energy consumption. This reasoning follows the argumentation by Rosenbaum and Rubin (1983) who discuss the role of the propensity scores to claim causal effects when analyzing observational data.

5. Results

Table 4 describes and reports summary statistics of all the variables informing the propensity score. To capture household characteristics, we include dichotomous variables for whether the household head is the owner of the dwelling (*owner),* and whether he/she is employed (*employed)* or retired (*retired*). In addition, we define five dichotomous variables capturing whether the household's income falls within the corresponding quintile (*income 1* to *income 5*). To capture the composition of the household, we include number of household members (*members*), and share of members *younger than 30*, *between 30 and 45*, *between 45 and 60*, and *older than 60*. We also include a dichotomous variable on whether the household owns no car (*no car*).

Dwelling characteristics are controlled for through the energy label of the dwelling (*label A* to *label G*). This label results from the energy audit to the dwelling –i.e. it is based on estimates of energy consumption under engineering calculations that take into consideration dwelling characteristics, appliances at the dwelling, and average weather conditions. In addition to the energy labels, we control for whether the dwelling is an individual housing unit (*house*), and for the surface of the dwelling (*surface*).

In terms of location, we control for the size of the city (measured in number of inhabitants) where the dwelling is located. There are 9 dichotomous variables defining a range of number of inhabitants: *size 1* captures locations with less than 1,999 inhabitants; *size 2*, locations with more than 2,000 and up to 4,999 inhabitants; *size 3*, locations with more than 5,000 and up to 9,999 inhabitants; *size 4*, locations with more than 10,000 and up to 19,999 inhabitants; *size 5*, locations with more than 20,000 and up to 49,999 inhabitants; *size 6*, locations with more than 50,000 and up to 99,999 inhabitants; *size 7*, locations with more than 100,000 and up to 199,999 inhabitants; *size 9*, locations with more than 200,000 and up to 1,999,999 inhabitants; and *size 9* which takes value one if the location is Paris, and zero otherwise.

Table B.1. reports, for each sample under analysis, the pre-matched means of the variables informing our propensity score. In general, the figures across samples and preferences imply a large imbalance. To better illustrate this imbalance, figure 1 reports the standardized percentage bias across variables before and after the match has been performed. This bias is calculated as the difference in the means between energy savings respondents and thermal comfort respondents divided by the standard deviation of the energy savings respondents. It measures the effect from not controlling for the specific variable and it is determined by the size of the imbalance.

According to figure 1, the two variables whose imbalance has the largest impact on the bias are *income 1*, *size 4*, owner, and *income 5*. In contrast, the standardized bias for the matched sample is close to zero for all variables –which implies the resulting sample is well balanced on the observables. As illustrated by figure 2, the resulting propensity score yields a common support that ranges from 0.2 to 0.8, with a relatively similar distribution across preferences. This matching process has been replicated for the no renovation sample and the two renovations samples. Figures B.1 to B.6 illustrate the results. Figures B.1 and B.2 show that, for the no renovation sample, we obtain similar balancing and common support results than for the entire sample. Figures B.3 to B.6 show that, for the two renovation samples, the common support property holds also in the range of 0.2 and 0.8 but the balancing of the variables in the propensity score is less promising than for the entire sample or the no renovation sample.

Table 5 reports the comparisons that of matched means of actual household energy consumption and estimated CO_2 emissions. In stark contrast to table 3, comparisons in table 5 point to no differences in actual energy consumption or estimated CO_2 emissions across preferences for thermal comfort. This lack of differences holds for the four samples under analysis –i.e. the entire sample, the no renovation sample, and the two renovation samples. It seems to be the case that the differences documented in table 3 are driven by factors such as household's socioeconomics and composition, dwelling's characteristics and appliances at the dwelling. Once we restrict the comparisons to households that are comparable in terms of those factors, table 5 documents that preferences of household heads for energy savings are not enough to produce an impact in actual energy consumption or estimated CO_2 emissions.

Appendix C reports sensitivity analysis to deviations from the conditional independence assumption (CIA). This assumption implies that, given the observable characteristics, actual energy consumption and estimated CO_2 emissions should be independent from the probability of a household head reporting preferences for thermal comfort. This assumption is not satisfied if unobserved characteristics differ across preferences for thermal comfort. Appendix C report sensitivity of the results to a deviation from this assumption. For each outcome, situations with and without confounder (or main covariates) stay relatively stable. The sensitivity analysis confirms the robustness of the results.

6. Conclusions and discussion

Focusing on the French residential sector, this paper documents that household heads' habitual energy saving behaviors produce no discernible impact on household's actual energy consumption or estimated CO_2 emissions. This lack of effects holds across dwellings' renovation status –i.e. with no renovation and with renovations— which we interpret as evidence that this (null) result holds for the French residential sector –conditional on carrying out comparisons on balanced samples.

We suggest that this lack of impacts implies that energy saving behaviors of a household head generally does not compensate the energy intensive behaviors of other household members. While the head of a household pays the energy bills, all household members consume energy. As suggested by the literature documenting intra-household heterogeneity in preferences for thermal comfort and associated energy saving behaviors, household energy consumption results from a decentralized, usually unnegotiated dynamic among household members. That is, while a household head may do her best to save energy, the eldest member may pursue higher temperatures in his/her own room and the spouse may be more incline to manipulate the thermostat.

