Energy_Heuristic

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Better rules for judging joules: Exploring how experts make decisions about household energy use

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ABSTRACT

Public understanding of home energy use is rife with biases and misunderstandings that can stymie the adoption of efficient technologies and conservation practices. Studying how energy experts make energy-related judgments can help design decision support tools to correct misperceptions held by novices. Here we conduct interviews with electrical engineers (n = 10), physicists (n = 10), and energy analysts (n = 10) to document expert judgments about energy use and to identify their cognitive shortcuts (heuristics) for household energy decision making. Performance on an energy estimation task confirmed that energy experts have more accurate estimates of home energy use than novices. We document 24 unique expert heuristics related to device functions, components, and observable cues used by experts while making energy-use judgments. A follow-up survey with the experts indicated that these expert heuristics are generally more accurate than novice heuristics. The library of heuristics created in this study can be useful additions to education programs designed to improve public energy literacy and decision making.

Supplementary Table 2: Novice heuristics

*The following set of 24 heuristics were collected by van den Broek and Walker (2019)[2]. The accuracy of the heuristics in **bold** was evaluated in Survey 2.*

1. When the device can be set on a higher unit (e.g., higher temperature) the device uses more energy
2. The more a device produces heat to heat up air or water or itself, the more energy it consumes
3. The fast a device completes its task, the more energy the device consumes
4. More active devices use more energy
5. **Larger devices consume more energy**
6. Knowledge about the energy consumption of the device that stems from public discourse or an unspecified sources
7. Devices with similar functions consume same levels of energy while devices with different functions consume different levels of energy
8. **Devices with a lot of components use more energy**
9. **Devices use less energy in the utility phase compared to its use in a 'preparation phase'**
10. Devices that use a lot of Wattage consume more energy
11. Devices that reduce the temperature of an element such as air or water will consume high levels of energy
12. Devices that have previously cut out the fuse box consume a lot of energy
13. **Devices that have an initial heating up period consume more energy than devices that do not**
14. **Devices that have an energy label use more energy**
15. Devices that complete several tasks (either simultaneous or successive), or large tasks, consume more energy
16. **Devices that charge other devices use more energy**
17. Devices that carry out complex tasks consume more energy
18. Devices that are switched on for a longer period of time consume low levels of energy
19. Devices that are small but conduct a large task use a lot of energy
20. Devices that are more powerful use more energy
21. Devices that are less energy intense use less energy
22. **Devices that 'keep up the heat' or movement consume more energy**
23. Devices from some brands or certain type of devices are more energy consuming
24. **Appliances that are semantically related to each other consume similar levels of energy**

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2.2.1. *Choice task*

In the choice task, experts were presented with nine sets of two or three common household devices. For example, one set was a choice between a window air conditioning unit and an electric oven. For each set, experts were asked to state which of the presented devices would use less energy than the other(s) given that all devices were run for the same length of time. In total, 24 devices were used across the nine choice tasks, covering the major categories of domestic electricity use: heating and cooling, water heating, small and large appliances, lighting, and electronics.

The choice task was paired with protocol analysis, wherein research participants are asked to think aloud as they perform a task, thereby providing instantaneous and unfiltered insight into the cognition associated with completing the task [30]. In this case, experts were asked to verbalize their thinking and thought processes to the best of their abilities while they selected the device that used the least energy in each choice set. Experts were given practice exercises to accustom them to thinking aloud [30]. When, in the middle of a given choice task set, an expert spent a moderate amount of time without speaking, they were given a gentle prompt to continue vocalizing their thoughts.

2.2.2. *Appliance estimation*

Following the choice task, experts were asked to provide their estimates of the energy use of 17 household devices. To provide a concrete reference point for quantifying their judgments about energy use, experts were told: "A standard incandescent light bulb uses about 100 units of energy in one hour. When you are asked to estimate units of energy, please compare each appliance to this light bulb. Think about whether each appliance below uses less energy or more energy than this light bulb. Please use this number to help you make your estimates." (The term "unit" was used rather than the more technical Watt-hour to be consistent with previous research on energy estimation by the general public, which tends to be less fluent with units of energy.) Based on these instructions, experts were then asked to estimate the units of energy used by these 17 devices when they are in use for one hour. To compare expert performance with that of energy "novices," we examined the baseline data of the estimation task in previous work [28].

Data collection ended with a set of questions to collect information about the experts' sense of numeracy (drawing two items from the Subjective Numeracy Scale [31]), educational and professional backgrounds, perception of the applicability of their expertise to assessing energy use, and demographic profile.

