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Improving the visibility of energy use in home heating in England: Thermal images and the role of visual tailoring

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Abstract

This study examined the use of thermal imaging as a communication tool that allows householders to 'see' where a building is losing heat. We tested the effect of tailored and non-tailored thermal images on energy beliefs, behavioural intentions and a simple self-report behaviour question in an English field study. Householders received tailored thermal images of their home, thermal images of other homes with typical problems for the area ('non-tailored'), or information on the same typical problems in text format. A post-intervention survey (*N* = 233) indicated that showing occupants any thermal image (tailored or non-tailored) led to higher vividness when recalling the communication, compared to text-only information. Householders engaged with the reports to a greater extent when they were personal to their home: the tailored thermal images were more likely to be shared with others and led to stronger energy saving intentions and reporting energy efficiency behaviour compared to non-tailored reports. This is a promising approach integrating technology and social science knowledge and methods.

Keywords: energy efficiency, tailoring, visualisation, vividness, communication

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1. Introduction

Energy conservation remains an important domain (Gifford, 2014) because energy prices are rising, and an increase in energy-related carbon emissions has been identified (DECC, 2013a; European Environment Agency, 2012). Moreover, in 2012, 17 per cent of English households were spending more than 10 per cent of their income on fuel to maintain an adequate standard of warmth and this percentage is expected to increase (DECC, 2014). This creates a 'moral' imperative to encourage energy savings as it is becoming more difficult for vulnerable groups to pay their energy bills. Technological solutions have been proposed to reduce domestic energy consumption (e.g. efficient boilers; energy efficient light bulbs). However, technical solutions can fall short of their potential impact if people are not engaged with them or have no clear understanding of the issue they address (Abrahamse, Steg, Vlek, & Rothengatter, 2005; Midden, Kaiser, & McCalley, 2007; Steg, 2008). One important barrier in bringing about behaviour change in the public is the invisibility of domestic energy consumption (Darby, 2001). To reduce this invisibility, scholars have called for vivid and personal communications that can connect the householder to his/her own energy consumption (Darby, 2001; 2006; Gardner & Stern, 1996; Hargreaves, Nye, & Burgess, 2010; McKenzie Mohr, 1999; Parnell & Popovic Larsen, 2005). The two main approaches that have been put forward seem to be the use of visual information and tailoring. While the former could be rolled out across many homes, tailored interventions that are specific to the home require a lot of resources such as expertise, time and money. This paper will test the effect of visual energy information and tailoring visual information ('visual tailoring') by means of a report that communicates where heat escapes from homes. Space heating is an important issue to address: in the UK space heating can contribute as much as 66 per cent to a home's overall energy use (DECC, 2013a). We use thermal imaging as an innovative approach to visualising energy use in home heating and investigate the influence of different levels of visual tailoring in a field study. The current study aims to address two main questions derived from the literature: What are the effects of a thermal imaging visualisation on householders' energy beliefs, behavioural intentions and self-reported behaviour? And, what is the effect of a *tailored* thermal imaging visualisation compared to a *less personalised* thermal imaging visualisation?

1.1 Tacking the invisibility of energy through feedback and visualisation

Energy use in homes is typically invisible, abstract and intangible (Brandon & Lewis, 1999; Fisher, 2008). Energy is rarely consumed directly. Instead, it is embedded in everyday actions and needs (e.g. watching TV, cooking, need for comfort). Thus, energy consumption is not a coherent field of action (Fisher, 2008), and energy use is not easily connected with what we do on a day to day basis (Burgess & Nye, 2008). In addition, there is a lack of feedback on energy consumption in everyday life (Fisher, 2008). It is difficult for householders to imagine how much energy is used overall (Burgess & Nye, 2008). It is thought that 'making the invisible visible' with regards to energy use will help reduce energy demand (Darby, 2006; Hargreaves, 2010; Hargreaves et al., 2010). Information on energy consumption aids the decision making process: it can provide householders with a tangible problem to tackle, increase the relevance of individual actions, and increase a sense of control (Fisher, 2008). For example, based on this reasoning the UK government is planning a national roll-out of smart meters along with in-home displays to all households by 2020 (DECC, 2013b), similar to many other countries.

Visual imagery has been used in many contexts. In the environmental domain, climate change imagery has attracted considerable interest. Visual imagery associated with climate change (e.g., changing landscapes, iconic images such as polar bears) has the ability to communicate messages quickly and powerfully (Sheppard, 2005), and condense complex information (Nicholson-Cole, 2005). Images are associated with vividness and thus have an advantage over text information (Taylor & Thompson, 1982). Compared to text, images can be interpreted without relying heavily on knowledge of technical terms, and have the potential to overcome language barriers. Also, images are indexical, which means that they are seen as directly representing reality – they are 'speaking the truth' (p.74; O'Neill & Smith, 2014). However, at the same time, when compared to text, visual cues may be less precise. Visuals can be interpreted in many ways (O'Neill & Smith, 2014).

Scholars have identified considerable research gaps with regards to how individuals make sense of visual images (O'Neill & Smith, 2014; Sheppard, 2005). This is reflected in research on energy visuals. Research on energy information tends to present energy data as text, load curves or bar charts. However, there has traditionally been a lack of research on the specific design of energy information (Fisher, 2008). Recently the field has been moving more quickly (e.g., Chiang, Natarajan, & Walker, 2012; Chiang, Mevlevioglu, Natarajan, Padget, & Walker, 2014), looking more closely at information design - this work is beginning to test the potential role of visuals in communicating many of the 'invisible' issues that surround energy consumption behaviours. Furthering our understanding of energy visuals, the present research examines thermography as a tool to visualise energy and heat. Thermographic cameras measure infrared radiation from the surface of buildings (Pearsons, 2011). Thermography visualises temperature differences, so for buildings it is possible to 'see' or infer where a building is losing heat or where cold air is entering a building. For example, Figure 1 shows cold air entering the home through a cat flap. The dark area by the cat flap indicates a colder surface temperature than the surrounding area, suggesting that this is where cold is coming into the house. So, thermal images can increase the visibility of the normally invisible heat flows in and around the home (Goodhew, Pahl, Auburn, & Goodhew, 2014). If energy consumption is largely invisible, then the necessity of behaviours that save energy through preventing heat loss such as closing curtains at night, installing draught proofing or loft installation might be difficult to imagine. This could be a problem especially when the negative consequences of insufficient energy saving behaviours (e.g. feeling draughts/cold) might not be directly noticeable or are difficult to attach to a certain cause.

