Picturing the invisible: What is the impact of thermal imaging on householder intentions to install energy efficiency?

Method Section, Upgrade Report.

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Research population

For this part of the study the target population, i.e. the population for which information is required, was UK householders living in low-income areas, both homeowners and tenants. Studying the impact of thermal images amongst this population it could (1) increase understanding of the impact of thermal images on householders in low income areas and (2) suggest hypotheses and methods that could be used to increase understanding of impact of thermal images on householders in medium and high income areas.

The survey population, i.e. the part of the target pop that is studied, were potential recipients of a grant scheme designed to reduce fuel poverty and stimulate economic development by delivering energy efficiency measures in areas that scored highly on multiple indices of deprivation[1].

Experimental design

Introduction

The aim of experimental design was to generate *causal inference*, e.g. that A causes B (Shadish et al., 2001). In this part of the study the aim was to understand whether thermal images *cause* a change in behavioural beliefs or intentions to install measures. The characteristics of the design used here were:

- the random assignment of sampling units to conditions (R)
- a control and intervention group (C, X_1)
- pre and post –tests in the form of self-completed questionnaires (Q1, Q2)

Figure 1: Schematic Diagram of the randomised design used in this study (R=random assignment, Q1= pre-test, Q2= post-test, C= control group, X_1 = intervention group)

R Q1 C Q2

R Q1 X_1 Q2

[1] Deprivation is a wider concept than 'low income' as it includes lack of opportunities /access to resources. Multiple deprivation refers to deprivation in the domains of employment, income, education, health, community safety, geographical access to services, housing and physical environment.

The steps involved in this experimental design is as follows, each of which are described below:

1. Identify salient behavioural beliefs
2. Intervention design
3. Sampling & randomisation
4. Design of pre and post tests
5. Analysis

Identify salient behavioural beliefs

A conventional way to identify behavioural beliefs within Theory of Planned Behaviour studies is via elicitation interviews. For example Bamberg and Schmidt's TPB study included an open-ended questionnaire to elicit positive and negative consequences of car use and situational factors that might restrict or facilitate car use (2003). Elicitation interviews consist of a series of open-ended questions is asked about the specific behaviour in the specific target populations of interest (Middlestadt et al., 1996).

This study conducted 6 elicitation interviews on 20th and 21st May 2013 with householders in the target population, i.e. potential recipients of the grant. These householders were selected via accidental contact, i.e. all householders whose homes received a home assessment from a particular assessor on these two dates were interviewed. All assessments in this group were 'archetype' home assessments, i.e. these assessments were intended to inform what efficiency measures would be offered to that particular community. Householders were found for the archetypes largely via word-of-mouth, therefore it is reasonable to assume that these householders are not typical as they may have a larger social network or greater interest in energy issues than the average grant recipient (this issue is discussed in Intervention Design).

The interviews lasted between 44 minutes to 1 hour 11 minutes. The interviews intended to elicit the positive and negative consequences, subjective norms and actual and perceived control issues surrounding the energy efficiency measures offered under the grant scheme (Appendix 5). Each interview was recorded. These recordings were listened to a number of times and the responses reviewed to understand salient consequences, subjective norms and control issues. This process, alongside other analysis (Appendix 6) led to the focus on wall insulation, loft insulation and draught-proofing as the measures of interest for this study.

Following this review the parts relating to salient beliefs and factors that might affect perceived and actual control were transcribed (Appendix 8). Table 1 gives example quotes and the related Theory of Planned Behaviour (TPB) variables. The salient behavioural beliefs elicited via this process and the language used by interviewees informed the design of the pre and post-tests (Appendix 4).