The implication for energy policies aiming to increase habitual energy saving behaviors is that only targeting occupants that are involved in energy-related decisions may not be enough –all household members need to be reached. Also, our results have implications for engineering models that aim to take into account occupants' energy saving behaviors. These attempts are carried out to avoid that the energy performance gap is due to an incorrect calibration of parameters. However, our results suggest that it is not enough to account for heterogeneity across households but also within households. The previous implication requires the gathering of richer datasets that describe energy related behaviors of all household members. Indeed, there are previous study cases that collect rich information on each household member (e.g. Tweed et al., 2014) but we are not aware of whether such a rich dataset is available for a nationally representative sample.

Indeed, a drawback that this study shares with previous ones is the limited data availability. In the context of this study, had we observed the preferences and behaviors of all household members, we could have tested the assumption that household head preferences for energy savings do not, in average, represent the preferences of the rest of the household members. Also, as social desirability might be behind our results if respondents report more energy saving behaviors than they actually carry out because they want to look good to the eyes of the enumerator, it would be ideal to rely on observed energy saving behaviors instead of self-reported ones. On this respect, we rely on the consistency that we document between self-reported preferences for thermal comfort and self-reported energy saving behaviors.

We acknowledge that matching households based on differences in household heads' preferences is not only unconventional but likely problematic due to the potential for endogeneity. That is, economists would expect that households with lower energy consumption are the ones whose heads prefer energy savings and, therefore, our comparison strategy should mechanically yield lower energy consumption in households whose heads report energy saving habits. We highlight that we observe differences in average energy consumptions when carrying out comparisons on unmatched samples, but once balanced samples are compared, differences become statistically insignificant. Had systematic unobserved heterogeneity remained once samples were balanced, the differences in energy consumption should have remained as well.

Current practice in energy economics research make no difference between respondents' energy saving behaviors and the rest of the household members when analyzing samples that are representative at the household level. We identify the need for further research on the implications of this practice.

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Tables and figures

Table 1. Households heads' preferences for thermal comfort (n=2,243)

Sample of reference		Number of respondents	% of entire sample	Number of respondents (% of sample of reference) with preference for …[1] thermal comfort	energy savings
Entire sample		2'243	100	935 (41.68)	1'308 (58.31)
No Renovation		1'151	51.33	483 (41.94)	668 (58.05)
Renovation		1'092	48.67	452 (41.40)	640 (58.66)
Reasons for renovation					
Replacement/ Protection/ Health	Replacement of used appliances/ protection against noise and/or humidity/ health-related reasons	262	11.67	103 (39.24)	159 (60.83)
Energy-related	Decrease energy expenditures and/or improve of heating system	298	13.28	124 (41.64)	174 (58.35)
Thermal comfort/ Other	Other reasons, including comfort Reasons	532	23.74	225 (42.29)	307 (57.70)

[1] "When it comes to indoor heating, do you prefer …?". This question is asked after gathering energy saving behaviors.

Table 2. Household heads' preferences for thermal comfort and energy-saving behaviors

Habitual energy saving behaviors	Preference for …[1]							
	thermal comfort	energy savings	thermal comfort	energy savings	thermal comfort	energy savings	thermal comfort	energy savings
	Entire sample (n=2,243)		No renovation sample (n=1,151)		Renovation for energy-related and replacement[2] reasons (n=560)		Renovation for comfort and other reasons (n=532)	
Last winter, were you in the habit of regularly lowering the temperature or turning off the heating in the bedrooms …								
At daylight time	0.27	0.35	0.26	0.34	0.26	0.36	0.28	0.38
At night	0.43	0.50	0.41	0.46	0.46	0.53	0.45	0.54
During the last heating period, when your dwelling was unoccupied, did you …								
turn off the heat?	0.09	0.13	0.11[3]	0.12[3]	0.07	0.12	0.09	0.14
When you open the window to ventilate a room, do you turn down or off the heating of the room?								
Always	0.33	0.42	0.33	0.42	0.32	0.45	0.36	0.42
Sometimes	0.06[3]	0.05[3]	0.05[3]	0.05[3]	0.09[3]	0.06[3]	0.05[3]	0.05[3]

[1] "When it comes to indoor heating, do you prefer …?". This question is asked after gathering energy-saving behaviors.

[2] Replacement stands for replacement, protection, and health-related reasons.

[3] The null hypothesis of equality of proportions cannot be rejected with 90% confidence level. All the rest of the proportions are statistically different at 90% confidence level or more.

Table 3. Comparison of pre-matched outcome variables across preferences for thermal comfort

Outcome variable	Preference for …[1]				t-test	
	thermal comfort		energy savings			
	Mean	Std. Dev.	Mean	Std. Dev		
Entire sample (n= 2,243)						
Energy consumption (KWh/m²)	160.62	10.32	163.47	12.71	-5.85	***
CO2 emissions (kg.CO2/m²)	8.30	4.93	6.35	4.49	9.60	***
No renovation sample (n=1,151)						
Energy consumption (KWh/m²)	155.33	10.18	169.08	14.05	-19.25	***
CO2 emissions (kg.CO2/m²)	6.98	4.72	6.41	4.63	2.06	**
Renovation for energy-related and replacement[2] reasons (n=560)						
Energy consumption (KWh/m²)	172.64	10.91	157.11	10.33	16.90	***
CO2 emissions (kg.CO2/m²)	9.44	5.22	6.77	4.46	6.29	***
Renovation for comfort and other reasons (n=532)						
Energy consumption (KWh/m²)	158.59	9.85	156.86	10.25	1.97	*
CO2 emissions (kg.CO2/m²)	9.80	4.97	5.77	4.16	9.86	***

Difference between average numbers is statistically significant at * 90%, ** 95%, and *** 99% level.

