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His, hers or both's? The role of male and female's attitudes in explaining their home energy use behaviours

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ABSTRACT

Building energy research has historically overlooked the role of attitudes, instead focusing on building and socio-demographic influences. Even when attitudes are measured, usually, the attitudes of just one household member are measured even though household energy consumption is the result of actions of all household members. This research explored first whether attitudes could help explain heating usage and second whether the attitudes of a *couple* could explain more of the variability in heating behaviour than the attitudes of one partner. The attitudes towards home heating energy use (i.e. attitudes towards *thermal comfort*, *economical with energy*, *industry and technology's role and individual's role*) of 128 English couples were used in this study. Together with building and socio-demographics, attitudes were examined to explain heating temperatures and durations, which were derived from temperature sensors placed in the homes in 2007–2008. The results showed that attitudes helped explain heating temperatures and durations, even when building and socio-demographic variables were controlled. *Economical with energy* was the most highly identified influence on heating behaviours, with *thermal comfort* a close second. In households that included a couple, combined attitudes of both partners explained heating usage behaviours more accurately than the attitudes of either male or female only.

1. Introduction

Home energy use accounts for nearly a third of energy use in Britain and approximately 61% of home energy use is attributable to space heating [1]. Clearly, reducing heating energy use is imperative if the UK is to cut carbon emissions from housing. Historically, building energy research has focused on the influences of building-demographics and socio-demographics on heating energy use. Tenure [2,3], household size [4,5], age [6,7], building age [8], dwelling type [9], and energy-efficiency variables [6] have all been shown to affect home energy consumption and heating use.

However, *attitudes* also influence home energy use, as found by research in the 1980s–1990s. Attitudes to personal comfort were frequently found to be an important influence [10–12]. Other attitudinal influences were: environment and energy concerns [10–12], personal responsibility to save energy [10–12] and price concerns [10]. However, no recent UK study explores whether these attitudes are related to home heating. This analysis sought to explain home heating temperatures and durations derived from internal temperatures measured over a winter period. It was tested whether home heating energy use attitudes helped to explain heating temperatures and durations over and above the explanatory power of building characteristics and socio-demographics. Home heating energy use attitude was defined as people's attitude and perception towards four aspects of heating energy use in this study, i.e. *thermal comfort, economical with energy, industry and technology's role and individual's role.* Temperatures in the living room were measured in the winter of 2007–2008, over a 92-day period. These temperature measurements were used to estimate heating hours and maximum temperatures, and heating durations were estimated heating hours per day over this period.

Most previous home energy use attitude studies focused on the attitudes of one person from the household, taking their views to represent those of the entire household. However, one person's attitudes may not be representative of everyone's attitudes in households with more than one person [13]. Consequently measuring just one person's attitudes could be one cause of the poor explanatory power of attitudes in some research [13,14]. In 2008,

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70% of all households in the UK had more than one person and 85% of those households included a couple [15]. This study explored the effects of home heating attitudes of male and female partners on home heating usage in those households that included a couple. Exploring couple's attitudes is essential also because that research in the field of psychology has found that environmental values and attitudes are generally higher in females than males [16,17]. This would lead to a misrepresentation of household attitudes if only one occupant was studied (e.g. when males were asked, the positive attitudes would generally be underestimated in the whole population). However, very little empirical research has tested whether couple's attitudes explain household energy consumption better than an individual's attitudes do. Although some research was done in the 1980s to examine the correlations between attitudes of husbands and wives with home energy consumption [10,18,19], finding that the combined attitudes of husbands and wives had a slightly higher correlation with the household energy consumption than individual attitudes, the research was far from recent and was not based in the UK. Moreover, there may be a possibility that couple's attitudes are so similar that we only need to measure attitudes of one person to express attitudes of both. Previous research did not explore the relationship between the couples' attitudes, and did not verify whether the combined couple's attitudes explained energy consumption better than the attitudes of a single partner did. Recognizing this gap in knowledge, this empirical study compared the attitudes of the male partner and the female partner and explored whether the attitudes of *both* partners influenced home heating temperatures and durations more than the attitudes of one person. In the next sections, to compare home heating attitudes of couples, correlation coefficients of both male and female partners were calculated for home heating energy use attitudes using correlation analysis. Second, to compare attitudes' influences, home heating temperatures and durations were regressed on combined attitudes of couples as well as one partner's attitudes, using multiple linear regression method.