2.3. *Coding the choice task*

To extract the list of heuristics employed by experts during the choice task, the verbal reports made by the experts were transcribed and analyzed. The first layer of analysis entailed developing a coding scheme to categorize the content of the verbal reports. A codebook was developed to sort the information used by the experts into primary and secondary categories. Primary codes were developed for the three general content areas of the expert interviews: references to (1) observable cues about energy use, (2) device functions, and (3) device components. (A fourth primary category was created to catch comments that did not fall in the areas of the main primary categories.) Each primary code was disaggregated into several secondary codes, each of which refers to a more detailed aspect of the primary code's general theme. For example, the "Observable Cues" primary code family contained eight secondary codes, including "hot to touch," "dims lights/trips circuits," and "thick cord."

This codebook was drafted by a single researcher then modified based on four rounds of independent coding by two coders. Each round involved two coders using the codebook to code a single, randomly selected interview transcript. Following the first two rounds of coding, qualitative discussions of differences between the two coders guided revisions to the codebook. After the third and fourth rounds of coding, unweighted Cohen's kappa (κ) values were calculated to quantify

achieved and was replicable (κ = 0.80). Based on the high level of intercoder reliability, a single coder was used to code all the remaining interviews.

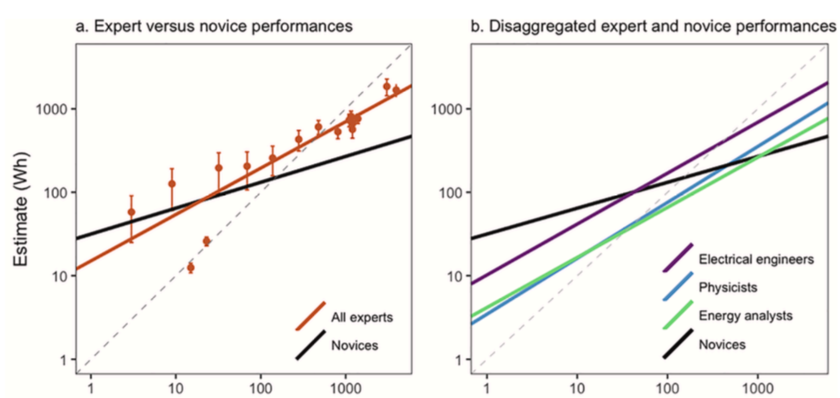
After the expert interviews were coded according to the list of secondary codes, a second layer of analysis extracted a set of heuristics from the secondary codes. This extraction was performed by a single researcher. In this process, all pieces of text with a given secondary code were first read for whether they stated a rule related to energy use and then assessed for thematic similarities across the texts. In each secondary code group, coded quotes were sorted into collections that describe a similar rule.

The secondary code "hot to touch," for example, was applied 28 times across 19 separate experts. As these 28 excerpts were read, they were grouped together when they expressed similar ideas. Within "hot to touch," the following quotes were two among several that were seen as conveying the same idea: "I know that the light bulbs in the digital projector are pretty intense and they can be, they're very hot, so you're drawing quite a bit of power." (Physicist #9) and "… I know that the XBox that my son used tends to be warm. Warm tends to tell me it's using energy." (Energy Analyst #8). After reviewing the set of these case-specific statements, the generalized heuristic: "Devices that become hot to the touch use more energy than similar devices that do not" was extracted.

For each thematically similar cluster of quotes, a heuristic was extracted and defined such that it articulated a general form of the ideas expressed by the experts. The result was a list of 24 unique heuristics (see Table 1 below).

Table 1
Heuristics extracted from the choice task, classification of heuristics, their use by experts, and expert assessment of their accuracy. Note that expert heuristics have been classified into types, whereas novice heuristics have not (blank in column 2).