[1] "When it comes to indoor heating, do you prefer …?".

[2] Replacement stands for replacement, protection, and health-related reasons.

Table 4. Definition and summary statistics of variables informing propensity score (n=2,243)

Variable	Units	Label	Mean	Std Dev	Min	Max
Household characteristics						
Household head is owner	(0/1)	Owner	0.69	0.46	0	1
Household head is employed	(0/1)	Employed	0.52	0.50	0	1
Household head is retired	(0/1)	Retired	0.36	0.48	0	1
Household income fall within first quintile	(0/1)	Income 1	0.20	0.40	0	1
Household income fall within second quintile	(0/1)	Income 2	0.19	0.40	0	1
Household income fall within third quintile	(0/1)	Income 3	0.18	0.39	0	1
Household income fall within fourth quintile	(0/1)	Income 4	0.21	0.41	0	1
Household income fall within fifth quintile	(0/1)	Income 5	0.21	0.41	0	1
Number of household members	(0/1)	Members	2.44	1.33	1	10
Share of members < 30	(0/1)	younger than 30	0.07	0.25	0	1
Share of members between 30 and 45	(0/1)	30 to 45	0.26	0.44	0	1
Share of members between 45 and 60	(0/1)	45 to 60	0.30	0.46	0	1
Share of members > 60	(0/1)	older than 60	0.37	0.48	0	1
No car	(0/1)	No Car	0.14	0.35	0	1
Dwelling characteristics						
Energy label A	(0/1)	Label A	0.00	0.03	0	1
Energy label B	(0/1)	Label B	0.02	0.14	0	1
Energy label C	(0/1)	Label C	0.13	0.34	0	1
Energy label D	(0/1)	Label D	0.26	0.44	0	1
Energy label E	(0/1)	Label E	0.30	0.46	0	1
Energy label F	(0/1)	Label F	0.15	0.36	0	1
Energy label G	(0/1)	Label G	0.13	0.34	0	1
Individual housing unit	(0/1)	House	0.66	0.47	0	1
Squared meters	m^2	Surface	99.04	50.44	8	999
Location characteristics						
Urban size 1 (< to 1,999 inhabitants)	(0/1)	Size 1	0.21	0.41	0	1
Urban size 2 (2,000 to 4,999 inhabitants)	(0/1)	Size 2	0.07	0.25	0	1
Urban size 3 (5,000 to 9,999 inhabitants)	(0/1)	Size 3	0.05	0.22	0	1
Urban size 4 (10,000 to 19,999 inhabitants)	(0/1)	Size 4	0.05	0.22	0	1
Urban size 5 (20,000 to 49,999 inhabitants)	(0/1)	Size 5	0.06	0.24	0	1
Urban size 6 (50,000 to 99,999 inhabitants)	(0/1)	Size 6	0.08	0.27	0	1
Urban size 7 (100,000 to 199,999 inhabitants)	(0/1)	Size 7	0.06	0.23	0	1
Urban size 8 (200,000 to 1,999,999 inhabitants)	(0/1)	Size 8	0.28	0.45	0	1
Urban size 9 (Paris)	(0/1)	Paris	0.15	0.35	0	1

Table 5. Comparison of matched outcome variables across preferences of household head for thermal comfort

Outcome variable	Difference	Std. Error	t-test
Entire sample (n= 2,243)			
Energy consumption (KWh/m²)	1.86	5.34	0.34
CO2 emissions (kg.CO2/m²)	-1.27	1.19	-1.07
No renovation sample (n=1,151)			
Energy consumption (KWh/m²)	1.86	5.46	0.34
CO2 emissions (kg.CO2/m²)	2.88	2.96	0.97
Renovation for energy-related and replacement reasons (n=560)			
Energy consumption (KWh/m²)	15.67	11.29	1.39
CO2 emissions (kg.CO2/m²)	2.46	2.08	1.18
Renovation for comfort and other reasons (n=532)			
Energy consumption (KWh/m²)	-2.31	9.94	-0.23
CO2 emissions (kg.CO2/m²)	-3.94	2.09	-1.89

Figure 1. Standardized percentage bias across variables informing propensity score before and after matching (entire sample, n=2,243)