2. Methods

2.1. Data collection and measures

2.1.1. Sampling

The Carbon Reduction in Buildings (CaRB) project commenced the Home Energy Use Survey in England, in winter early in 2007 (for more details, see Ref. [20]). Stratified random sampling was used to select households from the Postcode Address file, to ensure a good geographic and demographic spread; 427 households participated, yielding an eligible response rate of 38%. During the computer-assisted face-to-face interviews, householders answered structured questions on their home's built-form, heating technologies, heating practices and socio-demographics. A structured interview with pre-defined answer categories is a quantitative research method commonly employed in survey research. The aim of this approach was to ensure that each interviewee is presented with exactly the same questions in the same order. This method was preferred to open-ended questions because it ensured that answers could be reliably aggregated and that comparisons could be made with confidence between sample subgroups or between different survey periods. Following the interview, households that agreed to be involved in a future survey were sent self-completion questionnaires. The sample size would have made interviews too expensive to realize, and open-ended questions too time-consuming to analyse. Hence, a mail survey was used to collect the responses on attitudes. The component that included questions on home heating energy use attitudes was directed to up to three adults in each household. 63% of eligible households responded to the questionnaire.

2.1.2. Measuring sensor-based estimates central heating hours & maximum temperature

After the face-to-face interviews, 387 households agreed to the request to place two temperature sensors in their homes, recording temperatures in the living room and bedroom from mid July 2007 to early February 2008. HOBO UA 001-08 sensors were used. These were self-contained data loggers that were programmed to record spot temperature every 45 min, resulting in 32 measurements per day. They are small, silent and with a reported accuracy of ±0.47 °C; calibration measurements were taken on each sensor before the installation. Homeowners, sometimes with the help of interviewers, placed the sensor with the instruction of "on a shelf or other surface between knee, head height away from any heat sources and away from direct sunlight". Hobos from 275 living rooms were returned; 110 were not returned and 2 were faulty. In this study, the analysis focused on living room temperature data in the winter months over a 92-day period between 1st November 2007 and 31st January 2008. The living room temperature was selected as the dependent variable because this study wanted to measure the temperature in a room used by the couple during their awake hours. According to the definitions by EHCS [21], compared with bedroom, living room might be more frequently shared by family, especially during daytime when they all might have a chance to set the thermostat. According to the average daily external temperature created from the data of local weather stations within the respondent's Government Office Region, all of these days had maximum external temperatures of no higher than 15.5 °C [3], meaning those days were considered heating days where the heating was assumed to be in use. For more details on data collection method, please see [20,22].

It was assumed that, during the recorded winter period, internal temperatures would decrease when the central heating system was turned off, because of heat loss through the building fabric. Therefore, central heating active periods were estimated as those periods during which living room temperatures were not falling, by comparing the measured internal temperatures with the external temperatures and the internal temperatures between sensor time intervals. This might make the assumption occasionally incorrect when high solar gains or use of secondary heating were the cause of the rise in living room temperatures rather than the use of the central heating. The time intervals during which the central heating system was assumed to be active is defined as those where the living room temperature at time interval $i+1$ is higher than the temperature at time interval i. For heating days, they were defined as those days with the estimated central heating active time longer than 2 h. Estimated active hours of central heating per day were calculated for each home. They were computed as the mean value of the heating hours for each heating day over all heating days. To arrive at the number of heating hours of each single heating day, the sensor time interval (45 min) was multiplied by the number of time intervals during which the heating was estimated to be on (the temperature was not falling).

For each day, the maximum temperature was identified for each home, and this value was then averaged across the three winter months. It was assumed that this maximum temperature reflected approximately the residents' demand for heating temperature.

2.1.3. Measuring socio-demographics and building variables

Socio-demographic and building-demographic variables were derived from answers given by the main respondent during the computer-assisted personal interview. Accommodation type was coded by the interviewer directly. The wall insulation variable was derived from building year, external wall type, cavity wall insulation status, according to the u-values in SAP 2005 [23]. Questions measuring socio-demographics used National Statistics harmonised methods, which defined how questions on socio-demographics were structured and how the categories were organized [24,25]. Harmonizing with National Statistics allowed comparison of the sample under question to other surveys and nationally representative studies.

Since small sub-samples reduce the likelihood of detecting differences between socio-demographic groups, several variables were excluded from the analysis based on two criteria: (1) the number of missing values of the variable was more than 10% of the 128 sub-sample; (2) the number of cases of one or more categories of the variable was less than five. Accordingly, income, heating fuel type, extent of window double-glazing, extent of window draught-proofing and roof u-value were excluded from the study. Besides, this study did not particularly consider the number of rooms heated because it was limited to analysing temperature data from the living room.