Figure 1. Example of a thermal image showing cold air coming into the home through a cat flap.

1.2 Personalisation through tailoring

Darby (2001) notes that information on a personal level is needed to motivate individual action. Personal information can make householders aware of *specific* actions that they can take in *their* home. Tailored information can be defined as 'any combination of strategies and information intended to reach one specific person, based on characteristics that are unique to that person, related to the outcome of interest, and derived from an individual assessment' (Kreuter, Farrell, Olevitch, & Brennan, 2000, p.277). This differentiates **tailored** information from less personalised information such as **targeted** communications that are developed for a particular segment of the population, or **generic** communications which are not aimed at a specific individual or group at all (Noar, Benac, & Harris, 2007).

Tailoring has been tested thoroughly in the literature on health behaviour change (cf. Skinner, Campbell, Rimer, Curry, & Prochaska, 1999; Revere & Dunbar, 2001), it should be noted however that this research largely focuses on the tailoring of textual information. Although a different topic area and approach, this can provide useful insights when applying tailoring to energy visualisations. Noar et al. (2007) conducted a thorough review of the literature on tailored information in health behaviour change studies. The results of their metaanalysis of 57 studies showed that tailored information outperformed generic and targeted information, as well as no-treatment control conditions. However, Noar et al. (2007) point out that studies most frequently compared a tailored message to a no-treatment control condition. They note that this comparison does not allow for firm conclusions to be drawn on the effectiveness of tailored information over other types of information. The question that needs to be addressed more is whether and how tailored information is more effective in bringing about health behaviour change compared to similar comparison messages.

Moving over to the environmental domain, a tailored message was found to be more effective compared to a non-tailored message to encourage pro-environmental behaviour in an organisational setting (Daamen, Staats, Wilke, & Engelen, 2001). In this study, based on a pre-test, garage managers were given information on whether behavioural routines in their workshop were environmentally (in)correct. This was compared to a group of garage managers who were provided with general information on environmentally friendly alternatives of behavioural routines. The tailored approach was found to be more effective.

There has been some research on the role of tailoring in energy use communications. Early research focussed primarily on the effect of energy audits (Winett, Love, & Kidd, 1982-1983; Hirst & Grady, 1982-1983). In a home audit, energy experts visit a household to provide personalised advice on energy saving measures based on the specific situation. Several studies support the effectiveness of home audits in achieving energy savings, through behaviour change and an increase in knowledge (Abrahamse, Steg, Vlek, & Rothengatter, 2007). Recently, studies have examined other types of tailored information provision. For instance, McMakin, Malone, & Lundgren (2002) conducted focus groups and interviews prior to the start of their intervention to identify appropriate domestic energy conservation strategies specific to residents at two US military base communities. Site-specific campaign materials were developed based on this baseline assessment. This can also be described as **targeted** (rather than **tailored**, Noar et al., 2007) information: personalised at group level, not individual level. Savings of 10% were achieved at one study location, but no savings were achieved at a second study location. Abrahamse et al. (2007) compared two experimental groups that received tailored information (as well as goal setting information) to a control group. The tailored information consisted of a website providing householders with energy saving measures based on details provided in a baseline survey. Also, after a 2-5 month period householders were provided with tailored feedback on their energy savings. Significantly higher energy savings were achieved by the tailored groups compared to the control group.

So, whether it is messages promoting pro-environmental behaviour (Gifford, 2014; Daamen et al., 2001), health behaviour (Noar et al., 2007; Skinner et al., 1999; Revere & Dunbar, 2001; Rimer & Kreuter, 2006), or providing energy feedback (Fisher, 2008; Abrahamse et al., 2007), scholars suggest that tailoring or personalising a message improves its effect. A number of explanations have been provided for the beneficial effect of tailored information over less personalised information. First, there is a large variation between households in terms of the energy saving actions they could take, and the energy that they could save. As a result of this variation, predicting energy saving actions and optimising advice is difficult. This may lead to over-generalised and prescriptive advice that could decrease interest in energy saving (Wood & Newborough, 2003). Tailored messages include less redundant information, therefore more attention can be placed on the main message (De Vries & Brug, 1999; Daamen et al., 2001). Tailored approaches provide individuals with information that is specific and relevant to them, without overloading individuals with general information (Abrahamse et al., 2005). Also, generic information in this context can be confusing to the receiver of the information. Energy use in buildings is affected by idiosyncratic features of a building, its location, orientation, design and construction materials. Generic information cannot encapsulate that. Residents may understand these nuances and so may not value generic information (Guy & Shove, 2000). Second, the elaboration likelihood model (ELM; Petty & Cacioppo, 1986) provides an explanation for the beneficial effect of tailored information (see also Noar et al, 2007). According to the ELM, information is processed via two main routes. Information is more likely to be processed via the central, more careful and elaborate route of processing when it is seen as personally relevant – as would be the case with tailored information. This is thought to lead to more stable attitudes as it involves careful examination of the arguments in the message. This is in contrast to the peripheral, shallower route of processing which relies on heuristics and superficial cues and is associated with short-term, more fickle attitude change.

1.3 Visual tailoring

Smart meter displays that help to increase the invisibility of domestic energy consumption have been shown, albeit with large variations in energy savings, to affect behaviour via feedback (cf. Darby, 2006; Ehrhardt-Martinez, Donnely, & Laitner, 2010). They have the ability to provide householders with personalised information on the energy consumption in their own homes. As this information is often personal in nature, with specific information for the household, it is unclear to what extent personalising or tailoring accounts for the change in behaviour and to what extent it is the new information which the energy interventions provide. Also, while feedback, by its nature, is tailored, it is rarely visual in the sense of an emotionally powerful, vivid and memorable image. Understanding more what visuals, and visual tailoring adds is important as tailored information can be costly and time-consuming to provide.

Technologies, such as thermal imaging, can help make cause-and-effect relationships more visible (Midden, Kaiser, & McCalley, 2007). Goodhew et al. (2014) present two small studies that support the ability of thermal images to encourage simple energy saving actions. Compared to a control and audit-only group, a group of householders that received a carbon footprint audit and thermal images of their home made more carbon savings and reported an increased number of energy saving actions at a 1-year follow-up (Study 1). Furthermore, compared to an audit-only group, householders that received an energy saving audit with thermal images were nearly five times as likely to install draught proofing measures (Study 2). Burchell, Rettie and Roberts (2014) implemented house visits with thermal imaging as part of a community energy programme. Qualitative data show that householders particularly appreciated the highly visual nature of the thermal images. But more research is needed on the effect of visuals, such as thermal images, to explore the potential to communicate environmental issues such as energy conservation further (O'Neill & Smith, 2014). Specifically on the degree of tailoring visuals – do we need highly personalised, tailored thermal images, or do less personalised thermal images have the potential for engaging householders too?