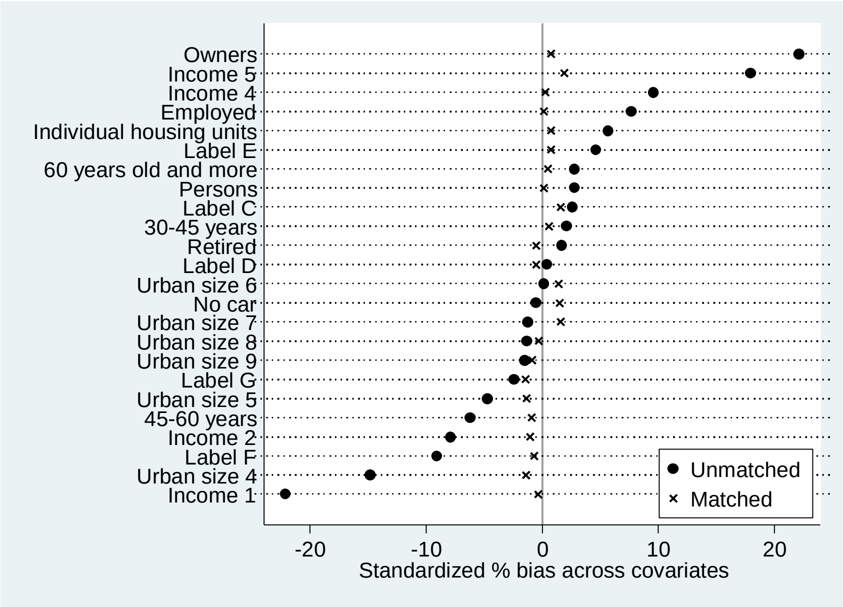
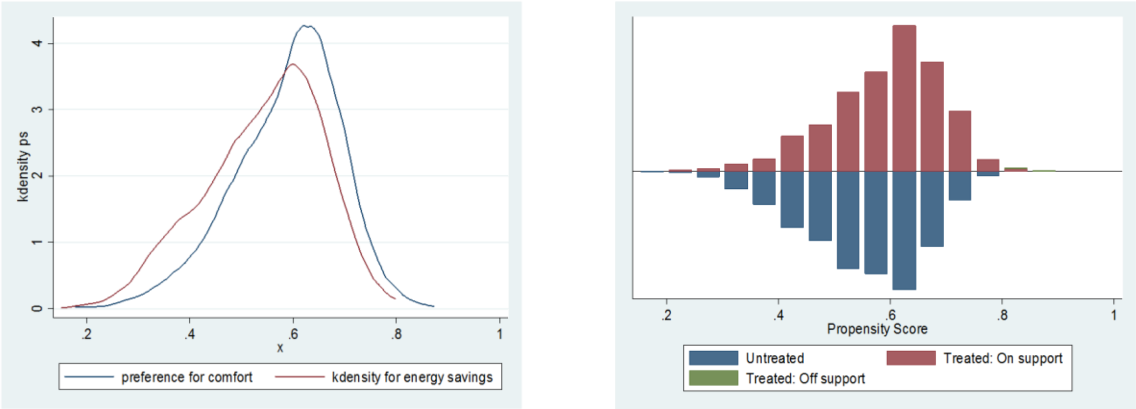


Figure 2. Distribution of propensity score on entire sample (n=2,243), and common support



APPENDIX A.

The theoretical energy measure available in the PHEBUS survey is the Energy Performance Certificate (EPC). EPC certification includes an energy audit realized by an approved auditor (the same for all audits) based on visual inspection and collection of technical data followed by an assessment of the theoretical energy consumption calculated by engineering models with the assumption of standardized behaviours. This measure considers three energy uses: heating, hot water production and cooling. Neither lighting consumption nor domestic appliances are considered. Characteristics such as house construction data, window and wall insulation, heating system performance and climate data are collected and merged to obtain an aggregated measure of energy consumption.

The theoretical energy consumption of each dwelling is obtained from the 3CL method[7], which allows an estimate of the predicted dwelling energy consumption, expressed as C.

$$C = Cch + Cecs + Ccool \tag{1}$$

Cch is the theoretical heating energy consumption of the dwelling, $Cecs$ the theoretical energy consumption for hot water use and $Ccool$ the theoretical energy consumption for cooling use. Cch consumption is calculated based on the heating needs of the building (Bch) multiplied by the inverse of the heating system power (Ich).

$$Cch = Bch \ \times Ich \tag{2}$$

where

$$Bch = SH.ENV.METEO.INT \tag{3}$$

Heating needs Bch are defined according to SH, habitable area; ENV, heating loss in the envelope and ventilation; $METEO$, which accounts for past environmental features due to dwelling location; and INT, an intermittence factor (INT), which accounts for indoor heating management (depending on heating system, building type, etc).

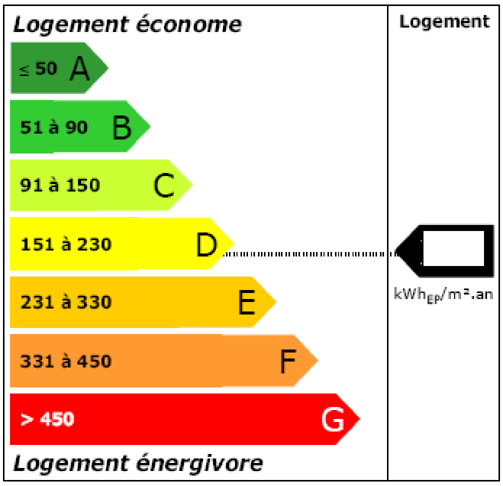
The main assumptions in the calculation are the following. Concerning environmental factors, the meteorological data used are the heating degree hours of the county of reference to assess the heating needs of the building. Degree hours used are an average for the last 30 years for each county Regarding heating management, 19°C is the conventional target heating

[7] http://www.rt-batiment.fr/fileadmin/documents/RT_existant/DPE/DPE_outils/Nouvel_Algorithme_3CL-DPE_vf.pdf

temperature used in the calculation. The entire dwelling surface is considered as heated permanently during the heating period. Moreover, hot water needs are set according to the habitable area and the county where the dwelling is located.
In the end, this engineering calculation provides the theoretical energy consumption for each dwelling, expressed in primary and final energy, in kilowatt-hours per square meter.

As explained above, the EPC result is a quantitative assessment of final energy consumption of the dwelling in kilowatt-hours per square meter. It ranks the dwellings into energy classes (seven classes, from A to G, figure A1).