2.1.4. Measuring home energy use attitudes

The CaRB self-completion survey was a postal questionnaire. The "Personal Section" of the questionnaire was completed by up to three people per household (i.e. the main respondent from the interview survey, the partner if there was one and the youngest other adult if there was one). The CaRB study from which this database is drawn had a longitudinal dimension, so it was needed to replicate the attitude instrument from a 1984 study [26,27]. Thus CaRB sought to measure the attitudes of the "youngest other adult" besides the main couple in the attitude survey. However, there were very few of these in the sample, so it was not useful to include the youngest other adult in this analysis. A spare questionnaire was sent to most of the households in case there was a new partner or youngest other adult at the time of the self-completion survey. In total 965 questionnaires were sent out to 365 issued sample households for self-completion; 365 to the main respondent who had responded at the face to face interview, 365 to the partner of the main respondent (or possible new partner) and 235 to the youngest other adult (or possible new adult household member). Since a spare questionnaire was posted to most of the households, the number of eligible respondents was less than the number of questionnaires sent out ($N = 965$). The eligible number of respondents to the questionnaire survey was estimated from the socio-demographics recorded at the face-to-face interview and the feedback from the postal questionnaires. This yielded a final response rate of 59% with 399 actual returned questionnaires from 230 households (227 from the main respondent, 137 from the partner, 35 from the youngest other adult).

The attitude questions used in the questionnaire replicated those questions about people's attitudes towards home energy use in a survey designed by the University of Surrey in 1984 [26,27]. The measures consisted of 13 questions, which were asked on a five-point Likert scale, ranging from 1 "strongly agree" to 5 "strongly disagree". The items were analysed using exploratory factor analysis to get four dimensions, i.e. attitudes towards *thermal comfort*, *economical with energy*, *industry and technology's role* and *individual's role*. *Thermal comfort* measured people's attitudes towards whether reducing their heating use would affect their thermal comfort; *economical with energy* was about people's attitudes towards using less energy in order to save money; *industry and technology's role* indicated people's attitudes towards whether parties other than themselves should be responsible for and could solve the energy crisis; *individual's role* was about people's attitudes towards their personal responsibility for and capability of reducing energy consumption.

The only item excluded in the analysis of this paper was "I've really no idea what I'd have to do to cut down my gas consumption". This item was excluded for two reasons: first, the item's factor loading was lower than 0.4 (i.e. a commonly used cut point of factor loading) in the exploratory factor analysis. A factor loading is the correlation between the latent factor (the attitude in this case, which cannot be directly observed) and the observed variable (the attitude scale item in this case). A low factor loading indicates that the observed variable only correlates weakly with the factor and cannot be well described by the factor. Second, it was not answerable for people not using gas as a heating fuel. The full set of home energy use attitude items are available in Table A1 in Appendix A.

Table 1
Sample characteristics.

Variable	Valid percent (%)	N
Tenure		
Owner Occupied	89.8	115
Rented	10.2	13
Person over 64-years-old in the household		
Yes	40.6	52
No	59.4	76
Accommodation type		
Any terraced	22.0	28
Semi-detached	22.8	29
Detached	31.5	40
Bungalow	18.1	23
Any flat	5.5	7
Wall *u* value		
0.8–2.1	41.7	50
0.35–0.6	58.3	70

N varies for variables due to missing values. No comparisons were made in the table due to no corresponding national statistics for couple households being available. For the whole sample's (427 households) characteristics comparisons with national statistics, see Refs. [19,20].

2.2. Sample characteristics

Household level variables (socio-demographics, building variables and temperature data) were combined with individual level variables (attitudes from the self-completion questionnaire) using the *exact* match method as Refs. [28,29]. Individual's attitude responses were matched with the corresponding household level data. In 128 households both partners responded to the self-completion attitude questionnaires; these comprise the sub-sample in this study. The mean household size was 2.6 people. Almost two-thirds (62.5%) households consisted of a pair of couple only, followed by household with dependent children ($N = 30$) which accounted for 23.4% of the sub-sample. Household type was not used in this study as a predictor due to its collinearity with household size. Average factor correlations between couple's attitudes in households without children, with children and with other members did not differ significantly (tested using a one-way ANOVA test ($F(2, 117) = 0.25$, $p = 0.78$)). This indicated that it was appropriate to have a joint sample. Also, in the regression analysis the household size was controlled for, accounting for the effect of multiple occupants in the household. The mean age of males was 59.8, while that of females was 58.1. The main couple in the household was asked to respond to the questionnaire. They are the HRP and his/her partner, and the HRP tended to be the older person of the household. This might be potentially underlying the relatively high mean age. For details of other socio-demographics and building characteristics of these 128 households, see Table 1.

3. Results

3.1. Deriving attitude factors

Exploratory factor analysis was carried out to extract the main factors latent in the 12 attitude questions on home energy use.