Overall, previous research suggests that when attempting to encourage energy efficient behaviours, making energy visible, and tailoring any information to the specific household is helpful in achieving behaviour change. However, more research is needed on the impact of tailored information on energy efficiency behaviours (Steg, 2008). In particular, there is a lack of research on *visual* tailoring (Noar et al., 2007).

1.4 Research context and aims

The current research examined the benefits of using thermal imaging, a powerful technological tool to visualise energy use in the form of heat loss in the home. Specifically we compared a tailored thermal image visualisation (i.e. own home) with a targeted thermal image visualisation (i.e. other homes with typical problems for the area) and with a text report. These comparisons will allow us to understand the effect of this novel visualisation compared to textual information, and how tailored this visualisation needs to be.

A field study was conducted in collaboration with the Eden Project (an educational visitor attraction and charity in Cornwall, UK) on a large householder sample. This study examined the 'value added' (as Noar et al., 2007 for health behaviour) of tailored visual information over less personalised 'targeted' visual information (i.e. information for a particular segment of the population) in the context of a thermal imagery intervention targeting energy efficiency beliefs and behaviour. Noar et al. (2007) suggest that a tailored message needs to be compared with a similar comparison message to assess the effect of tailored information on behaviour change.

1.4.1 Hypotheses

Hypothesis 1. We expected either of the thermal imagery reports to be more effective in raising energy beliefs, intentions and behaviour compared to the textual report because of the proposed beneficial effect of visual information over text, as well as previous research highlighting the potential impact of making the invisible energy visible.

Hypothesis 2. We expected the tailored thermal images to be more effective in raising energy beliefs, intentions and behaviour compared to the targeted thermal images, given previous research on the strength of tailored information in behaviour change.

Thus, if providing tailored visuals is better than less personalised visuals, we would expect a stepwise effect: with tailored visual better than targeted visual better than targeted text. If the visuals are the key factor, we would expect very few differences between tailored and targeted visuals. Next to the main hypotheses the research examined various avenues by which the effects could take place. Using an exploratory approach here, the research investigated:

1. How information from the report is processed. Here we focused on the vividness (i.e. likely to attract and hold attention and to excite imagination) and intrusiveness (i.e. whether thoughts enter the mind frequently) of thoughts related to the report. According to research in cognitive psychology vivid and intrusive thoughts about a topic, in particular recalling imagery ('mental imagery'), have an important motivational influence on behaviour (Andrade, May & Kavanagh, 2012; Kavanagh, Andrade, & May, 2005).

2. The use of the report. According to the literature, tailoring can support in-depth elaboration of information (cf. Petty & Cacioppo, 1986). To examine the extent to which information from the report is elaborated upon the study will measure how often the report is looked at and whether the report triggers thoughts about energy efficiency in the householder's own home, and conversations with others about the report.

2. Method

2.1 Participants

Participants consisted of householders in Cornwall in Southwest England (see Figure 2) who had signed up to a collective energy supplier switching scheme organised by the Eden Project (i.e. through the "Cornwall Together" initiative). Participants were mainly recruited via email invitations sent out to householders. In addition, a small number of participants were recruited via events organised by the Eden project for householders signed up to Cornwall Together.

In total 980 participants (438 females) signed up by filling in the baseline survey, the average age was 53 (*SD* = 14.76). The majority owned their own home (94%), living in houses (86%) as opposed to flats or others (mobile homes, maisonettes etc.), and 40% of sign-ups lived in detached homes. The median number of occupants per home was 2.00.

Two hundred and thirty three householders (80 females) participated in the post-intervention survey, after receiving the reports (a 24% response rate after the intervention). The average age was 56 (*SD* = 14.87). When comparing participants in the different conditions, demographics were similar, the majority owned their own home (97%), χ^2 (6, N = 233) = 6.09, exact p = .40, living in houses (85%) as opposed to flats or other, χ^2 (4, N = 233) = 6.34, exact p = .17, and 42% lived in detached homes, χ^2 (6, N = 233) = 10.11, p = .12. The median number of occupants per home was 2.00, χ^2 (12, N = 233) = 10.35, exact p = .58[i].

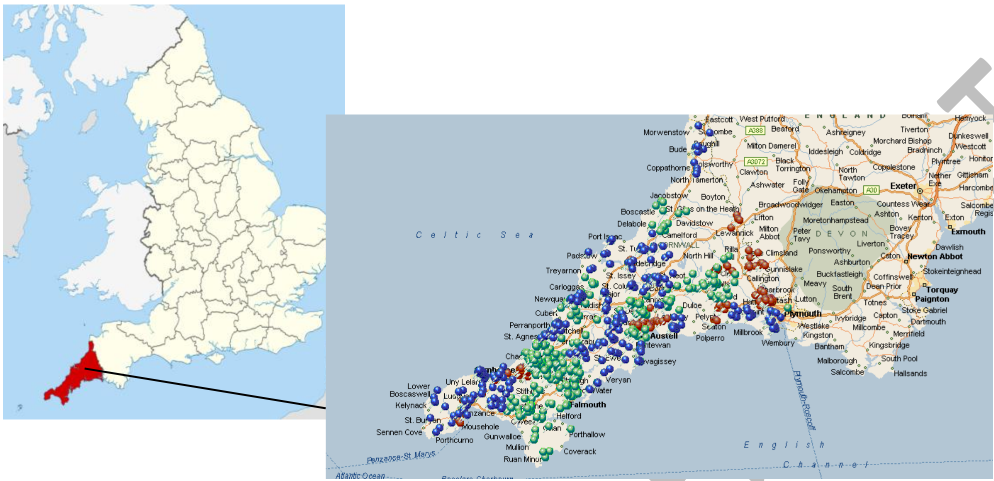


Figure 2. Location of the 980 homes in the project (Tailored thermal images = Red, Targeted thermal images of other homes = Green, Targeted text of other homes = Blue)

2.2 Design and Procedure

The study had a between-subjects design with message type (Tailored Thermal; Targeted Thermal; Targeted Text) as the independent variable (see Table 1 for an overview of the study design). Householders signed up for the study by filling in an online baseline survey recording demographics as well as perceived fuel poverty and awareness of consequences of energy use. From the baseline cohort of nine hundred and eighty homes, geographical clusters (towns) were randomly allocated to receive the Tailored Thermal report (N = 202), the Targeted Thermal report (N = 415) or the Targeted Text report (N = 363). The budget allowed for thermal images of 200 homes, thus allocation to the Tailored Thermal group was curtailed once this number was reached, which accounts for the differences in sample size. Randomisation of clusters of houses rather than individual houses was used to mitigate against the effect of social influence and contamination (i.e. with randomisation at the level of the house, neighbours could feasibly be allocated to different conditions and receive a different report which they could show one another and talk about). The design also aided the logistics of the thermal imaging visits.