(1) Heuristic	(2) Type	(3) Number of experts who used the heuristic at least once (conditional probability in parenthesis: when the heuristic is used, does the expert choose the correct answer) Electrical Engineers (n = 10)	Physicists (n = 10)	Energy Analysts (n = 10)	(4) Expert assessment of heuristic accuracy (N = 16) (1 = mostly inaccurate, 4 = mostly accurate) Mean (SE)
A greater temperature change requires more energy than a smaller temperature change	Function	3 (50%)	4 (60%)	1 (100%)	3.9 (0.06)
Insulation helps to reduce the energy use of devices that heat and cool	Component	0 (–)	4 (67%)	3 (50%)	3.8 (0.10)
Devices that become hot to the touch use more energy than similar devices that don't	External cue	7 (91%)	6 (71%)	4 (100%)	3.8 (0.11)
Devices that need to be cooled while they are working use a lot of energy	Component	2 (100%)	0 (–)	1 (100%)	3.8 (0.11)
LED lights do not use a lot of energy	Component	4 (100%)	2 (100%)	1 (100%)	3.7 (0.20)
Heating or cooling something takes a lot of energy	Function	6 (71%)	6 (100%)	6 (75%)	3.6 (0.13)
Boiling water and turning it into steam requires a lot of energy	Function	5 (50%)	6 (56%)	3 (67%)	3.6 (0.15)
Appliances that move or heat water use a lot of energy	Function	7 (0%)	7 (64%)	3 (67%)	3.4 (0.16)
Devices with heating elements use a lot of energy	Component	5 (50%)	5 (86%)	7 (71%)	3.4 (0.20)
It takes less energy to heat something with microwaves than with heating elements	Component	5 (100%)	4 (100%)	3 (100%)	3.3 (0.25)
Thicker power cords are associated with more energy use	External cue	2 (33%)	1 (25%)	1 (100%)	3.2 (0.21)
Producing sound (music) does not require much energy	Function	1 (100%)	2 (100%)	1 (100%)	3.1 (0.24)
Devices that plug into a 240-volt outlet use more energy than devices that plug into a standard 120-volt outlet	External cue	6 (64%)	3 (75%)	4 (100%)	3.1 (0.27)
Devices with small or focused functions (for example, a desk lamp) need less energy than devices that are designed to perform large or broadcast functions (for example, an overhead lamp)	Function	9 (72%)	9 (76%)	4 (50%)	3.1 (0.21)
Devices that 'keep up the heat' or movement consume more energy					3.0 (0.22)
Devices that primarily heat or cool use more energy than devices with a primary function involving motion	Function	4 (0%)	3 (100%)	2 (25%)	3.0 (0.22)
A device that runs on its own circuit uses a lot of energy	Component	1 (100%)	0 (–)	0 (–)	2.9 (0.20)
Devices that have an initial heating up period consume more energy than devices that do not					2.8 (0.21)
Devices that either make lights dim/flicker or trip circuits when turned on use a lot of energy	External cue	4 (50%)	1 (0%)	1 (100%)	2.8 (0.26)
Devices that can run on batteries are low energy consumers	Component	2 (100%)	3 (100%)	0 (–)	2.8 (0.28)
Electronics that produce graphics (images) use more energy than other types of electronics	Function	4 (75%)	0 (–)	4 (100%)	2.8 (0.19)
The larger the plug a device has, the more energy it will use	External cue	1 (100%)	0 (–)	0 (–)	2.7 (0.24)
Heating takes more energy than cooling	Function	0 (–)	1 (100%)	0 (–)	2.6 (0.26)
Larger devices consume more energy					2.6 (0.16)
Performing a task quickly tends to take more energy than performing that same task more slowly	Function	5 (43%)	5 (67%)	3 (25%)	2.5 (0.26)
Quieter devices use less energy than ones that make noise (for example, a rattle or hum) when they are in operation	External cue	2 (100%)	1 (100%)	1 (0%)	2.4 (0.20)
Devices with a lot of components use more energy					2.4 (0.29)
Devices that charge other devices use more energy					2.1 (0.17)
Devices that have an energy label use more energy					2.1 (0.25)
Devices use less energy in the use phase compared to its use in a 'preparation phase'					2.1 (0.21)
Cooling takes more energy than heating	Function	0 (–)	1 (0%)	0 (–)	2.1 (0.21)
Devices that are related to each other (for example, DVD players and televisions) use similar amounts of energy					1.7 (0.24)