The responses of 128 couples, i.e. 256 individuals, were used as the basis for the factor analysis. Items were ascribed to the factor on which they loaded as highest, with a minimum identified factor loading of >40. The criterion for choosing a factor was an eigenvalue of greater than one. Four factors emerged after varimax rotation, based on two to four items each, and explaining 59.3% of the total variance. Varimax rotation is generally used to obtain the rotated factor loadings that represent the contribution of each variable in a specific factor. It is aimed at maximizing the sum of variances of squared structure elements in the columns of the factor structure matrix, thereby distributing variance away from the general factor that is usually produced by the factor analysis. The factors were interpreted as "*Thermal Comfort*", "*Economical with Energy*", "*Industry & Technology's Role*" and "*Individual's Role*". Accordingly, items were first summed and averaged to create a mean score, which were then reversed coded such that—a high value corresponds with strong attitudes. For details on the factor loadings and the results of reliability test for the attitude factors see Table A1 in Appendix A.

The factor "*Thermal Comfort*" measured whether people believe that reducing their heating use would affect their thermal comfort. Note that thermal comfort in this study indicated beliefs about the impact of reduction of heating on thermal comfort, and hence did not correspond to the definition of thermal comfort as condition of mind that expresses satisfaction with the thermal environment from ASHRAE [8]. A high "*Thermal Comfort*" score indicated that respondents believed that they would be uncomfortable and cold if they reduced their heating use. "*Economical with Energy*" referred to people's willingness to use less energy in order to save money. Respondents with high "*Economical with Energy*" scores were more willing to reduce energy consumption in order to save money. "*Industry & Technology's Role*" was about whether people believed parties other than themselves should be responsible for and could solve the energy crisis. A high score indicated a belief that energy crisis is caused by industry, and technology is the main way to resolve it. "*Individual's Role*" reflected people's attitude toward their personal responsibility for and capability of reducing energy consumption. Respondents scoring high on "*Individual's Role*" thought they were personally responsible for saving energy. The score on each factor was calculated for every person in the sample. Hence, for each household, eight attitude factors were computed, four for the male partner and four for the female partner.

3.2. Descriptive and correlations

Table 2 summaries the correlations between male partner's and female partner's attitudes. Male's attitudes and female's attitudes correlated significantly when correlating the same attitude factors, especially on "*Economical with Energy*", with a correlation coefficient of 0.64 ($p < 0.001$). The correlation coefficient for "*Thermal Comfort*" was the lowest but still highly significant ($r = 0.45$, $p < 0.001$).

The relationships between the eight attitude factors of the couples and heating use behaviours were examined (see Table 3). Note that the exact same sub-samples were used for this analysis reported in this section as were used in the regression analysis reported in Section 3.3. The sample size was reduced from 128 because first, the cases with missing values for any variables used in the regression (e.g. attitudinal measurements) were deleted, second, the required full set of temperature measurements (from which the dependent variable were developed) were only available for a subset of homes (i.e. $N = 84$ for average heating hours and $N = 98$ for maximum temperature). *Thermal comfort* attitudes of both male and female partners correlated positively and statistically significantly with both average heating hours and maximum temperature in the living room. This indicates that people who had a strong belief that thermal comfort was related to heating use tend to have their central heating on at higher temperatures and for longer. Both partners' *economical with energy* correlated weakly, but statistically significantly, with average active hours of central heating and maximum temperature. Scores on "*industry & technology's role*" of both male and female partners correlated statistically significantly but weakly with maximum temperature. Only the female partner's "*industry & technology's role*" attitude correlated significantly (weakly) with average heating hours. Only female's "*individual's role*" was significantly correlated with maximum temperature.

3.3. Explanatory power of couple's attitudes for heating hours and maximum temperature

Hierarchical linear regression was used to investigate whether couples' attitudes added to the explanatory power of heating usage behaviours in addition to socio-demographics and building variables. Three regressions were run for each of the two heating behaviour variables. All regressions included building and socio-demographic variables. Model MA added male's attitudes only; Model FA added female's attitudes only; Model CA added both partners' attitudes. Previous studies have found socio-demographics and building variables impact on heating temperatures and durations [3,20], so these were entered in the first block of the regression to be controlled for in all regressions, an approach similar to previous studies [29]. In order to identify the attitude factors with greatest influence and explanatory function, the attitude variables of male only, female only and both partners were entered at level two using the bidirectional stepwise method in Regression 1–3, respectively. In the stepwise method, only those attitude variables that can statistically significantly increase the explained variance in the dependent variable under examination are included in the model; for details, see SPSS 19.0 user's guide [30]. Stepwise regression has also been frequently used in previous studies on the predictive power of environmental attitudes and behaviours [31–35]. Tables 4 and 5 exhibit the results of three regression analyses for average heating hours per day and maximum temperature, respectively, with no collinearity found for any variables in the regressions (all VIF < 2). As can be seen from Table 4, Model 1 shows

Table 2
Correlations between male's attitudes and female's attitudes.