Table 1

Overview of study design

Baseline survey (N = 980)	Intervention phase	Post-intervention survey (N = 233)
❖ Demographics ❖ Perceived fuel poverty ❖ Awareness of consequences of energy use	Reports sent out: 1. Tailored Thermal 2. Targeted Thermal 3. Targeted Text	❖ General feedback on the study and the report ❖ Imagery vividness and intrusiveness ❖ Sharing the report ❖ Applying information ❖ Beliefs on risk and benefits ❖ Interest in energy efficiency ❖ Intentions and self-reported behaviour

After the baseline survey the study consisted of three parts:

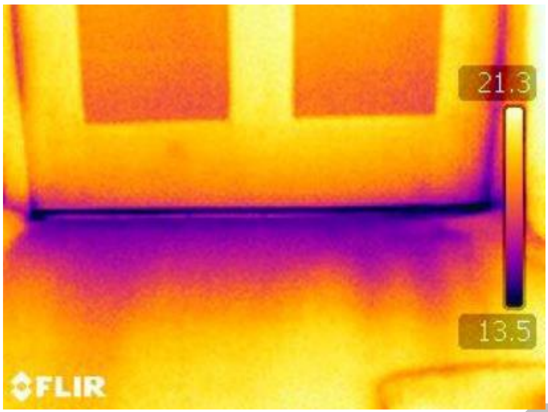
Part 1: Thermal imagery visits (Tailored Thermal condition only)

During a 2 - 3 month period in the heating season a team, trained by two thermographers with a certificate in thermography (as defined by the UKTA; Snell & Spring, 2008) conducted thermal imagery visits at the properties in the Tailored Thermal condition. Two of the team visited each property. To ensure that the images just showed heat loss, images were taken in the evening during the winter season. Householders were asked to turn the heating on before the visit. Visits took place on days with no high sun, precipitation or high winds. These measures limit the confounding effects of moisture or solar heating through the day, and ensure that a difference of around 10^0C was achieved between the outside and inside temperature (cf. Pearson, 2011). The team took the images according to a set protocol. Wherever possible an image was taken of the entire façade (front and back), with close up supplementary images of: the windows and doors (external and internal images), and the loft hatch. However, because each house was different, the exact thermal images that could be taken differed slightly for each house. All images were checked and any misleading images referred to the thermographers; unclear or misleading images (e.g. showing a heated surface temperature due to confounding factors and not heat loss) were not included in the final report to the householder.

Part 2: Reports

Between one and two months after finalising the thermal imaging visits the reports were sent out to all three groups. In the Tailored Thermal condition and Targeted Thermal condition the report consisted of a brief explanation on how to read the thermal images, followed by a series of thermal images of their own home (Tailored Thermal condition; see Appendix A for example report), or thermal images of an unknown home displaying the problem areas commonly found in other homes in the area (Targeted Thermal condition). The Targeted Text condition received a report with similar information as the Targeted Thermal Condition but in text format only (see Box 1). In addition, all reports included a short list of energy efficiency measures taken from the Energy Saving Trust website, relating to roof insulation, insulating loft hatches, energy loss through windows and doors, and preventing draughts through lined curtains.

Box 1. Example of a part of the Targeted Thermal and Targeted Text report.

<table>
<tr><th>Targeted Thermal</th><th>Targeted Text</th></tr>
<tr><td>

DOORS:
Internal Image: Colder air often enters the house via draughts around doors, as in this example at the base of a door.</td><td>DOORS:
Colder air often enters the house via draughts around, at the top and the bottom of an external door.</td></tr>
</table>

Part 3: Post-intervention survey

Approximately two weeks after participants had received their report (approximately three months after the baseline survey) the post-intervention surveys were sent out by email to participants in all three conditions. In total two hundred and thirty-three participants filled in the post-intervention survey, the response rate varied between conditions: Tailored Thermal $N = 134$, Targeted Thermal $N = 51$, and Targeted Text $N = 48$. We will come back to the differences in the response rate between conditions in the Discussion. The survey measured feedback on the report, energy-related beliefs, behavioural intentions and self-reported behaviour. A debrief was provided at the end of the post-intervention survey.

2.3 Measures

2.3.1 Baseline Questionnaire

Perceived fuel poverty. Participants were asked whether they would say they experience fuel poverty. Response options included: yes, no, and I don't know what fuel poverty is.

Awareness of consequences. Three items were included to measure participants' awareness of the consequences of energy use: Saving energy helps address climate change; I'm worried about the effect that our current energy use will have on our future health and well-being; The UK will easily maintain a reliable energy supply in the future. The third item was recoded; a mean score for awareness of energy consequences was computed (3 items, $\alpha = .52$). One of these items was omitted from the scale (The UK will easily maintain a reliable energy supply in the future) to increase the reliability of the scale (2 items, $\alpha = .70$).

2.3.2 Post-intervention Questionnaire

General feedback on the study and report. At the start of the post-intervention questionnaire participants were asked how often they had looked at the report in total. This was followed by more specific questions related to how participants perceived the study and the report.

1. *Informative/Difficult to understand*

Participants were asked to rate whether they found the thermal images (or the information in the report for the text group) informative and difficult to understand on a scale ranging from 1 (Completely disagree) to 5 (Completely agree).

2. *Tailored Thermal specific*

Because the Tailored Thermal condition was the only group to receive a home visit an item was included to measure the perceived influence of each element in the study, in the survey for this condition only. Participants were asked to select which part of the thermal imaging process they found most useful to understand the energy efficiency of their home. They could select all that applied from: Talking to the thermographer; Looking at the thermal camera as the images were taken; Looking at the thermal images in the report; All were equally useful; or Other (please specify).

Imagery vividness and intrusiveness. One item was included to measure whether participants experienced vivid mental images after exposure to the report. Participants were asked to rate on a scale from 1 (Not at all) to 7 (Extremely) how vividly they recalled images (or the text in the report for the text group) from the report. Another item was included to measure how intrusive thoughts about the report were. On a scale from 1 (Not at all) to 7 (Constantly) participants were asked to rate to what extent thoughts about the report seemed to pop into their head (Boomsma, 2013).