Figure A.1 – Energy classes



APPENDIX B.

Table B.1 Pre-matched means of variables informing propensity score

Variable's label	Preference for …[1]							
	thermal comfort	energy savings	thermal comfort	energy savings	thermal comfort	energy savings	thermal comfort	energy savings
	Entire sample (n=2,243)		No renovation sample (1,151)		Renovation for energy-related and replacement reasons (n=560)		Renovation for comfort and other reasons (n=532)	
Household characteristics								
owner	0.73	0.64	0.68	0.54	0.83	0.77	0.74	0.72
Income 1	0.15	0.25	0.20	0.28	0.09	0.19	0.13	0.24
Income 2	0.18	0.21	0.19	0.22	0.21	0.23	0.13	0.17
Income 3	0.19	0.18	0.16	0.16	0.21	0.25	0.20	0.17
Income 4	0.23	0.19	0.22	0.20	0.24	0.14	0.24	0.20
Income 5	0.25	0.17	0.22	0.13	0.26	0.19	0.29	0.22
Employed	0.54	0.50	0.55	0.50	0.48	0.46	0.57	0.53
Retired	0.37	0.34	0.35	0.32	0.45	0.39	0.32	0.35
Persons	2.45	2.43	2.40	2.40	2.39	2.52	2.62	2.42
less than 30 years	0.07	0.06	0.09	0.08	0.03	0.03	0.08	0.03
30-45 years	0.26	0.26	0.27	0.25	0.22	0.22	0.27	0.31
45-60 years	0.28	0.33	0.28	0.33	0.26	0.33	0.32	0.32
60 years and more	0.38	0.36	0.36	0.33	0.48	0.42	0.33	0.35
No Car	0.14	0.13	0.15	0.17	0.14	0.07	0.14	0.11
Dwelling characteristics								
Label A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Label B	0.02	0.02	0.03	0.02	0.02	0.02	0.01	0.00
Label C	0.14	0.12	0.15	0.15	0.13	0.10	0.11	0.09
Label D	0.26	0.27	0.25	0.25	0.28	0.30	0.24	0.31
Label E	0.31	0.28	0.28	0.27	0.33	0.26	0.38	0.32
Label F	0.14	0.17	0.13	0.16	0.15	0.20	0.13	0.17
Label G	0.13	0.14	0.15	0.16	0.10	0.12	0.12	0.10
House	0.67	0.65	0.61	0.61	0.75	0.75	0.71	0.64
Surface	102.50	94.55	97.23	90.94	108.01	102.96	107.59	94.45
City characteristics								
Urban size 1	0.24	0.18	0.23	0.19	0.26	0.16	0.21	0.18
Urban size 2	0.06	0.07	0.06	0.08	0.07	0.09	0.08	0.03
Urban size 3	0.04	0.06	0.06	0.07	0.03	0.06	0.02	0.02
Urban size 4	0.04	0.07	0.04	0.06	0.02	0.08	0.05	0.07
Urban size 5	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.07
Urban size 6	0.08	0.08	0.07	0.08	0.10	0.10	0.07	0.07
Urban size 7	0.06	0.06	0.06	0.06	0.05	0.06	0.05	0.05
Urban size 8	0.28	0.29	0.26	0.26	0.30	0.29	0.28	0.35
Paris	0.15	0.14	0.15	0.14	0.10	0.12	0.19	0.16

[1] "When it comes to indoor heating, do you prefer …?".

Figure B.1 Standardized percentage bias across variables informing propensity score before and after matching (no renovation sample, n=1,151)

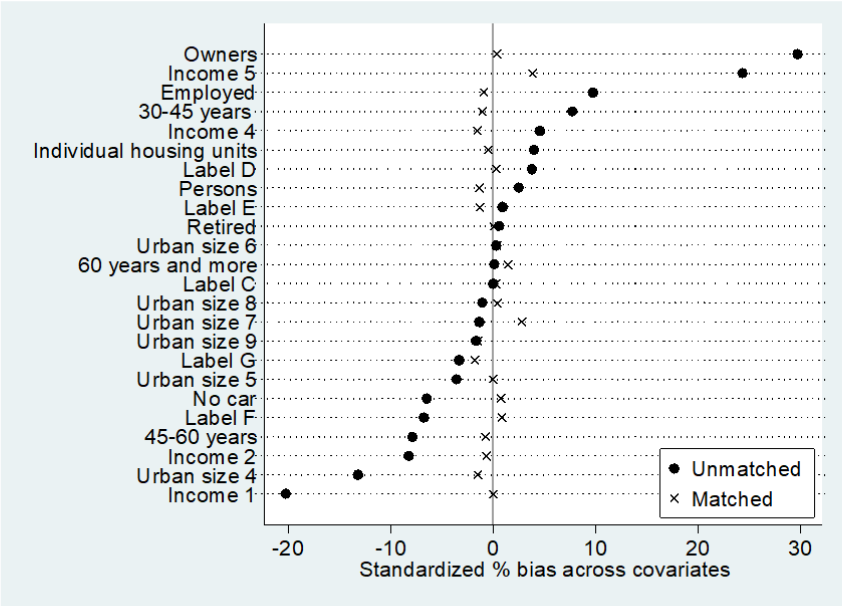


Figure B.2 Distribution of propensity score on no renovation sample (n=560), and common support