Table 1: Selected quotes from elicitation interviews and related Theory of Planned Behaviour (TPB) variables

Quote	Reference to	TPB variable	URN
"I think it would enhance the appearance"	external wall insulation	Behavioural belief (appearance)	001
"It'd reduce heat loss"	external wall insulation	Behavioural belief (heat loss)	001
"It'd cut down on the heating bills for a start"	external wall	Behavioural belief	001

	insulation	(reduce heating bills)	
"How much disruption is it going to cause?	heating system repair	Behavioural belief (disruption)	001
"Anything to make it warmer really"	external wall insulation	Behavioural belief (warmth)	002
"It'd make the rooms a bit smaller but I don't think it makes them that much smaller"	internal wall insulation	Behavioural belief (space)	002
"It would warm up that room which would warm up this room."	More loft insulation	Behavioural belief (warmth)	002
"I don't think it looks nice"	external wall insulation	Behavioural belief (appearance)	003
"I am quite conscious of not having it on too much… you just think it's a waste isn't it if you've got it on but you don't need it."	heating fuel use	Behavioural belief (heat waste)	005
"I would have to know how thick it was and how much it was going to stick out"	external wall insulation	Actual / perceived control (knowledge)	003
"I wouldn't object to it but I'd like to know some facts first."	external wall insulation	Actual / perceived control (knowledge)	004

Intervention design

All recipients of the grant scheme were subject to home energy assessments in order to establish which of the energy efficiency measures available under the grant scheme were suitable for their home. Householders were randomly assigned into either the control or intervention group.

Householders in the control group (C) were asked to fill in the pre-test (Q1), at the start of the home energy assessment, after the assessor introduced himself and the researcher. This timing was used in order to reduce confounding factors associated with the manner/knowledge of the assessor and/or any feedback the householder receives from the assessor about which measures will be suitable, after the assessment. Householders were asked at this stage whether they agreed to the conversation being recorded, this was done using a visible Dictaphone.

Having filled in the questionnaire householders in the control group were then asked consent to have a conversation about heating and comfort in the home. These conversations took the form of semi-structured qualitative interviews which covered householder perceptions of the heating and comfort of their home, cost of heating and ways in which comfort could be increased or costs reduced. The intention was both to attempt to validate/verify responses to the pre-test and to explore in householders own words, and in further depth, the behavioural beliefs they held about the thermal efficiency measures under examination.

Finally householders were asked walk round their home with the researcher and, in each room, were asked how they found the room for heating and comfort and also to identify any draughts, damp/ condensation/ mould or cold spots.

10-16 weeks after the home assessment householders in the control group were then sent a generic 'Home Thermal Image Report' along with the post-test (Q2) The report showed thermal images, and the accompanying photographic images of the same scenes, of homes similar to their own thermal images, accompanied by a simple statement about how to interpret thermal images (Appendix 7). The thermal images used were a selection of those taken in homes in the intervention group. Images

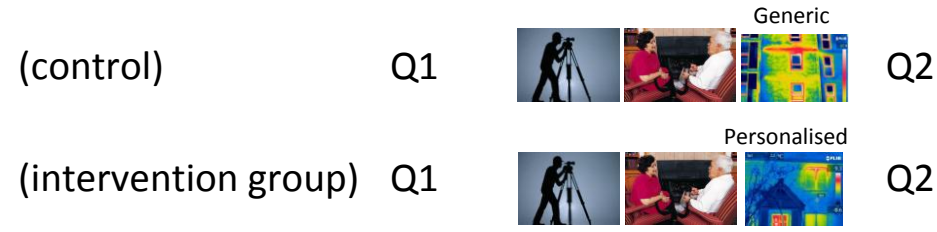
were selected based on their representativeness, impact and ability to maintain the anonymity of the householder. Their use was subject to permission from the householder.

Householders in the intervention group (X_1) received Q1, their home assessment and qualitative interview in an identical manner to the control group (C), in order to maximise consistency between groups. However after the qualitative interview householder's in the intervention group were shown a thermal camera and given a brief description of how to interpret thermal images. For these householders the thermal camera was used during the walk-around to examine and take images of the areas identified by householders as draughty, damp / mouldy or cold.

10-16 weeks after the home assessment householders in the intervention group were then sent a a 'Home Thermal Image Report' along with the post-test (Q2) which consisted of the thermal images taken of the inside of their home, and related visual images. The reports were identical to those sent to the control group aside from the images being of their own home (personalised) rather than a home similar to their own (generic).

In order to control for the effect of different assessors all questionnaires were coded to indicate which assessor was present. In order to try to minimise the influence of weather the study sent post-tests to householders in control and intervention groups on the same date.