Variable	Thermal comfort_female	Economical with energy_female	Industry & technology's role_female	Individual's role_female
Thermal comfort_male	0.45*** (122)	−0.09 (122)	0.07(121)	−0.29*** (122)
Economical with energy_male	−0.25** (121)	0.64*** (121)	0.03 (120)	0.32*** (121)
Industry & technology's role_male	0.17+ (123)	−0.06 (123)	0.60*** (122)	−0.17+ (123)
Individual's role_male	−0.14 (122)	0.23** (122)	0.03 (121)	0.52*** (122)

N various due to missing values.
+ $p < 0.1$..
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Table 3
Correlations between attitudes and measured heating behaviours.

	Attitude factor							
	Thermal comfort		Economical with energy		Industry & technology's role		Individual's role	
	Male	Female	Male	Female	Male	Female	Male	Female
Average heating hours per day (N = 84)	0.26**	0.40***	−0.25*	−0.14+	0.07	0.23*	−0.13	−0.10
Maximum temperature (N = 98)	0.31***	0.28**	−0.19*	−0.28**	0.22*	0.27**	−0.09	−0.25**

N various due to missing values.
For the details of the meaning of attitude factors, please see Section 3.1.
+ $p < 0.1$.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

the standardized coefficients and model parameters for building and socio-demographics variables which are exactly the same for all three regressions. In the bidirectional stepwise method, one variable is added or removed as a predictor at each step, resulting in several intermediate models. The last model is the best model at explaining dependent variables; hence, only the final models of three regressions are shown in Table 4. Model MA is the final model when only male's attitudes were added (same as Model 1 plus the attitudes of male that increased the explained variance of heating hours significantly), Model FA is the final model when only female's attitudes were added (same as Model 1 plus the attitudes of female that increased the explained variance of heating hours significantly) and Model CA is the final model when both male and female's attitudes were added (same as Model 1 plus the attitudes of male and female partners that increased the explained variance of heating hours significantly). Note that ΔR^2, ΔF of Model CA in Table 4 showed the change between Model 1 and Model CA, and the values attained by entering both the attitude variables at one time in the second block in another regression in particular.

As shown in Table 4, the socio-demographics and building variables explained 4.8% of the variance of heating hours, and accommodation type was the only statistically significant predictor affecting heating hours in Model 1. When the attitudes to home energy use of male only, female only and both partners were added to Model 1 separately, three final models (Model MA, FA, CA) had adjusted R^2 ranging from 0.14 to 0.21; the adjusted R^2 for Model CA, i.e. containing both male and female attitudes, was the highest. Both Model MA and Model FA with Model CA were compared using ANOVA (Analysis of Variance) test in R (version 3.1.1). In the context of a regression, the accompanying ANOVA tests whether the model fit of two nested models is statistically significantly different. It performs an F test between two models, where a p-value of less than 0.05 indicates that the models are statistically significantly different. The results indicated that the model fit of Model CA were statistically significantly better than either Model MA (F = 4.72, $p < 0.05$) or Model FA (F = 7.81, $p < 0.01$).

In Model CA, "*economical with energy*" of male and "*thermal comfort*" of female proved to be the only two significant predictors; each contributing similarly to the regression equation. The addition of

Table 4
Regression of average heating hours per day on socio- and building- demographics, male's/female's/both partners' attitudes.

Predictor	Average heating hours per day			
	Same for regression 1–3	Final model regression 1	Final model regression 2	Final model regression 3
	Model 1 (Socio-demographics & building variables/Enter) coefficient	Model MA (+Male's attitudes/Stepwise) coefficient	Model FA (+Female' s attitudes/Stepwise) coefficient	Model CA (+both partners' attitudes/Stepwise) coefficient
Constant	−0.113	−0.061	0.059	0.057
Tenure_rented	0.022	−0.051	0.019	−0.040
Person over 64-years-old	0.176	0.290*	0.106	0.218+
Household size	0.010	−0.017	−0.020	−0.034
Semi-detached house	−0.005	0.020	0.003	0.021
Detached house	0.288+	0.257+	0.240	0.227
Bungalow	0.289*	0.321*	0.184	0.238+
Any flat	0.015	0.010	−0.007	−0.005
Building age	−0.082	−0.178	−0.140	−0.203
Wall u_value_0.35–0.6	−0.110	−0.136	−0.133	−0.148
Economical with energy_male	/	−0.390***	/	−0.320** (1)
Thermal comfort_female	/	/	0.325**	0.239* (2)
N	84	84	84	84
Adjusted R^2	0.048	0.171	0.137	0.211
ΔR^2	/	0.119	0.090	0.164
F	1.467	2.710**	2.323*	3.018**
ΔF	1.467	11.948***	8.661**	8.639***