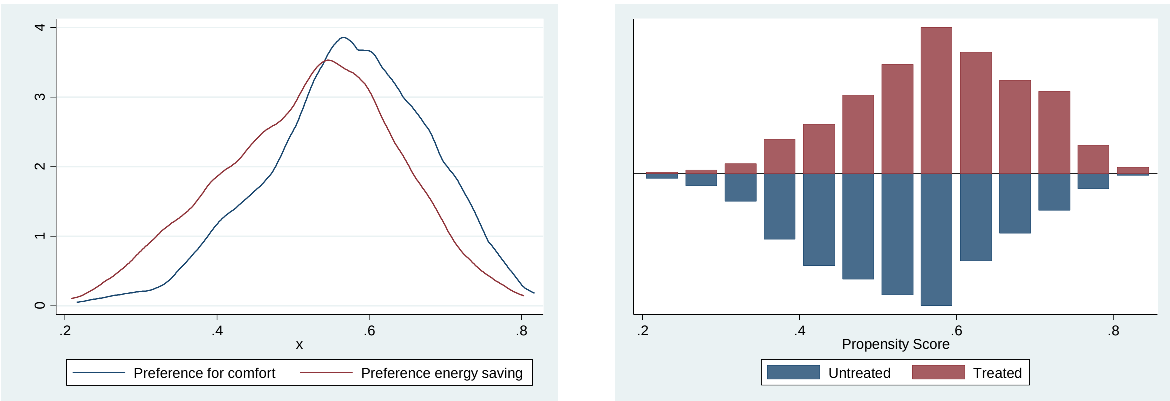


Figure B.3 Standardized percentage bias across variables informing propensity score before and after matching (energy-related and replacement reasons sample, n=560)

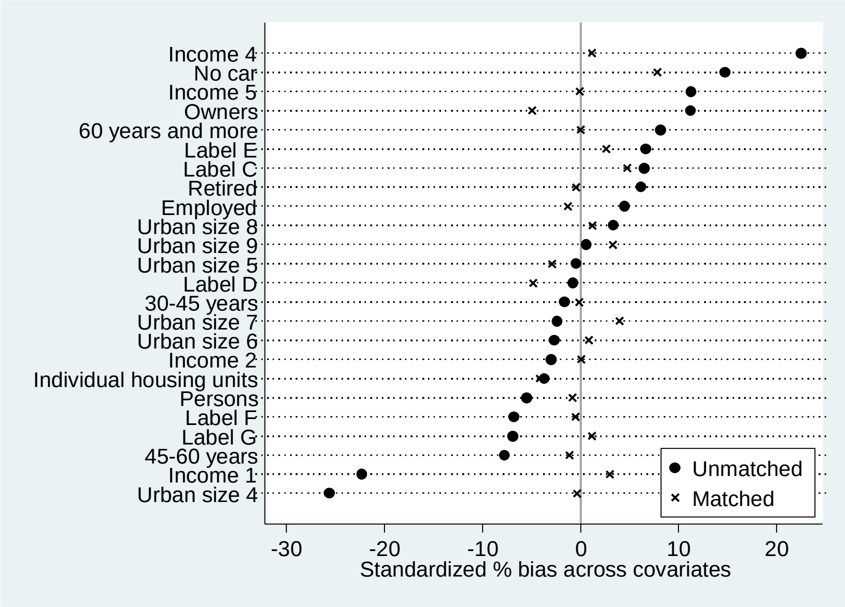


Figure B.4 Distribution of propensity score on energy-related and replacement reasons sample (n=560), and common support

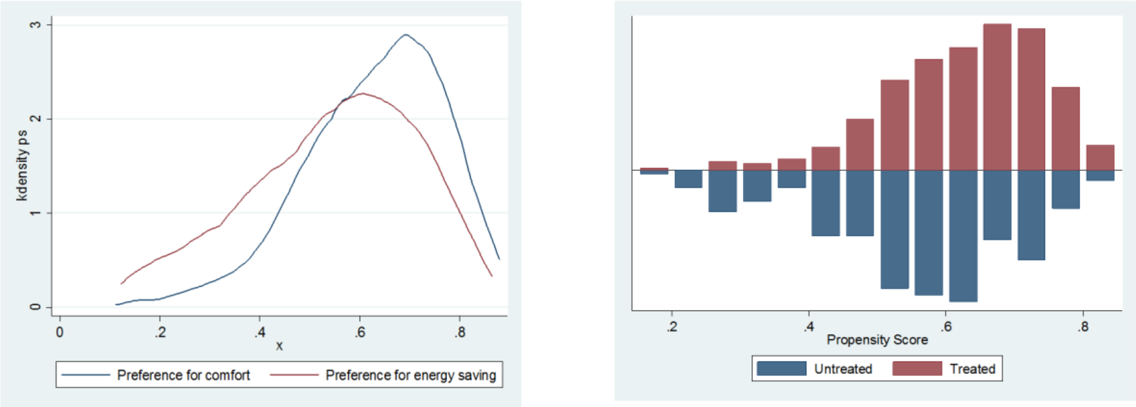


Figure B.5 Standardized percentage bias across variables informing propensity score before and after matching (comfort or other reasons sample, n=532)