Figure 2: Pictorial schematic of the intervention design (Q1= pre-test 1, Q2=post-test)



Key:


Interaction with householder

Personalised thermal image

Non-personalised thermal image


Home assessment

Colour coding of images

Other research has used ironbow palette thermal images, i.e. white-hot, purple-cold (Boomsma, 2013; Goodhew, 2013). However evidence from the elicitation interviews suggested that images in the rainbow palette (red-hot, blue-cold) attracted more attention (they were the first to be commented on by participants) than the ironbow palette (apart from amongst one colour-blind participant). This palette may be more intuitive as takes colours at each end of the visible spectrum to represent extremes of temperature within any one image. Furthermore the rainbow palette is standard in building applications. Following this rationale the thermal images sent with Q2 were rainbow palette (red-hot, blue-cold).

Sampling procedure & randomisation

Sampling

The sampling procedure employed to extract samples for the study is non-probability, i.e. accidental sampling (Sarantakos, 2005). Householders will be selected for the study based on their home energy assessment date. The reasons for using non-probability sampling are:

- Probability sampling would include recipients to the grant scheme who would have their home energy assessments done outside of the heating season. Creating interpretable thermal outside the heating season is not possible, therefore this places a practical constraints on probability sampling
- It would be inconvenient and costly to randomly attend assessments. Therefore the sample size can be maximised by including all assessments taking place on particular dates.

As homes that are geographically close are more likely to be surveyed on the same day this will his might mean some localities will be overrepresented in the intervention groups. However these localities are not expected to be *systematically* biased on factors which might influence independent variables, such as external temperature, building envelope thermal performance or occupant characteristics.

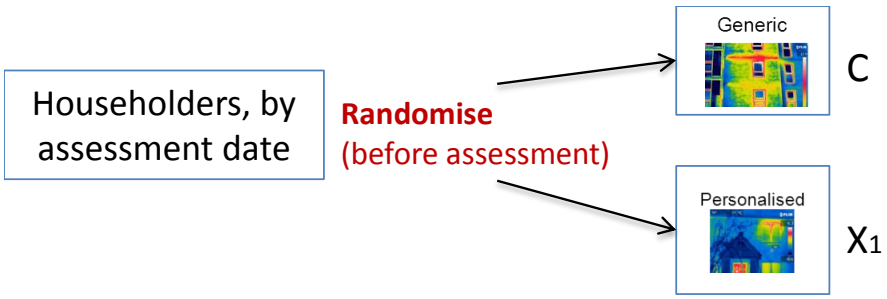
However householders who are part of the 'archetype' assessment process; the initial assessments done in each community to establish what measures will be offered in that area, are recruited by word-of-mouth therefore these occupants are likely to be different to standard assessments householders. Therefore 'archetype' householders might be either more engaged in the process or have larger social networks, or both. This study assumes that, in comparison to 'archetype' householders, standard householders may be less inclined to adopt energy-efficient technology (as suggested by Mills and Schleich, 2012). The study aims therefore to sample homes in areas where standard assessments rather than archetypes are taking place, in order to establish whether thermal images have any effect amongst 'harder to reach' groups. This will be done in collaboration with the delivery agent.

Randomisation

Randomisation of householders into control or intervention groups must be done *before* the home assessment has been completed, as these householders will either have a walk-round their home during the assessment without the taking of thermal images (control group) or a walk-round their home which includes the taking of thermal images (intervention group).

For this reason batch randomisation was used to assign householders to control or intervention groups. Batch randomisation is used when small groups (with more units than treatments) are available to be randomised but not the whole sample, (Shadish et al., 2001, p. 295). Assignment of units to conditions was made periodically in batches, i.e. when the list of the homes being assessed on particular dates is released by the delivery agent. This randomisation procedure also forced equal sample sizes for control and intervention groups, e.g. 6 assessments in batch resulted in 3 being randomly assigned to the control and 3 randomly assigned to the intervention group in order to increase the statistical power of the analyses (Shadish et al., 2001, p. 297). Responses were coded by their date of assessment and batch in case any differences between batches, e.g. location or weather, are shown to be significant.