All the nominal variables were transformed to dummy variables before the regression, and the reference categories for three nominal variables are: "Owner occupied" was use as the reference category for Tenure, "Any terraced house" was used as the comparison category for Dwelling type, Wall u-value "0.8–2.1" was used as the comparison category for Wall u_value. (1) indicates that the corresponding variable was the first variable included in the model in stepwise method, (2) indicates that the corresponding variable was the second variable included in the model in stepwise method. ΔR^2, ΔF of Model CA showed the change between Model 1 and Model CA, and the values were got by entering both the attitude variables at one time in another regression.
For the details of the meaning of attitude factors, please see Section 3.1.
+ $p < 0.1$.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Table 5
Regression of maximum temperature on socio- and building- demographics, male's/female's/both partners' attitudes.

Predictor	Maximum temperature			
	Same for regression 1–3	Final model regression 1	Final model regression 2	Final model regression 3
	Model 1 (Socio-demographics & building variables/Enter) coefficient	Model MA (Male's attitudes/Stepwise) coefficient	Model FA (Female' s attitudes/Stepwise) coefficient	Model CA (both partners' attitudes/Stepwise) coefficient
Constant	0.001	0.013	0.025	0.013
Tenure_rented	0.027	−0.050	−0.027	−0.037
Person over 64-years-old	0.241*	0.224*	0.273**	0.214*
Household size	0.171	0.157	0.146	0.164
Semi-detached house	−0.105	−0.084	−0.095	−0.081
Detached house	−0.379**	−0.347**	−0.381**	−0.326**
Bungalow	0.095	0.100	0.104	0.118
Any flat	0.044	0.042	−0.033	−0.020
Building age	0.151	0.107	0.098	0.109
Wall u_value_0.35–0.6	0.238*	0.245*	0.244*	0.244*
Economical with Energy_male	/	−0.262** (1)	/	/
Thermal comfort_male	/	0.204* (2)	/	0.196* (2)
Economical with energy_female	/	/	−0.336***	−0.306** (1)
N	98	98	98	98
Adjusted R^2	0.124	0.227	0.227	0.253
ΔR^2	/	0.107	0.101	0.133
F	2.528*	3.586***	3.843***	3.994***
ΔF	2.528*	6.839**	12.667***	8.621***

All the nominal variables were transformed to dummy variables before the regression, and the reference categories for three nominal variables are: "Owner occupied" was use as the reference category for Tenure, "Any terraced house" was used as the comparison category for Dwelling type, Wall u_value "0.8–2.1" was used as the comparison category for Wall u_value. (1) indicates that the corresponding variable was the first variable included in the model in stepwise method, (2) indicates that the corresponding variable was the second variable included in the model in stepwise method. ΔR^2, ΔF of Model MA/CA showed the change between Model 1 and Model MA/CA, and the values were got by entering both corresponding attitude variables at one time in another two regressions.
For the details of the meaning of attitude factors, please see Section 3.1.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

two attitude factors to the basic Model 1 in Model CA increased the explanatory power from 4.8% to 21.1% of the variance of heating hours.

The coefficient of male's *economical with energy* indicates that, when a man had higher *economical with energy* about energy consumption, his household had fewer active hours of central heating. Household, where the male partner had the highest *economical with energy* (Score 5.0) had the central heating on for 1.28 h fewer than those household where the male partner had the lowest *economical with energy* (Score 1.0). This was calculated by multiplying the biggest score difference on *economical with energy* by the coefficient of *economical with energy* in Model CA.

Female's *thermal comfort* attitude highly influenced the heating hours, indicating that women who express a greater belief strength that using less heating has a higher impact on thermal comfort tend to have their central heating on for a longer time periods. The households where the female partner had the highest *thermal comfort* score (5.0) used heating for 0.96 h longer than households whose female partner had the lowest *thermal comfort* score (1.0).