Sharing the report. To examine how the report was shared with others, two items were included (i.e. I have shown the report to others; The report has led to considerable discussion with others). Participants indicated their answers on a 5-point scale ranging from 1 (Strongly disagree) to 5 (Strongly agree). A mean score for willingness to share the report was computed (2 items, $\alpha = .88$).

Apply information. Three items measured whether participants started to apply the information in the report to their own home (i.e. When reading the report to what extent: did you feel that the messages applied to your own house/did you think about the energy wasted in your house/did you think about the things you could do in your house to improve energy efficiency). Items were rated on a 7-point scale ranging from 1 (Not at all) to 7 (To a very large extent). A mean score for applying information from the report was computed (3 items, $\alpha = .84$).

Beliefs about risks and benefits. To assess participants' feelings of risks and benefits in relation to draught proofing, participants were asked to rate, on a scale from 1(Extremely unlikely) to 5(Extremely likely), how likely they thought it was that they would experience cold draughts entering their home (i.e. risk) and how likely they thought it was that they would benefit – in terms of warmth – from taking measures to reduce the cold draughts entering their home (i.e. benefit).

Interest in energy efficiency. To measure overall interest in energy efficiency, participants were asked to rate 6 items on a 5-point scale, ranging from 1 (Strongly disagree) to 5 (Strongly agree). These items included: I have always had an interest in energy efficiency; I am quite interested in the technical side of buildings; I take a lot of pride in my home; I am very keen on making my home energy efficient; I can talk about home improvement for ages; I think energy saving is the most boring topic you could discuss down the pub. The last item was recoded, and a mean score was computed for interest in energy efficiency (6 items, $\alpha = .77$).

Intentions and self-reported behaviour. First, participants were asked whether they agreed with the statement: The report hasn't really changed my plans for my home, on a scale from 1 (Strongly disagree) to 5 (Strongly agree). Second, an 8-item scale was included measuring energy intentions for the rest of the year. Items varied from general (e.g. I intend to do everything I can do to reduce heat loss in my home) to more specific items (e.g. I intend to close all curtains at night). Answers were indicated on a 5-point scale, ranging from 1 (Strongly disagree) to 5 (Strongly agree). A mean score was computed for energy intentions (8 items, $\alpha = .88$).

Finally, one item was included to measure self-reported behaviour. Participants were asked to indicate whether they had done anything already to increase the energy efficiency of their home since seeing the report.

3. Results

For the experimental measures, we will first discuss the results with regards to our main research questions, followed by the results on how the information was processed and how the information from the different reports was used by the householders. In these analyses Games-Howell post-hoc tests were used because of the unequal sample sizes for the post-intervention survey, and to control the Type I error rate (Field, 2013). All means are reported in Table 2.

Table 2

Mean scores on the experimental measures for all three conditions

	Tailored Thermal $M(SD)$	Targeted Thermal $M(SD)$	Targeted Text $M(SD)$
Beliefs on risks[i*]	3.57(1.22)	3.55(1.27)	3.04(1.41)
Beliefs on benefits[i*]	4.12(1.00)	3.65(1.26)	3.63(1.32)
Change plans for home[ii**]	2.64(0.96)	3.20(0.96)	3.77(1.19)
Behavioural intentions[ii*]	4.02(0.51)	3.76(0.75)	3.71(0.73)
Informative rating[iii**]	4.23(0.64)	3.76(1.14)	3.38(1.23)
Difficulty rating[iii**]	2.46(1.10)	1.94(0.99)	1.73(0.77)
Imagery vividness[iv**]	5.15(1.24)	4.73(1.54)	3.17(1.73)
Imagery intrusiveness[v**]	4.06(1.48)	3.22(1.75)	2.29(1.53)
Looking at the report**	3.01(1.13)	1.59(0.85)	1.38(0.53)
Sharing the report[ii**]	6.32(2.13)	4.06(1.82)	3.63(1.67)
Applying information[ii**]	5.54(1.18)	4.82(1.63)	4.11(1.66)

*Note: [i]Response scale 1(Extremely unlikely) – 5 (Extremely likely); [ii]Response scale 1(Strongly disagree) – 5 (Strongly agree); [iii]Response scale 1(Completely disagree) – 5 (Completely agree); [iv]Response scale 1(Not at all) – 5 (Extremely); [v]Response scale 1(Not at all) – 5(Constantly). *Significant difference between conditions at p<.05. **Significant difference between conditions at p<.001.*

3.1 Beliefs and behavioural intentions

Beliefs on risks and benefits. Whether participants perceived themselves to be at risk of cold draughts entering their home depended on condition, $F(2,230) = 3.26$, $p = .040$, partial $\eta^2 = .03$, partially supporting Hypothesis 1. Participants who received the Tailored Thermal images felt slightly more at risk compared to the participants who received the Targeted Text report , 95% CI[-.02; 1.08], $p = .06$, $d = .40$. But participants who received the Targeted Thermal images of other homes did not differ from the Targeted Text condition, 95% CI[-1.15; .14], $p = .15$, $d = .38$. The expected difference (Hypothesis 2) between the Tailored Thermal condition and Targeted Thermal condition was not found, 95% CI[-.47; .52], $p = .99$, $d = .02$.

How likely participants thought they were to benefit from taking draught proofing measures also depended on condition, $F(2,230) = 5.18$, $p = .006$, partial $\eta^2 = .04$. Again, Hypothesis 1 was partially supported. Participants who received the Tailored Thermal report thought it more likely that they would benefit from draught proofing measures compared to the Targeted Text condition , 95% CI[-.01; .99], $p = .053$, $d = .42$, but there was no significant difference between the Targeted Thermal and Targeted Text condition, 95% CI[-.64; .60], $p = 1.00$, $d = .02$ (see Table 2). As proposed in Hypothesis 2, beliefs about the perceived benefits of draught proofing were stronger in the Tailored Thermal condition compared to the Targeted Thermal condition, 95% CI[.00; .94], $p = .049$, $d = .41$.