Figure 3: Randomisation procedure for the control group (C) and intervention group (X_1)



Sample size

The study aimed to recruit 46 householders into the sample for randomisation (24 per group). This sample sizes was based on power calculations assuming:

- Effect size ≈ 20% difference in intentions to install thermal efficiency measures between control and intervention groups (as suggested by Boomsma, 2013). This equates to a 1.68 difference in intention rating between control and intervention groups on the 1 to 9 scale used.
- The p-value is set at 0.05 (~95% probability of correctly establishing if the null hypothesis is true)
- Power is set at 80% (~20% chance of incorrectly accepting the alternative hypothesis)
- The standard deviation is 2.0 rating points (1 to 9 scale), based on pilot testing.

Design of pre and post tests

The aim of the pre and post-tests was to ascertain any difference in behavioural beliefs (belief evaluation & belief strength), attitudes, intentions and perceived/ actual behavioural control between the control and intervention group towards thermal efficiency measures as a result of the intervention.

The pre and post-tests consisted of self-completed questionnaires which are a conventional way of measuring variables within TPB. This study did not aim to test all the variables within TPB but focused on behavioural beliefs, attitudes, intentions and perceived/actual behavioural control. The post-test also included questions designed to directly investigate householder responses to thermal images in terms of processing ease, attention and behavioural responses to images, using persuasive message theory as a framework. As intentions to install thermal efficiency measures may also be influenced by occupant and property characteristics, questions regarding the most relevant characteristics of the householders and property were included (taken from Parker et al., 2005), including householder age and gender, years lived at property, years planning to stay at property , tenure and property age.

For belief evaluation, belief strength, intentions and perceived/actual control the question wording was informed by the elicitation interviews and by TPB and TPB studies (Ajzen, 1991; Bamberg and Schmidt, 2003; Tonglet et al., 2004).

Scale and item construction

Self-report scales have to consider the motivation and ability of respondents to answer questions, their language proficiency alongside the test's reliability, validity, cost, ease of administering and scoring (Tinsley and Brown, 2000). This research used the language used in the elicitation interviews as a guide and pre-tested the questionnaires for comprehensibility (see Testing of questionnaires). Q1 took place within the context of the grant scheme's home assessments so the research assumes answers to questions may be affected by what householders believed would be available to them through the scheme.

Survey design theory suggested that the optimal number of response alternatives should be related linearly to the cognitive level of the respondent (Tinsley and Brown, 2000, p. 73). As respondents in this study were based in areas of multiple deprivation, including low educational attainment, originally a 5-point scale was used (in preference to a 7 or 9 point one). The first version of the questionnaire used a bipolar scale (+2 to -2) scale, informed by Ajzen's work which suggests that bipolar scoring of belief strength and evaluation produced stronger correlations with global attitude measures than unipolar scoring (1991). However pre-testing suggested that respondents found this bipolar scale confusing and so this converted to a unipolar scale (1 to 5). Furthermore the initial application of the questionnaire yielded a large proportion of responses that were on, or close to, the upper end of the scale. Therefore, in order to get more granularity of response, subsequent questionnaires offered respondents a 1 to 9 scale.

Finally the item construction took account of the fact that generalised measurements of "energy efficiency behaviour" often fail to predict specific behaviours (Macey, 1991) and that different attitudes and control factors apply will to different measures (Black et al., 1985). Therefore it was important to measure householder attitudes and intentions towards specific measures separately. The measures chosen for inclusion were those where the hypothesised impact of thermal images on attention and attitudes was the greatest (see analysis in Appendix 6).

Belief evaluations

Aim: to measure the extent of positively or negatively evaluation of the outcomes/ characteristics associated with thermal efficiency measures

Question: How important is it to you to make your home warmer/ save money on your heating bills/ make your home look better / avoid wasting heat /avoid hassle and disruption from work being carried out on your home/ avoid losing storage space in your loft / reduce dampness or condensation? [Not at all important – Extremely important]

Belief strength

Aim: to measure the subjective probability of specific outcomes/ characteristics associated with thermal efficiency measures

Question: I feel that having [the walls of my home insulated/more loft insulation put in my home /the doors and windows of my home draught-proofed] would make my home warmer/ reduce my heating bills / make my home look better / reduce heat loss from my home / cause hassle or disruption/ reduce the storage space in my loft / increase dampness or condensation in my home]? [Don't agree at all – Strongly agree]