For maximum temperature, attitude factors increased the explained variance by up to 12.9%, with the adjusted R^2 changing from 12.4% (for Model 1 that excludes attitude variables) to 25.3% (for Model CA which includes both male and female attitudes). The adjusted R^2 for Model MA (male attitudes) and Model FA (female attitudes) were both 22.7%. An ANOVA test was computed to compare Model FA with Model CA, the result showed that the model fit of the latter was statistically significant better than that of the former ($F = 0.0454$, $p < 0.05$). As existing tests for comparing models can only be applied to nested (e.g. ANOVA, Likelihood ratio test etc.) and non-nested (e.g. Vuong test etc.) models in practice [36,37], it was not feasible to compare Model MA and Model FA since they were overlapping. Given that the R^2 of Model MA and Model FA were identical, Model CA was the best fitting model among the three models.

Among the eight attitude factors from both partners, "*economical with energy*" of female and "*thermal comfort*" of male were the only two included in the final Model CA. This indicated that people who cared more about their energy usage expenses and who did not think less heating usage would lower their comfort level have a lower maximum temperature than others. The maximum temperature difference between the households whose female partners had highest (5.0) and lowest (1.0) *economical with energy* scores was −1.23 °C, while the maximum temperature difference between the households whose male partners had highest (5.0) and lowest (1.0) *thermal comfort* scores was 0.78 °C. These values were calculated by multiplying the biggest score difference on *the specific attitude factor* by the coefficient of *this factor* in Model CA.

Hence, for both heating behaviours measured (average heating hours per day and maximum temperature), attitudes added significantly to the regression model in addition to building characteristics and socio-demographic factors. The attitudes that had any explanatory power were *economical with energy* and *thermal comfort*, and the attitudes of both male and female partners significantly improved the models, when compared to using male or female attitudes only.

4. Discussion and conclusion

4.1. Result discussion

The four attitude factors generated from exploratory factor analysis in this study were very similar to those found in previous research on attitudes to home energy use around 1980s–1990s [10,12,18,38,39], even though other studies had slightly different wordings, such as “comfort and convenience”, “family finances”, “optimism/belief in science” and “individual’s role” etc. The correlations between attitudes and heating usage behaviours presented in this paper indicate that attitude–behaviour relationships were of similar strength for both male and female partners on most of the factors; but for heating hours, male’s attitudes were slightly stronger than female’s. Of the eight attitude factors, *economical with energy* and *thermal comfort* of both male and female partners affected heating temperatures and hours of use significantly, and these were also the highest attitude–behaviour correlations found. This was in accordance with previous studies that attitudes towards comfort and finances always correlated most with home energy use than other attitudes [12,18].

The correlation analysis between the attitudes of couples revealed that, English couples who participated in this study held moderately similar attitudes towards heating energy use; as shown by correlation of the magnitude of about $r = 0.45$ to $r = 0.64$ between male’s and female’s attitudes. Their levels of *economical with energy* ($r = 0.64$, $p < 0.001$) were the most similar, their attitudes to *industry and technology’s role* ($r = 0.60$, $p < 0.001$) and the *individual’s role* ($r = 0.52$, $p < 0.001$) were slightly less similar and their attitudes to *thermal comfort* ($r = 0.45$, $p < 0.001$) were the least similar, although they were still statistically significantly correlated. This corresponded to previous research which has demonstrated that females preferred higher indoor winter temperatures to keep thermal comfort than males [17,40].

The regression results showed that attitudes impact on household heating temperatures and duration, in addition to the effects of socio-demographics and building variables. This finding indicated attitudes’ influence on home heating usage; going beyond previous studies which have not shown the reason for the large variability of heating temperatures between identical homes (identical building characteristics) [28], and those that only demonstrate the impact of residents’ characteristics on temperatures in the homes [3]. This finding differed from Abrahamse and Steg’s study, which found that psychological factors did not help explain energy use [41]. However, their study only used general attitudes towards comfort and convenience to predict home energy use, and only one person’s attitudes were measured in the household, and they were trying to predict home energy use as a whole, which might result in the poor explanatory power of attitudes. This leads to the other important finding of this study, which was that couple’s attitudes together explained heating temperatures and durations more accurately than a single partner’s attitudes. Similarly to this study, Seligman et al. [10] once found that combined husband’s and wife’s comfort attitudes correlated with household energy consumption more than those of a single person’s.

Among the four attitude factors used in this study, it was found from the regression analysis that *economical with energy*, as well as *thermal comfort* of both male and female partners together explained measured household heating use more closely in the regression model. Specifically, male’s *economical with energy* and female’s *thermal comfort* predicted heating hours more accurately, while female’s *economical with energy* and male’s *thermal comfort* predicted maximum temperature more accurately; the model with both partners’ attitudes fitted statistically significantly better than the models with either male’s or female’s attitudes, suggesting that the greatest benefit in understanding heating use is gained when both male and female partners’ *economical with energy* and *thermal comfort* attitudes are measured.