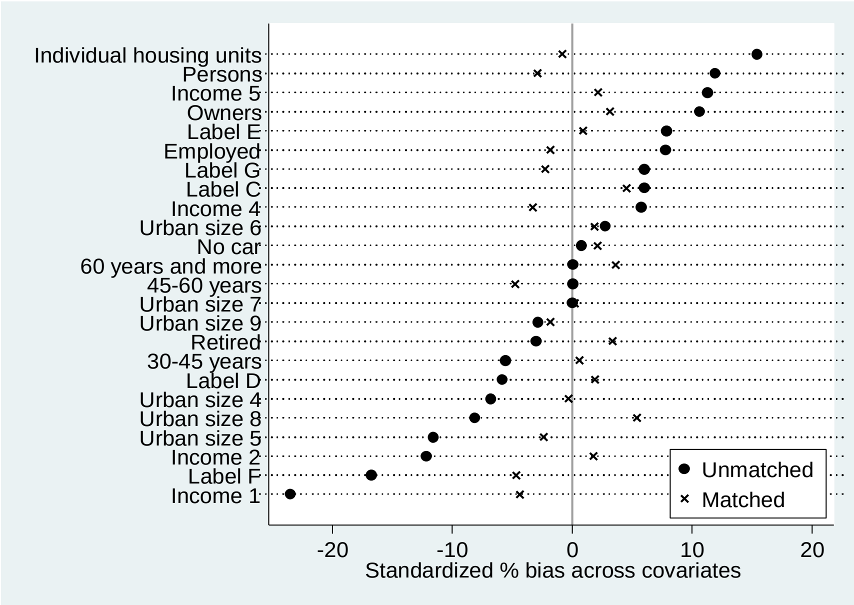
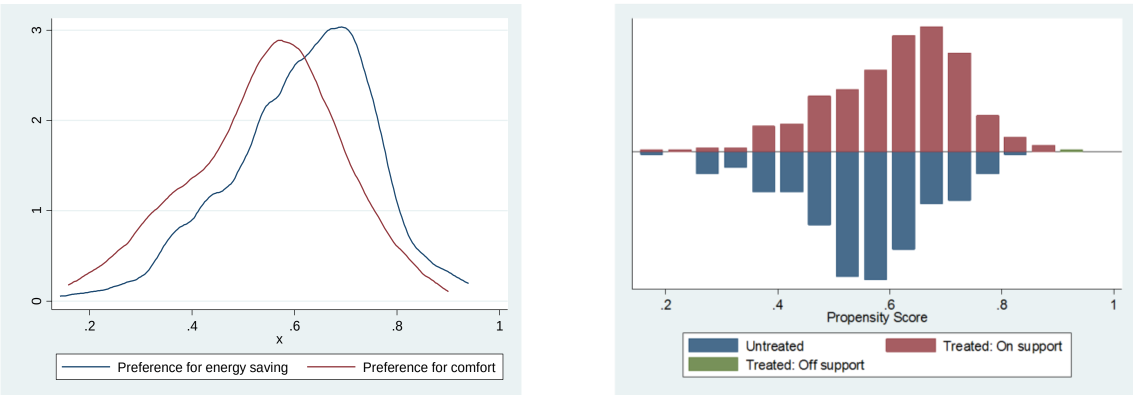


Figure B.6 Distribution of propensity score on comfort or other reasons sample (n=532), and common support



APPENDIX C.

The impact of an unobserved binary variable u that affects the potential outcome Y (i.e. energy consumption, CO2 emissions and temperature) and preferences for thermal comfort (T = 1) is measured using Ichino et al.'s (2008) approach. The conditional independence given the set of variables *x* is not valid, but this assumption holds given *x* and *u*. In other words,

$$Pr(T = 1|Y_0, Y_1, x) \neq Pr(T = 1|x)$$

and

$$Pr(T = 1|Y_0, Y_1, x, u) = Pr(T = 1|x, u),$$

where u is assumed to be binary. It is possible to define four groups which gives the probability that u = 1 in each of the four groups defined by the treatment status (i = 0 or 1) and the outcome value (j = 0 or 1). We assign arbitrary values to a parameter Pij. A neutral confounder Pij is considered when Pij = 0.5, and then we can let u mimic the behavior of some important covariates. We choose variables that we assume to have an effect on the outcome. Second, we simulate *u*, which is considered like any other variable and is used to estimate the propensity score and the kernel-matching estimates.

Results are presented in table C.1. The first four columns contain probabilities Pij. For each value we give at *u*, the next two columns present, respectively, the outcome effect (i.e., the effect of u on the untreated outcome, controlling for observables *x*) and the selection effect (i.e., the effect of *u* on having preferences for thermal comfort, controlling for observables *x*). The last column provides the effect and the standard error of preferences for thermal comfort, controlling for observable *x* and unobservable *u*.

For instance, we consider on the variable "Income5" in the energy consumption in kwh section. P11 equals 0.16, i.e. 16% of energy consumption due households who stated preferences for thermal comfort belong to the highest quintile of income. The effect of preferences for thermal comfort, controlling for *x* and *u*, is slightly higher than the situation without a confounder (461.379 vs 453.792). For each outcome, situations with and without confounder stay relatively stable. The sensitivity analysis confirms the robustness of the results concerning the effect of thermal preferences on energy consumption, carbon dioxide emissions and temperature.