Intentions

Aim: to measure strength of intention to install thermal efficiency measure

Question: How likely are you to agree to have [wall insulation/loft insulation/new windows/draught-proofing] if it is offered to you free of charge in the next year? [Not at all likely – Extremely likely]

Perceived / actual behavioural control

Aim: to measure to what extent the householder intentions to install thermal efficiency measures are predicted by the perceived or actual control

Questions:

1. I feel my home is suitable for [wall insulation/more loft insulation/ draught-proofing of doors and windows] [Don't agree at all – Strongly agree]
2. Is there anything that might stop you/help you from agreeing to have [your walls insulated/some or more loft insulation/new windows/draught-proofing]? [open-ended]

Occupant and property characteristics

Aim: to identify occupant or property characteristics that may influence intentions to install thermal efficiency measures

Questions:

1. When was your home built? [Before 1919, 1919-44, 1945-92, 1993 or after]
2. How long have you lived there? [Less than 2 years, 2-4 years, 5-9 years, 10+ years]
3. How long are you planning to stay at your current home? [Less than 2 years, 2-4 years, 5-9 years, 10+ years]
4. Which one of these best describes how well you and your household are keeping up with your energy bills? [I / we manage very well, I / we manage quite well, I / we get by alright, I / we have some difficulties, I / we have severe difficulties]
5. How old are you? [16-34, 35-44,45-54, 55-64, 65+]
6. Are you? [Male, Female]
7. Do you? [Own your home, Rent your home (private landlord), Rent your home (social landlord)]
8. Do you suffer from any form of colour-blindness? [Yes, No]

Intervening factors

Aim: to qualitative explore whether any other factors may have changed between Q1 and Q2 which may have affected intentions to install thermal efficiency measures

Questions:

1. What has the temperature been like in your home over the past week?
2. [Cold Cool Slightly cool Neutral Slightly warm Warm Hot]
3. What has the temperature been like outside your home over the past week?
4. [Cold Cool Slightly cool Neutral Slightly warm Warm Hot]
5. Are you intending to make any changes to your home in the next year? [Open-ended]

Additional post-test questions:

- Processing ease (based on Kreuter et al., 2000)
    - Do you understand or not understand the thermal images included with this questionnaire? (Don't understand them at all – Understand them very well)
- Attention to / scrutiny of message: (based on Kahlor et al., 2003; Kreuter et al., 2003)
    - Do you remember or not remember (Don't remember it at all – Remember it very well)
        - having your home surveyed for insulation and energy use
        - having your home thermally imaged
    - Have you looked at or not looked at the thermal images included with this questionnaire (Not looked at them at all - Looked at them very closely)
- Behavioural response to message (based on Kahlor et al., 2003; Kreuter et al., 2000)
    - Do these images make you more or less likely to believe wall/more loft insulation / draught-proofing will [Much less likely to believe – Much more likely to believe]:
        - make your home warmer
        - reduce your heating bills
        - reduce heat loss from your home
        - increase dampness or condensation in my home
    - Do these images make you more or less likely to install [Much less likely to install – Much more likely to install]:
        - Wall insulation
        - More loft insulation
        - Draught-proofing
    - How likely is it that you will [Extremely unlikely – Extremely likely]:
        - look at these thermal images again in the future
        - Show these thermal images to people you know
        - make changes to your home or behaviour based on these images

Testing of questionnaires

The questionnaires were tested via field pre-testing i.e. testing the questionnaire with respondents from the survey population (Fowler, 1995) in this case the participants of elicitation interviews. The field testing aimed to establish the ease of completion, whether the length was appropriate and check response consistency (Francis et al., 2004). The questionnaires were also sent, via an online survey tool, to a separate, larger sample (75 in total) in order to check responses and expected correlations. This larger sample were UK householders but not members of the survey population (grant recipients), recruited via a snowball process. Finally during experiment respondents were verbally asked, after completing the questionnaire, how the questionnaire had been to fill in and whether they had any problems with it. Responses were factored into the design of the post-test.