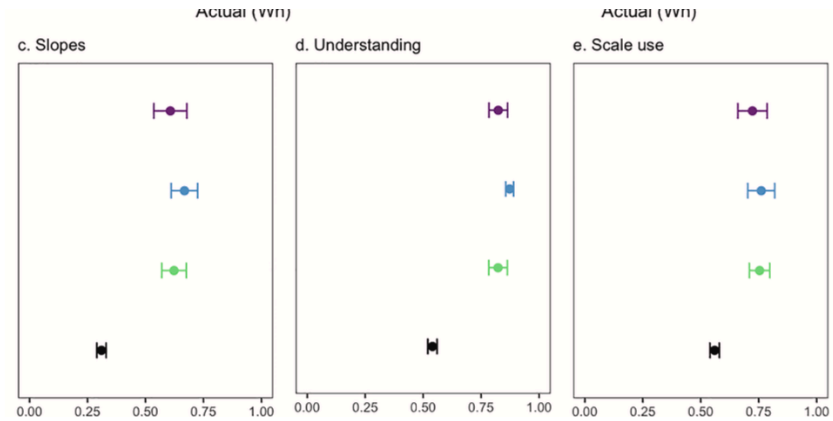


Fig. 1. Relationship between actual and estimated energy use. a. The estimated values for the 17 household devices, averaged across the 30 expert participants (orange dots), with the average expert slope line given in orange. The solid black line represents the average novice performance on the estimation task for the baseline control group in previous work [28]. The dashed line represents a slope of 1, a perfect relationship between estimated and actual energy use. b. The relationship between estimated and actual energy use for each of three expert groups: electrical engineers (purple), physicists (blue), and energy analysts (green). The novice reference value from the control group in previous work [28] is presented in black. c. Average estimate slopes for the three expert groups and the novice reference. d. Average understanding value (correlation between estimated and actual energy use) for the three expert groups and the novice reference. e. Average scale use value (ratio of standard deviation values for estimated and actual energy use) for the three expert groups and the novice reference. Points and error bars represent means ± standard error of the mean. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.3. Relationship between choice and estimation tasks

To assess the connection between the choice task score (9 items, 1 for correct and 0 for wrong, M = 5.6, SE 0.27) and estimation task slope (M = 0.63, SE 0.03), we calculated the correlation between the number of correct answers given on the choice task and the slopes of the estimation task. Across all 30 experts, the correlation between choice task score and estimation slope was quite low ($r = 0.06$, $p = 0.73$). There was some variation of this correlation between expert groups, as the correlation for electrical engineers was negative ($r = -0.18$, $p = 0.62$) while the correlations for physicists ($r = 0.17$, $p = 0.60$) and energy analysts ($r = 0.31$, $p = 0.39$) were positive. The negligible overall correlation between choice task score and estimation slope is consistent with prior research done that showed that the correlation between the choice task (20 items, M = 12.1, SE 0.12) and estimation slope (control condition M = 0.31, SE 0.01) was also weak and positive ($r = 0.20$, $p < 0.001$) in the control condition [28]. Note that the choice task items were different in the previous study, which does not allow for perfect comparison with the data presented here.

3.4. Expert heuristics

To capture expert heuristics, we analyzed the transcripts derived from the expert interviews using the protocol analysis method to extract a list of 24 heuristics employed by experts during the choice task (see heuristics listed in Table 1).

The set of heuristics can be divided into three general types based on how they relate to thinking about a device's energy use. The most common heuristics type relates to function – the tasks that the device is designed to perform. Eleven of the 24 heuristics belonged to the *function* type. Examples of specific device functions highlighted by experts include heating and cooling, producing sound, and moving water. Typically, when commenting on functions, experts expressed a general rule about the absolute or relative energy cost of a function, as in, "appliances that move or heat water use a lot of energy" or "producing sound does not require much energy."

The second most common heuristic type focused on the energy use by specific *components* or systems associated with devices. Seven of the heuristics were of this type. Most of the rules of this type assessed what could be inferred about the energy use of a device based on the presence or absence of specific components within the device, as in, "devices that can run on [small] batteries are low energy consumers." One rule, however, related to the household circuit on which a device is powered ("A device that runs on its own circuit uses a lot of energy"), which can be thought of as an external "component" rather than an internal one.

The final six heuristics made reference to *observable cues* that indicate higher levels of energy use. These are cues that do not rely on understanding the function of a device or on knowing its components, but rather require making observations about the physical presence or ambient effects of the device (e.g., its size or whether it gets hot to the touch when running). The heuristics of this type link the cues to judgments about energy use, as in, "the larger the plug a device has, the more energy it will use."

In the 290 instances of heuristic use documented across the 30 expert interviews, a majority (54%) of the heuristics used were *function*-based heuristics. *Components* (24%) and *external cues* (22%) heuristics were both used less frequently on average than *function* heuristics. There were some differences between the expert groups in terms of what kinds of heuristics were used. Relative to other groups, electrical engineers more frequently used external cues (29% of all heuristic use versus 17% for physicists and 16% for energy analysts). Physicists were more likely to reference the function of devices (62% versus 50% for electrical engineers and 51% for energy analysts), while energy analysts were more likely to employ a heuristic based on the components of the devices in the choice task (33% versus 20% for electrical engineers and 22% for physicists). The total number of instances of heuristic use by electrical engineers (119) and physicists (102) was higher than that of energy analysts (69).

Success with the choice task required selecting the lowest energy-using device in a set of two or three devices or activities. Many experts approached this task by eliminating options they viewed as clearly using more energy than at least one of the other devices. For example, many experts noted that an electric space heater (~1290 W) would use more energy than an electric blanket (~197 W) and so were able to quickly dismiss the space heater without needing to attend to it closely. (In the words of one physicist, "So, I'm going to say the blanket's less than the space heater just because you're trying to heat up less. Space heater is trying to heat up the whole room; the blanket, it's local heat.")