Intentions and self-reported behaviour. Participants were asked whether the report had changed the plans for their home. The results indicated that this depended on the report they received, $F(2,230) = 23.30$, $p<.001$, partial $\eta^2 = .17$. Participants in the Tailored Thermal condition were most likely to change the plans for their home based on the report (low scores indicate a change in plans). Ratings were significantly different from the Targeted Thermal condition, 95% CI[-.93; -.18], $p = .002$, $d = .58$, and the Targeted Text condition , 95% CI[-1.59; -.67], $p < .001$, $d = 1.05$. In turn, participants in the Targeted Thermal condition, who received thermal images of other homes, were more likely to change the plans for their home based on the report compared to the Targeted Text condition, 95% CI[-1.09; -.06], $p = .026$, $d = .53$.

With regards to the behavioural intentions scale, again a main effect of condition was found, $F(2,222) = 5.98$, $p = .003$, partial $\eta^2 = .05$. In line with Hypothesis 1, the Tailored Thermal condition indicated significantly stronger intentions compared to the Targeted Text condition (see Table 2), 95% CI[.03; .59], $p = .027$, $d = .49$; while in contrast to Hypothesis 1 no significant difference was found between the Targeted Thermal and Targeted Text condition, 95% CI[-.32; .41], $p = .95$, $d = .07$. Also, seemingly in contrast to Hypothesis 2, both thermal conditions (tailored and other homes) reported similar intentions with regard to energy efficiency behaviours, although a marginally significant difference was found, 95% CI[-.02; .55], $p = .07$, $d = .41$.

Furthermore, there was a statistically significant association between condition and whether participants reported doing anything to increase the energy efficiency in their home since seeing the report, χ^2 (2, $N = 233$) = 13.14, $p = .001$. In the Tailored Thermal condition 40% of participants indicated they had made energy efficiency improvements, compared to 19.6% in the Targeted Thermal condition, and 16.7% in the Targeted Text condition.

3.2 Information processing

Informativeness and difficulty. Tailored thermal images were seen as more informative compared to the thermal images of other homes, $F(2,230) = 17.06$, $p < .001$, partial $\eta^2 = .13$, 95%

CI[.06; .87], p = .020, d = .51, and the text report , 95% CI[.41; 1.30], p <.001, d = .87. The Targeted Thermal images and Targeted Text were seen as similarly informative, 95% CI[-.18; .96], p = .24, d = .32. There was also a main effect of condition on the difficulty ratings for the thermal images (or the information in the text report), F(2,230) = 11.28, p <.001, partial η^2 = .09. The tailored thermal images were perceived as more difficult to understand compared to the thermal images of other homes , 95% CI[.12; .92], p = .007, d = .50 and the text report , 95% CI[.39; 1.08], p <.001, d = .77. The Targeted Thermal images and Targeted Text were seen as similarly difficult to understand, 95% CI[-.21; .63], p = .46, d = .24 (see Table 2).

Mental imagery vividness and intrusive thoughts. The conditions significantly differed on mental imagery vividness, F(2,230) = 34.69, p <.001, partial η^2 = .23, and intrusive thoughts, F(2,230) = 24.02, p <.001, partial η^2 = .17 . The Tailored Thermal images and the Targeted Thermal images were recalled more vividly compared to the Targeted Text , 95% CI[1.33; 2.63], p <.001, d = 1.32 and 95% CI[.77; 2.34], p <.001, d = .95 respectively (Table 2). No significant difference was found between how vividly participants recalled the Tailored Thermal and Targeted Thermal images, 95% CI[-.15; 1.00], p = .19, d = .30. Thoughts about the Tailored Thermal images popped up more frequently compared to the Targeted Thermal images , 95% CI[.19; 1.50], p = .008, d = .52, and the Targeted Text , 95% CI[1.16; 2.38], p <.001, d = 1.18. These results suggest that thoughts about the tailored images were more intrusive compared to thoughts about the images and text regarding other homes. In turn, thoughts about the thermal images of other homes were perceived as more intrusive compared to thoughts about the text of other homes, 95% CI[.14; 1.71], p = .017, d = .57.

3.3 Use of energy report

Looking at the report. Participants who received the Tailored Thermal report reported looking at it more often compared to participants who received the Targeted Thermal report , F(2,230) = 69.40, p <.001, partial η^2 = .38, 95% CI[1.05; 1.79], p <.001, d = 1.42, or the Targeted Text report , 95% CI[1.34; 1.93], p <.001, d = 1.84. No difference was found in the number of times participants looked at the report between the Targeted Thermal report and the Targeted Text report, 95% CI[-.13; .55], p = .30, d = .30 (see Table 2).

Sharing the report. We asked participants to indicate whether they had shared the report with others, and whether the report led to discussions with others. A significant main effect of condition on likelihood to share was found, F(2,230) = 45.00, p <.001, partial η^2 = .28. Table 2 shows that participants who received the Tailored Thermal images were more likely to share and discuss the report with others compared to participants who received the Targeted Thermal images of other homes , 95% CI[1.52; 3.01], p <.001, d = 1.14, or the Targeted Text report , 95% CI[1.97; 3.42], p <.001, d = 1.41. There was no significant difference between participants who received the Targeted Thermal images and the Targeted Text, 95% CI[-0.40; 1.27], p = .43, d = .25.

Applying information. A main effect was found of condition on whether participants had applied the information in the report to their own home, $F(2,230) = 19.71$, p <.001, partial η^2 = .15 (see Table 2). Participants who received the Tailored Thermal images found it easier to apply the information to their own home, compared to participants who received the Targeted Thermal images , 95% CI[.12; 1.32], p = .014, d = .51, or the Targeted Text , 95% CI[.80; 2.05], p <.001, d = .99. The Targeted Thermal condition was not different from the Targeted Text condition, 95% CI[-.08; 1.49], p = .09, d = .43.

Thermal - Tailored visit. The report was seen as an important element in the Tailored Thermal image group. Participants in the Tailored Thermal image condition were asked to indicate which part of the thermal imaging process they found most useful to understand the energy efficiency of their home. Nearly half indicated that they found all parts of the process useful (48.5%). Of the remaining 51.5%, the majority reported finding the report most useful (78.3%), followed by talking to the thermographer (36.2%), and finally looking at the images on the thermal camera (11.6%). These percentages add up to more than one hundred because participants could select more than one part that they found useful.