Data Management

Data from Q1 and Q2 for each householder were entered into a password protected excel spreadsheet, alongside supplementary information such as the unique householder number (UHN), assessor code, weather data (maximum and minimum temperatures and wind speed) for the weather station nearest the home (from Met Office, 2013). Recording of the qualitative interviews

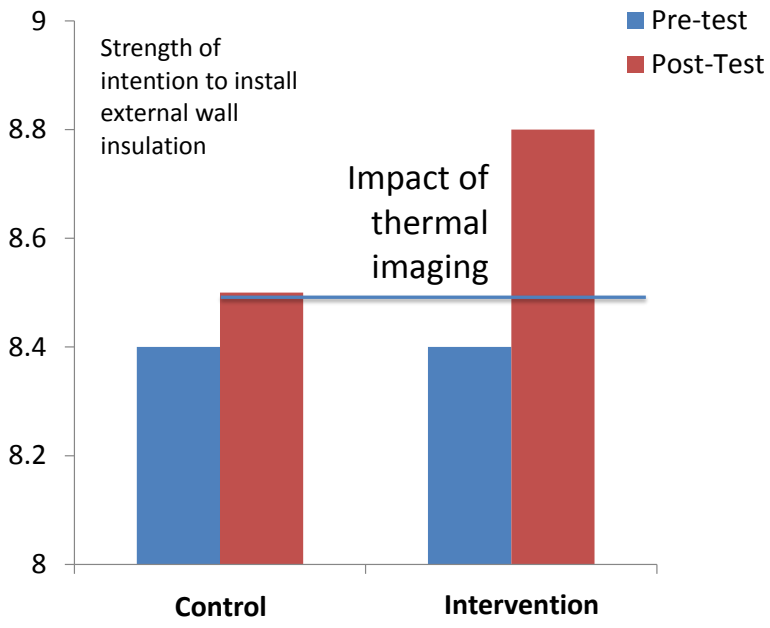
were stored on a password protected computer. Data was backed up in real-time via an online storage facility (Dropbox), apart from files which contain personal data. These will be stored in password protected documents on the computer hard drive. The computer hard drive was backed up weekly with physical back-ups to an external storage drive and network (O) drive. See Ethics Application for further details.

Quantitative Data Analysis

Hypothesis testing

The planned analysis of the experimental data will include comparisons of Q1 and Q2 responses using statistical tests to compare the control (generic thermal image) and intervention (personalised thermal image) groups in order to establish any significant differences in the intentions or attitudes between groups (see Figure 4)[2].

Figure 4: Example of planned analysis of data



Regression analysis

Regression analysis will be used to explore the correlation between attitudes towards measures and intentions to install. Data from both groups will be analysed to explore underlying correlations with intentions. The regression will be done separately for each thermal efficiency measure. The following correlations in particular will be explored in order to assess to what extent behavioural beliefs, attitudes and perceived behavioural control predict intentions to install thermal efficiency measures:

[2] If the groups contain unequal sample sizes, due to different response rates to Q2, this might increase the chance of violating the assumption of homogeneity of variance. In this case the research would consider taking a random subsample of the larger group in order to equalise the size of the groups.

- Belief evaluations (warmth, money, appearance, hassle) and intention to install
- Belief strength (warmth, money, appearance, hassle) and intention to install
- Behavioural belief (warmth, money, appearance, hassle) and intention to install
- Self-reported attitude and intention to install
- Perceived behavioural control and intention to install

This process will be repeated for the data collected at Q2, but this time regression will be done separately for each group in order to establish whether correlations differ by group.

Qualitative Data Analysis

The qualitative data analysis takes as its focus the study's research objectives and questions, see below. A thematic analysis will be conducted, based on these questions, in an attempt to identify any cross cutting themes as well as deviant cases.

Research questions

1. How do behavioural beliefs influence householder intentions to agree to install home thermal efficiency measures?
2. Does showing householders thermal images affect their behavioural beliefs or intentions towards agreeing to install home thermal efficiency measures?
3. Does the home assessment process affect householder behavioural beliefs or intentions towards agreeing to install home thermal efficiency measures?
4. Can the home assessment process be improved to strengthen positive behavioural beliefs and increase intentions to agree to install home thermal efficiency measures?

The analysis will also hope to use evidence from qualitative interviews to comment on the invisibility of home heat loss as a potential barrier to installations of home thermal efficiency measures (see Research Objectives).

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