To assess the quality of the 24 expert heuristics, we counted the number of choice task responses where the heuristic was used to reach the correct answer and divided this sum by the total number of instances when the heuristic was used (see the third column in Table 1). The resulting conditional probability – the frequency of arriving at the correct answer if the heuristic was used – provides a simple measure of heuristic usefulness, with higher values suggesting that a given heuristic was useful in reaching a correct judgment in the choice task. The heuristics were associated with varying levels of success in choosing the correct choice task response. Associated success rates ranged from 0%

described appliances or activities run for the same amount of time. Just as a reminder, please think aloud to describe how you are choosing your answer.

Which uses less energy?

A window air conditioning unit (1157 Wh)	An electric oven (3050 Wh)

Which uses the least energy?

Running an electric water heater (4286 Wh)	Running a vacuum cleaner (809 Wh)	Running a refrigerator (363 Wh)

Which uses the least energy?

Electric blanket (197 Wh)	Electric space heater (1290 Wh)	Electric treadmill (967 Wh)

Which uses the least energy?

Steam iron (1198 Wh)	Blender (358 Wh)	Humidifier (185 Wh)

Which uses the least energy?

Video game console *like a Nintendo Wii, Xbox, or Playstation* (110 Wh)	Cable box (33 Wh)	Smart speaker *like an Amazon Echo or Google Home* (27 Wh)

Which uses the least energy?

Clothes dryer	Washing machine	Dishwasher

Estimation task
[These appliances will all appear on one page in a table format as shown below; correct values have been added in parentheses but were not included in the original document; presented to participants in paper form is interview is in person, presented online via Qualtrics if interview is remote]

A standard incandescent light bulb uses about 100 units of energy in one hour. When you are asked to estimate units of energy, please compare each appliance to this light bulb. Think about whether each appliance below uses less energy or more energy than this light bulb. Please use this number to help you make your estimates.

How many units of energy do you think each of the following devices typically consumes if used for one hour? Please provide you best estimates. Enter whole numbers with no other text (no decimals, ranges, or percentages).

Appliance	**Your estimate of energy use**
Compact fluorescent light (CFL) bulb	(23 Wh)
Desktop computer	(138 Wh)
Laptop computer	(32 Wh)
Window air conditioner	(1157 Wh)
Clothes dryer	(3938 Wh)
Dishwasher	(1201 Wh)
Vacuum	(809 Wh)
Charging a smartphone	(3 Wh)
Refrigerator	(280 Wh)
Electric oven	(3050 Wh)
Washing machine	(478 Wh)
DVD player	(9 Wh)
Ceiling fan	(69 Wh)
Microwave	(1101 Wh)
Electric kettle	(1390 Wh)
Toaster	(1213 Wh)
LED light bulb	(15 Wh)

Expert profile questions
[Presented to participants in paper form is interview is in person, presented online via Qualtrics if interview is remote]

Please answer the following questions about yourself.

How good are you at figuring out how much a shirt will cost if it is 25% off? *Please circle the number that best fits your response.*

Extremely poor	Very poor	Fairly poor	Fairly good	Very good	Extremely good
1	2	3	4	5	6

When reading the newspaper, how helpful do you find numeric tables and graphs that are parts of a story? *Please circle the number that best fits your response.*

Not at all useful	Fairly not useful	Fairly useful	Useful	Very useful	Extremely useful
1	2	3	4	5	6

What is your current job title?

What is your field of expertise?

What is your primary sub-discipline of expertise within your field?

Supplementary Methods 2: Survey 2
[Presented online via Qualtrics to all participants; heuristic presentation order is randomized]

Please indicate how accurate or inaccurate you think each of the following rules are for energy use by devices in the home. When evaluating these rules, please consider their general accuracy rather than application to outlier cases.

	Mostly inaccurate (1)	Somewhat inaccurate (2)	Somewhat accurate (3)	Mostly accurate (4)
Devices that primarily heat or cool use more energy than devices with a primary function involving motion (1)	○	○	○	○
Heating or cooling something takes a lot of energy (2)	○	○	○	○
A greater temperature change requires more energy than a smaller temperature change (27)	○	○	○	○
Heating takes more energy than cooling (3)	○	○	○	○
Cooling takes more energy than heating (4)	○	○	○	○
Appliances that move or heat water use a lot of energy (5)	○	○	○	○
Electronics that produce graphics (images) use more energy than other types of electronics (6)	○	○	○	○
Devices with small or focused functions (for example, a desk lamp) need less energy than devices that are designed to perform large or broadcast functions (for example, an overhead lamp) (7)	○	○	○	○
Performing a task quickly tends to take more energy than performing that same task more slowly (8)	○	○	○	○
Boiling water and turning it into steam requires a lot of energy (9)	○	○	○	○
Producing sound (music) does not require much energy (10)	○	○	○	○
Devices with heating elements use a lot of energy (11)	○	○	○	○