3.4 Control measures: Ruling out differences in perceived fuel poverty, awareness of consequences and interest in energy efficiency

First, for perceived fuel poverty, 68% of householders who participated in the post-intervention survey did not experience fuel poverty. A chi-square analysis revealed no statistically significant relationship between condition and fuel poverty ratings at baseline, χ^2 (4, N = 233) = 2.91, p = .57.Second, looking at the baseline ratings for those who participated in the post-intervention survey, all three conditions were equally aware of the consequences of energy use on the future climate, $F(2,225) = 1.01$, p = .37, partial η^2 = .01 (Tailored Thermal M = 4.03, SD = 0.75; Targeted Thermal M = 3.85, SD = 0.90; Targeted Text M = 3.96, SD = 0.70). Third, overall, participants reported a level of interest in energy efficiency above the mid-point of the scale (M = 3.78, SD = 0.72), $t(225) = 16.24$, p<.001, d = 1.08. Post-intervention, participants in all conditions reported similar levels of interest in energy efficiency, $F(2,223) = 0.09$, p = .91, partial η^2 = .00 (Tailored Thermal M = 3.79, SD = 0.66; Targeted Thermal M = 3.79, SD = 0.81; Targeted Text M = 3.78, SD = 0.72). Thus, the level of interest in energy efficiency is not expected to affect any differences between the conditions.

In sum, the control measures suggest that the experimental groups were similar at baseline in terms of perceived fuel poverty and awareness of consequences of energy use. Also, post-intervention there was no difference between the groups on levels of interest in energy efficiency. So, any differences between the groups are not due to differences on these energy-related variables.

4. Discussion

The invisibility of energy is an important challenge when designing tools to encourage domestic energy conservation. The recent interest in smart meters and in-home displays reflects an attempt at reducing this invisibility. Scholars have recognized that householders need vivid, intuitive and personal energy information (Darby, 2001; 2006; Gardner & Stern, 1996; Hargreaves et al., 2010; McKenzie Mohr, 1999; Parnell & Popovic Larsen, 2005). The effect of making energy use visible and/or tailored provided the focus of this paper. This research aimed to respond to calls in the literature for more research on tailored information in the context of energy conservation (Steg, 2008) and specifically on visual tailoring (in the health domain - Noar et al., 2007). This research had two main aims, first to address the effect of making the invisible visible by examining the following question: What are the effects of a thermal imaging visualisation on householders' energy beliefs, behavioural intentions and self-reported behaviour? The second aim was to address the level of tailoring needed to effectively engage with householders when using a visual intervention by examining the following question: What is the effect of tailored thermal imaging visualisations compared to less personalised thermal imaging visualisations?

To examine these questions three conditions were compared: a group who received a report with thermal images of their own home (Tailored), a group who received a report with thermal images of other homes with typical problems for the area (Targeted – as defined by Noar et al., 2007), and a group who received a text report with similar information as the previous targeted report but without those images. Taking Hypothesis 1 and 2 together, a stepwise effect was expected for the measures included in this research. First, highlighting the impact of visual information, the thermal imagery reports (tailored and targeted) were expected to be more effective in raising energy beliefs, intentions and self-reported behaviour than the text report. Particular importance should be placed here on the difference between the targeted thermal report and text report as these presented information with the same level of tailoring. Secondly, looking at the role of visual tailoring, energy beliefs, behavioural intentions and self-reported behaviour were expected to be stronger for householders who received the tailored thermal report compared to the targeted thermal report of other homes.

Partial support was found for Hypothesis 1. Approximately two weeks after receiving the report, tailored thermal images consistently led to stronger beliefs and intentions compared to the targeted text report. But, a difference between the targeted thermal report and targeted text report was only found on behavioural intentions and self-reported behaviour change. With regard to Hypothesis 2, in line with expectations, householders who received the tailored thermal report reported a stronger belief, than those who received the targeted thermal report, that they would benefit from draught proofing measures, and stronger energy-related intentions and behaviour.

The results with regard to beliefs show an interesting pattern that warrant further discussion. The risk of draughts coming into the home was perceived similarly by householders who received the tailored and targeted thermal report, while the tailored thermal report led to stronger feeling of risk compared to the targeted text report. But when examining the perceived benefits of draught proofing a different but interesting pattern emerged. Householders exposed to the tailored thermal report felt they would benefit more compared to those exposed to the targeted thermal and text report. Thus, compared to a targeted visual, tailored visual information not only led to feelings of risk (for draughts) but also seemed to provide householders with the belief that they could benefit from measures reducing these draughts.

The data on behavioural intentions and self-reported behaviour demonstrate the 'value-added' of both visual (Hypothesis 1) and tailored visual information (Hypothesis 2). In terms of the benefits of visual information, the targeted thermal group, who received images of other homes with common problems for the area, was more likely to indicate they had changed plans for their home and were more likely to have already done something in their home since seeing the report compared to the targeted text group. But in turn, the tailored thermal group was most likely to change their plans out of all the groups, and the percentage of participants who indicated that they had already done something in their home since seeing the report doubled compared to the targeted thermal group. This, again, provides support for the beneficial effect of tailored visual information over targeted visual information in the context of an intervention to promote energy efficiency behaviours.

So far, the results seem to support a benefit of visualising energy information with thermal images over text by increasing the likelihood to change behaviour. But the effect of using tailored thermal images, compared to less-personalised thermal images becomes clear as well. Tailoring thermal images, increases the perception of the benefits of draught proofing, and increases the likelihood of behaviour change even further.

These effects were explored further by looking at how information from the report was processed and the use of the report. Given the lack of research on visual tailoring these results primarily focused on the mechanisms underlying the effects of personalised visual information, as well as shedding further light on the role of visual information over text.

4.1 The use and processing of the reports: Important insights into the role of visual tailoring

The processing of the report was investigated by examining the vividness and intrusiveness of thoughts ('mental images') after seeing the report. After the thermal imagery report, irrespective of the level of tailoring, householders recalled the images from the report more vividly compared to the information in the text report. So, visuals are more vividly recalled. This is in line with previous research on the beneficial effects of presenting information in visual form (e.g. Sheppard, 2005; Taylor & Thompson, 1982). However, how intrusive the information was – that is, how often thoughts about the report popped up – also depended on the level of visual tailoring. The thermal imagery reports (tailored and targeted) were perceived as more intrusive compared to the targeted text report. But, importantly, the tailored thermal report was perceived as most intrusive. Consequently, increasing the level of tailoring made the thermal images in the report more intrusive, compared to the less personalised thermal images: thoughts about the report came to mind more frequently.

The way the report was used by the householders provides further insight into the beneficial effect of personalised thermal images over viewing thermal images of someone else's home. In the introduction two explanations for the benefits of tailoring were discussed. First, tailored information is specific, allowing more attention to be placed on the main message (e.g. Abrahamse et al., 2005). Also, tailored information is thought to be processed via the central route leading to more elaboration of the materials (e.g. Petty & Cacioppo, 1986). The results seem to support the increased attention and elaboration of the tailored thermal report. Namely, compared to the other two reports, householders who received the tailored thermal report looked at the report more often, were more likely to share the report with others, and started to apply the information from the report to their own home. Note that this also extends the notion of elaboration from a purely individual context to a social context.