4.2. Limitations and future work

This study explored the influence of the main couples’ attitudes on home heating usage in households with couples. Due to insufficient numbers of a third adult in the household, this study did not consider the attitudes of additional adult household members. Due to the longitudinal research design and need to replicate a 1984 survey [26,27], this study did not measure children’s attitudes. Future research might want to explore more about other household member’s (e.g. Children’s) attitudes’ influence on home heating energy use and how children’s attitudes interact with their parents’. The sample was randomly selected using stratified sampling (of English postcodes), thus well distributed throughout England. This should ensure a representative sample. However, the 38% response rate to the main survey and the 48% response rate of couples to the postal survey indicate that the sample used in this analysis may not be completely representative. However, we would be surprised if couples in our sub-sample had attitudes that were systematically more similar or more different than the attitudes of all English couples. Although the exclusion of certain households (e.g. those without temperature measurements), reduced the sample size further, the study was still able to detect statistically significant effects, suggesting that the sample size was adequate for the purpose. Besides, this research carried out examining how attitudes impact on heating energy use but did not address what in turn determines those attitudes. Future research should address this question, in particular given the likely mutual influences, e.g. the functionality of the heating system might impact on people’s attitudes towards home heating.

Some variables that might have influence on home heating usage, such as household type, hours spent in the home etc., were not included in this study due to limited numbers of collected variables or missing values higher than 10% or collinearity with other variables. In future research, those variables should be taken into consideration when home heating usage is explored. For example, if one partner of the couple spends more time at home, their attitudes might affect heating usage more. For the regression method used in this study, Reinard [42] cautioned the stepwise method did not always select the best set of variables, since it emphasized selecting those variables with statistically significant contributions separately rather than considering the interactions between variables. This indicates that researchers should still make a deliberate choice on whom and what attitudes to target when exploring home energy consumption.

4.3. Conclusion

In contrast to Abrahamse and Steg [41], this study found that attitudes to home energy use do help explain heating use. The attitudes with the most explanatory power were those on “*economical with energy*” and “*thermal comfort*”, reinforcing the earlier findings of [12,18]. This study significantly advanced that of Seligman [10] by exploring the effect of adding a partner’s attitude to a regression model explaining heating usage–rather than simply exploring correlations as they did. This study also found that the attitudes of *both* male and female partners explained heating usage more accurately than the attitudes of only one partner.

Energy saving programs and appeals should take into account that both *economical with energy* and *thermal comfort* attitudes influence heating behaviours. Energy efficiency programs should emphasis both aspects, as suggested by [39]. For example, improved home insulation and more energy-efficient heating technologies improve thermal comfort and reduce energy bills simultaneously. Heating behaviour change programs also need to take into account that *thermal comfort* (not just *economical with energy*) also affects heating behaviour.

This research suggested that home energy conservation interventions targeted at both partners might be more successful than those targeted at the male or female partner only; future research could establish whether this might be the case and extend to explore the influence of other household members.

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Appendix A. Appendix A

Table A1

Table A1
Home energy use attitude items with loadings from exploratory factor analysis and factor reliability.

Factor	Items	Loading	Item description	Cronbach's Alpha
1. Thermal comfort	TC1	0.851	In my house it's impossible to be comfortably warm in the winter and also be economical with the heating	0.721
	TC2	0.787	It's just too uncomfortable to have the indoor temperature at home less than 70°(21 °C) during the winter months	
	TC3	0.617	There's nothing householders can do to cut their heating bills without unacceptable changes in the way they live	
2. Economical with energy	EE1	0.736	The size of my household's budget has meant that we've had to be very careful how we've spent our money over the past year	0.626
	EE2	0.706	My household is already doing everything it can to use the room and water heating as economically as possible	
	EE3	0.636	We wear heavier clothes at home during the winter so that we can set the thermostat lower than we otherwise could	
	EE4	−0.620	In my household we don't bother too much about being economical with the use of gas and electricity.	
3. Industry & technology's role	ITR1	0.757	Nuclear power will solve most of Britain's energy problems	0.574
	ITR2	0.707	It's more important to think about saving energy in industry than in homes	
	ITR3	0.699	Scientists will soon solve the 'energy crisis' by providing society with new sources of energy	
4. Individual's role	IR1	0.814	If everyone in Britain tried to save energy at home, it would have a real impact on the nation's overall energy consumption	0.623
	IR2	0.770	People can do a lot in their own homes to help avoid the possibility of future energy shortages	

KMO = 0.699; Bartlett's test of sphericity: $p < 0.001$.
59.3% Variance explained.

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