Supplementary Table 1: Choice task codebook

To extract the list of heuristics employed by experts during the choice task, the verbal reports made by the participants were transcribed and analyzed. The first layer of analysis entailed developing a coding scheme to categorize the content of the verbal reports. A codebook was developed to sort the information used by the experts into primary and secondary categories. Primary codes were developed for the three general content areas of the expert interviews: references to (1) observable cues about energy use, (2) device functions, and (3) device components. Each primary code was disaggregated into several secondary codes, each of which refers to a more detailed aspect of the primary code's general theme. For example, the "Observable Cues" primary code family contained eight secondary codes, including "hot to touch," "dims lights/trips circuits," and "thick cord."

Primary code	Secondary code	Description
External cues		Discusses the easily observable features or effects on the environment of a device
	Color	Assesses the color or color change of a device when in use
	Dim lights/trip circuit	Assesses whether room lighting dims or a circuit is tripped when a device is turned on or used

	Hot to touch	Mentions that the appliance or the air immediately around it gets warms up/gets hot while the appliance is in operation, or that the appliance needs a period of cool down after use
	Noisy	Assesses the amount of sound associated with the appliance while in use
	Plug size	Assesses the size or type of plug that a device uses, including references to physical dimensions or voltage
	Size	Assesses the size (volume) of a device or its components ("X is small"), excluding references to the volume of space that the device affects (e.g., "Ovens heat a small space" or "Space heaters heat a large room"); states or implies that energy use scales with the size of the device (e.g., bigger blenders use more energy than smaller ones)
	Thick cord	Assesses the size or type of the device's power cord
	Weight	Assesses the size (weight) of a device
Function		References function, activity, or purpose of the device; these could be either primary functions (e.g., space heaters heat the air) or secondary functions (e.g., dishwashers heat water to clean dishes)
	Comparisons	Makes a direct comparison of the relative energy requirements of two different functions (e.g., heating versus cooling) or compares the energy use of different devices with the same function (e.g., blenders and fans both circulate through fluids)

	Cooling	Explicitly names "cooling" or "moving heat" or decreasing the temperature of an object as a primary function or activity of the device
	Frequency	Comments on how often a device is used in day-to-day living, excluding references to their own ownership
	Graphics	Names producing graphics on a screen as a primary function or activity of the device
	Heating	Explicitly names heating or increasing the temperature of [air, water, or objects] as a primary function or activity of the device
	Information processing	Names **computing/**processing data/information/signals as a primary function or activity of the device
	Lighting	Names generating light as a primary function or activity of the device
	Motion/compression	References moving components (e.g., a spinning washing machine drum) or compression as part of the operation of a device
	Sound	Identifies making sound as a primary function or activity of the device
	Speed	Comments on the speed/rate with which a device performs its primary function or activity
	Task size	Comments on the amount, difficulty, or degree of concentration of work that a device does. Examples: "A water heater heats a lot of water"; "An oven raises the temperature to 350 degrees"; "Water has a high specific heat *so it takes a lot of energy to make steam*"; "Electric blankets focus their heating on a relatively small surface area")
	Water	Notes or implies that the device significantly interacts with water, including through heating, cooling, or moving water
Components		Discusses a specific element/component found within the device or in the system that the device relies upon (e.g., household wiring, cloud computing)
	Batteries	Notes whether a device can be/is typically run on batteries or is wireless
	Circuit size	Notes the size of the circuit (**e.g., the amperage)** on which the device is typically run, including references to maximizing the wattage for a given circuit
	Comparisons	Makes a direct comparison of the relative energy use of two different components (e.g., magnetrons are more efficient at transferring heat than resistive coils)
	Electronics	Notes that the device contains electronic components, including processors, transistors, capacitors, and transformers, or refers to the device as "electronic"
	External systems	Notes that the device relies on external systems (e.g., cloud computing, computers, or water heaters) to function

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Review

Household energy literacy: A critical review and a conceptual typology

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ABSTRACT

The concept of energy literacy is increasingly receiving more research attention within the fields of education, economics and psychology. A wide variety of definitions and approaches characterise the energy literacy literature, making comparisons and generalizability of the findings problematic. This paper aims to review and organise the energy literacy literate that focus on the understanding of domestic electricity and gas use, by providing a framework for categorisation of the different conceptual and methodological approaches. Four types of household energy literacy are distinguished based on the existing literature: 1) device energy literacy, 2) action energy literacy, 3) financial energy literacy and 4) multifaceted energy literacy. The literature on each type of energy literacy is critically reviewed, focusing on the level of household energy literacy, its predictors and its relation to energy use. We call for more common principles and measures within the energy literacy research to allow for direct comparisons and longitudinal research on household energy literacy. This would greatly improve the quality and impact of the research, which in turn will help policy makers to decide how to address (which type of) energy literacy to facilitate domestic energy conservation.