A finding that at first might seem to go against our expectations could provide further support for the increased elaboration of tailored thermal images. Householders were asked whether they found the information in the report difficult to understand. Although overall perceived difficulty was only moderate for all the reports, perceived difficulty was significantly higher for the tailored thermal report compared to the other two reports. Taking the other results into account, it could be argued that this result actually reflects increased engagement with the materials. Householders who received the tailored thermal report may have put more time and effort into interpreting the thermal images as suggested by the number of times householders looked at the report and shared the report with others. This increased effort for interpreting the images may have led to the increased perceived difficulty ratings. But, as the results on behavioural intentions and self-reported behaviour show, the higher perceived difficulty did not necessarily have a negative impact on behaviour. This is in line with research in education psychology. Although inappropriate difficulties in learning materials can have a detrimental effect on learning and memory retention, ‘desirable difficulty’ can improve learning (McDaniel & Butler, 2011). A level of desirable difficulty can trigger processes of encoding and retrieval that aid learning (Bjork & Bjork, 2011; Bjork 1994a; 1994b). Identifying which level of difficulty is desirable is challenging and sensitive to contextual variations such as the characteristics of the learner and the materials (McDaniel & Butler, 2011). But in this case, a level of desirable difficulty might have been reached and be indicative of a deeper level of elaboration of the material. There are alternative explanations for the difference in difficulty ratings, one of which could be that the term ‘difficulty’ was interpreted differently by the conditions. The targeted text and targeted thermal image condition, who did not receive information about their own home, perhaps just rated the report itself as being difficult to understand whereas the tailored thermal condition might have assessed the report’s difficulty by whether they could understand what each image meant for their home.

4.2 Limitations

The attrition rate of the study was relatively high, especially in the targeted thermal and targeted text group. The higher attrition rate in these groups might be because they did not receive a home visit, thus there was less contact between the researchers and householders in the period before the report and post-intervention survey were sent out. But, any bias due to differential attrition rate in the experimental groups is likely to have resulted in a more conservative test of the hypotheses. The attrition rate was lower in the tailored thermal group thus representing that group better; while the attrition rate was higher for the targeted thermal and targeted text group. The remaining participants in these groups may have been more engaged and possibly more interested. Such a bias would have made differences between these comparison groups and the tailored thermal group smaller, thus reducing our chances of finding a difference. Furthermore, it is encouraging that the results showed that householders who participated in the post-intervention survey, and those that did not, were similar in terms of demographics, perceived fuel poverty and awareness of consequences of energy use. Moreover, the householders in the three experimental groups who participated in the post-intervention survey were similar on these measures at the start of the study. So there is no indication from the data that the relatively high attrition rate led to unequal groups. However, the groups could differ on other variables not included in the study, and this needs to be taken into account when interpreting the results.

Furthermore, attempts were made to keep the influence of the home visits to a minimum. Thermographers were instructed not to engage in prolonged conversations with the householders about energy use and the actions that they could take to reduce their energy use. However, due to the face-to-face nature of the visits some interaction between the thermographer and the householder(s) about energy naturally took place. Nevertheless the results suggest that the report did play an important role in the tailored thermal group. Nearly half of the householders in this group found all parts of the thermal image project useful. Of the other half, the majority of the householders mentioned finding the report most useful. Due to the nature of the present study, and the time and resources available, it was difficult to omit the home visit from the research design altogether or include a home visit in the other conditions as well. However, Goodhew et al. (2014) included home visits to all householders in two studies and still showed added benefits of a thermal image visualisation over a home audit alone.

As the participants in this study had signed up for a collective energy supplier switching scheme, it could be argued that this was a particularly energy interested sample, not representative of the general public. Unfortunately the study did not include a baseline measure of interest in energy efficiency, but a measure was included in the post-intervention survey. Interest ratings were above the midpoint reflecting a relatively interested sample. But importantly, levels of interest were similar across the experimental groups, a difference in levels of interest in energy efficiency cannot account for the differences between the experimental groups. Moreover, even householders that are already interested in energy efficiency might be able to do more, when information is presented using the right approach. As suggested by Burchell et al. (2014), even interested individuals can lack household specific 'energy know-how': knowing alternative ways of doing things, and lacking the skills to implement these alternatives. Future research could aim at recruiting individuals with a particular low interest in energy efficiency.

A final limitation relates to the lack of a tailored text condition and a control condition. The focus of the study was the visual; specifically exploring whether there was an added behavioural value in a visual tailored approach over a less tailored visual and no visual (only text). This was in order to measure the effect of visual tailoring. A text and visual condition with the same level of tailoring was included in the design to allow for conclusions to be drawn with regard to the influence of visual, and tailored visual information. The current experimental groups included in the study fit with the research aims. Additional experimental groups would enable an even more in depth investigation differentiating the effect of visual and personal information. Because the current research studied these effects in the field, providing a tailored textual condition would have added considerable cost to the project as it would have involved visits to hundreds of homes across Cornwall. This was beyond our budget, but future research could explore further.

4.3 Conclusion

In conclusion, this paper provides support for thermal images as a method to visualise energy use in home heating to increase energy-related beliefs and intentions. Personal images visualising the householder's own home, compared to thermal images visualising other people's homes, seemed to be particularly effective. But less personalised images, which are less time-consuming and cheaper to provide to a larger sample, also provide certain benefits over textual information. Energy saving, like other pro-environmental behaviours, is complex with a number of motivations and barriers; thus there might be various factors that limit the effectiveness of visualisations, or any external intervention. But, visualising energy use has great potential in engaging people with energy efficiency.

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[i] Although there is a relatively high attrition rate, the data suggest that the baseline and post-intervention sample have very similar characteristics. Not only in terms of demographics but also: at baseline (*N* = 980), the majority of homes did not report experiencing fuel poverty (61%). For the group of householders who participated in the post-intervention survey a similar percentage was found (68% did not experience fuel poverty). Overall, awareness of consequences of energy use (see Section 2.3.1) was relatively high - there was no significant difference between householders who participated (M = 3.98, SD = 0.79), or did not participate (M = 4.01, SD = 0.76) in the post-intervention survey, F(1,960) = 0.27, p = .61, partial η2 = .00.