Table C.1 Sensitivity analysis to conditional independence scenarios

	Fraction *u* =1 by treatment/outcome				Outcome effect	Selection effect	Preference for comfort effect	SE
	P₁₁	***P₁₀***	***P₀₁***	***P₀₀***				
Energy consumption in Kwh								
No confounder	0	0	0	0	-	-		
Neutral confounder	0.50	0.50	0.50	0.50	0.991	1.004	453.792	13.601***
Confounder like:								
Income 5	0,16	0,18	0,22	0,2	1.202	0.813	461.379	31.610***
No car	0,05	0,14	0,04	0,14	0.291	1.027	451.203	19.916***
Age30	0,02	0,05	0,01	0,04	0.221	1.327	463.801	15.093***
Age between 30 and 45 year s old	0,2	0,24	0,18	0,24	0.687	1.082	456.409	17.136***
Age > 60 years old	0,46	0,4	0,47	0,38	1.471	1.043	446.978	21.279***
Urban size 9	0,03	0,19	0,03	0,19	0.117	1.016	447.326	30.437***
Energy consumption in Kwh/m^2								
No confounder	0	0	0	0	-	-		
Neutral confounder	0.50	0.50	0.50	0.50	1.025	1.009	0.898	0.247***
Confounder like:								
Income 5	0,19	0,16	0,21	0,2	1,032	0,822	0,948	0,492**
Age30	0,09	0,12	0,09	0,12	0.799	1.005	0.836	0.217***
Age between 30 and 45 year s old	0,03	0,04	0,02	0,04	0.368	1.333	0.929	0.196***
Age > 60 years old	0,19	0,26	0,19	0,24	0.701	1.046	0.944	0.289 ***
Urban size 9	0,45	0,41	0,46	0,38	1.479	1.061	0.855	0.315***
Difference between theoretical and effective consumption in Kwh/m^2								
No confounder	0	0	0	0	-	-		
Neutral confounder	0.50	0.50	0.50	0.50	1.025	1.006	7.146	0.236***
Confounder like:	0,18	0,16	0,17	0,24	0.671	0.828	6.545	0.648***
Income 5	0,06	0,17	0,08	0,14	0.485	1.038	7.043	0.232***
Age30	0,03	0,04	0,02	0,05	0.360	1.290	7.128	0.281***
Age between 30 and 45 year s old	0,25	0,2	0,23	0,21	1.256	1.045	7.066	0.303***
Age > 60 years old	0,37	0,5	0,39	0,43	0.852	1.089	7.007	0.377***
Urban size 9	0,08	0,2	0,11	0,16	0.654	0.984	7.079	0.249***
Carbon dioxide (CO_2) in total (in kg)								
No confounder	0	0	0	0	-	-		
Neutral confounder	0.50	0.50	0.50	0.50	1.009	1.016	206.702	2.901***
Confounder like:	0,15	0,18	0,25	0,2	1.432	0.815	212.979	6.345***
Income 5	0,03	0,13	0,03	0,12	0.196	1.006	206.680	4.121***
Age30	0,02	0,04	0,02	0,03	0.608	1.317	207.389	3.266***
Age between 30 and 45 year s old	0,21	0,23	0,24	0,22	1.144	1.047	207.487	3.077***
Age > 60 years old	0,42	0,42	0,46	0,4	1.311	1.072	205.934	3.975***
Urban size 9	0,01	0,16	0	0,16	.	0.976	204.060	7.487***
Carbon dioxide (CO_2) in m2 (in kg)								
No confounder	0	0	0	0	-	-		
Neutral confounder	0.50	0.50	0.50	0.50	1.046	1.011	1.697	0.031***
Confounder like:	0,16	0,18	0,26	0,2	1.502	0.820	1.756	0.072***
Income 5	0,03	0,12	0,03	0,12	0.242	1.005	1.686	0.039***
Age30	0,02	0,04	0,02	0,03	0.728	1.285	1.704	0.028***
Age between 30 and 45 year s old	0,22	0,23	0,24	0,22	1.104	1.063	1.692	0.032***
Age > 60 years old	0,42	0,43	0,45	0,4	1.311	1.064	1.688	0.037***

Urban size 9	0,01	0,16	0	0,16	,	1.676	1.676	0.066***
Difference between theoretical and effective Carbon dioxide (CO2) emissions								
No confounder	0	0	0	0	-	-		
Neutral confounder	0.50	0.50	0.50	0.50	1.021	1.003	4.045	0.053***
Confounder like:	0,16	0,19	0,2	0,21	0.935	0.828	4.015	0.129***
Income 5	0,08	0,14	0,09	0,13	0.712	0.985	4.031	0.066***
Age30	0,03	0,05	0,05	0,02	4.158	1.298	3.990	0.082***
Age between 30 and 45 year s old	0,24	0,21	0,24	0,2	1.324	1.057	4.014	0.078***
Age > 60 years old	0,41	0,44	0,35	0,47	0.605	1.063	4.092	0.099***
Urban size 9	0,07	0,2	0,1	0,17	0.583	1.011	4.020	0.109***
Temperature								
No confounder	0	0	0	0	-	-		
Neutral confounder	0.50	0.50	0.50	0.50	0.987	1.006	0.681	0.002***
Confounder like:	0,17	0,18	0,22	0,2	1.123	0.824	0.683	0.004***
Income 5	0,12	0,1	0,12	0,11	1.085	1.004	0.682	0.002***
Age30	0,04	0,03	0,05	0,03	1.915	1.285	0.681	0.003***
Age between 30 and 45 year s old	0,24	0,22	0,29	0,2	1.723	1.045	0.681	0.004***
Age > 60 years old	0,4	0,44	0,36	0,42	0.793	1.065	0.682	0.002***
Urban size 9	0,14	0,12	0,17	0,12	1.535	0.954	0.683	0.003***