1. Introduction

Householders say that saving energy is the most important strategy to reduce their impact on environmental problems [1], but do they know how to do this effectively? Studies have found that people do not currently save energy efficiently in their home [2,3], nor do they choose to purchase the most energy-efficient (or cost-effective) appliance, also called the energy efficiency gap [4]. To understand this apparent contradiction, research is increasingly investigating householders perceptions of energy use (e.g. [5]), including people's energy literacy, or people's understanding of domestic energy use.

The concept of energy literacy has been gaining research attention in a number of fields (e.g. education, economics, psychology) and applications (e.g. appliances, energy consumption, energy saving, efficiency investments), resulting in the use of the same term to refer to different concepts. This means that within the literature different requirements are set to classify a person as 'energy literate'. An energy literate person can be someone who knows the energy consumption of conceptualisation of energy literacy. It is therefore not surprising, that the level of energy literacy remains unclear, as well as which type of individual differences are associated with higher energy literacy, or, perhaps most importantly, whether energy literate people are better at saving energy. Hence, a common approach in terms of operationalisation and measures is needed to allow for comparison across studies. A first step towards such a standardised approach, is a categorization of the current approaches to energy literacy in the literature.

This paper therefore aims to provide an overview of the different types of energy literacy in the literature by proposing a typology of energy literacy. We have used an inductive approach for developing this energy literacy framework, meaning the categories are based on the existing energy literacy literature rather than a framework that was constructed a priori. Although the latter approach would facilitate the development of a unifying theoretical framework, covering all potential types of knowledge and domains, such a framework would is unlikely to allow for unambiguous categorization of the literature and would therefore heavily limit the conclusions that can be drawn from this their domestic appliances, knows with what actions they can save energy in their home, knows how to make economic energy efficient decisions or knows about the relation between energy use and climate

review. Instead, a framework based on the existing energy literacy literature was expected to be more valuable because it provides an overview of how the literature currently conceptualizes energy literacy.

relate attitudes with the *accuracy* of these perceptions, hence not energy literacy. Income could also reasonably be expected to predict device energy literacy, as energy saving aspirations can be rooted in environmental or financial drivers [20]. Nevertheless, research that has linked income to device energy literacy has not found any strong evidence for this relation [9,10]. Numeracy (the ability to solve simple mathematical problems) did predict device energy literacy, although, perhaps surprisingly, education levels did not [9].

While there is little evidence that shows that individual differences can account for varying levels of device energy literacy, the use of heuristics *has* consistently been found to relate to energy literacy. Heuristics are simple rules used in decision-making to prevent information overload [21,21]. The use of these heuristics involve a process of attribute substitution in which an alternative attribute is used to infer the target attribute [22,22]. The use of *energy judgement heuristics*, in which energy consumption is inferred from a heuristic attribute to produce an estimate of energy consumption, may be helpful when the alternative attribute is a valid indicator of energy consumption but certainly will be unhelpful when this is not the case.

A number of different types of heuristics that are used to judge the energy consumption of household devices have been identified. The energy judgement heuristic that has gained most support in the literature is the *size heuristic* [10,12,17,23,24]. With this heuristic, large devices are thought to consume more energy than small devices, meaning that the energy use of small devices tends to be underestimated while the energy use of large devices is likely to be overestimated.

A qualitative study also identified a *usage pattern heuristic* [17]. Devices used frequently or for long periods of time are expected to use a lot of energy per year whereas devices that are rarely used and for a short amount of time are expected to use low levels of energy. Hence, the use of this heuristic results in low energy consumption estimations for devices that are rarely and shortly used, and high energy consumption estimations for devices that are used frequently and for a long time.

As discussed above, the visibility of devices has also been suggested to be considered when judging the energy use of home appliances systems [13,15], similar to the well-known *availability heuristic* [68]. Only one study has specifically investigated the use of this heuristic with experimental methods and did not find sufficient evidence for the use of this heuristic, nor was the heuristic used in a consistent way [10].

A recent paper has suggests that the size and usage pattern heuristic may only present the tip of the iceberg of energy judgement heuristics, as it identified 23 more heuristics used by participants in energy judgement tasks [24]. In a series of studies, this research included both direct observations of the use of heuristics in energy judgements task as well as participants' self-reports on the use of the heuristics. The most frequently observed and reported heuristics were the heat heuristic (in which the amount of heat a device produces to heat up air or water or itself, is used an indicator of its energy use), the time-switched-on heuristic (with which devices that are switched on for a longer period of

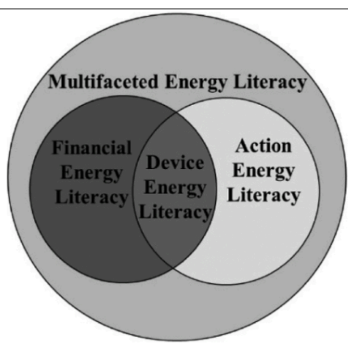

Fig. 1. Ven-diagram showing the relation between the different types of energy

meaning the use of electricity and gas that are used when consuming services in the home (e.g. heating, interaction with household appliances).

2. Device energy literacy

The most domain-specific type of energy literacy found in the literature is what we have termed device energy literacy. Device energy literacy reflects people's knowledge of the energy consumption of domestic appliances. This energy literacy therefore involves a semi-objective evaluation of people's ability to report the correct kWh for household devices or estimate the energy use of a device relative to other devices.

The literature presents contrasting findings on the nature or degree of such literacy. Studies have demonstrated that people tend to use a conservative range when judging the energy consumption of household appliances; the energy use of high energy consuming devices is underestimated while the energy use of low consuming appliances is overestimated [9,10]. However, in these studies participants rated the energy consumption of appliances in comparison to a reference point, a methodology that has been criticized because of its susceptibility to the literacy.

A review of the literature resulted in the identification of four types of energy literacy. These include *device energy literacy*, which reflects knowledge about the energy consumption of domestic appliances, *action energy literacy*, constituting one's ability to judge the impact of actions to save energy in one's home, *financial energy literacy*, which reflects a person's ability to make financially efficient energy decisions and *multifaceted energy literacy,* which includes all the aforementioned types of energy literacy as well as general energy knowledge, attitudes, values and energy conservation behaviour. These types of energy literacy differ in their comprehensiveness, with the latter type of energy literacy being the overarching type of energy literacy, including the most different aspects of energy knowledge. Financial energy literacy, as well as action literacy both include device energy literacy. In addition, financial energy literacy also includes knowledge on financial costs of energy use, and action energy literacy also includes knowledge about the impact of activities to save energy (i.e. the use of devices), see Fig. 1.

This paper will evaluate key features of each type of energy literacy, starting with the most confined type of energy literacy, to the most encompassing type of energy literacy. For each category of energy literacy, this paper will discuss literature that has explored the level of energy literacy, the predictors of the level of energy literacy (e.g. individual differences) and the link with energy use or savings. This paper will conclude with a comparison and evaluation of the different definitions of energy literacy and suggestions for future energy literacy research.

This paper will focus on energy literacy of an individual in the domestic context only. Although research on energy literacy outside of this scope exists, for example in the business sector (e.g. [6]) or on a

anchoring-and-adjustment heuristic [11]. This means that participants may have used the reference point that was provided (a light bulb) as a starting value (or anchor) to make a numerical judgement, without deviating sufficiently from this starting value. This method results in responses that are biased towards the reference point, and hence the reliability and validity of these findings are questionable. Indeed, Frederick et al. tested a variety of alternative reference points and concluded that participants' energy judgement is extremely sensitive to the energy consumption level of the reference point, and may even reverse Atari and colleagues' findings.

An early study on device energy literacy had participants rank household devices by energy consumption to assess device energy literacy, and found that participants' rank-order of the energy use of the appliances correlated strongly with the 'correct' rank-order, suggesting high levels of device energy literacy [12]. Survey studies report that the majority of respondents were not able to correctly identify the three household devices that consume most energy when in use for 20 min [70] or when considering their total energy use per billing-cycle [69]. In the latter survey, participants tended to incorrectly list short-use appliances such as the washing machine and dishwasher, and underestimated the energy consumption of long-use appliances such as the fridge and fridge-freezer. This suggests that participants may have discounted the length of time the appliances are commonly used for, and focused on the energy consumption of the appliances itself when judging the total energy consumption. Furthermore, survey studies have consistently found that people tend to overestimate the energy consumption of devices that are more visible in the household such as lights and entertainment, and underestimate the use of less visible items such as home heating systems [13–16]. This notion may suggest that people infer the energy use from the visibility of the appliance. Finally, qualitative studies that have explored device energy literacy through interviews and drawing methods echo the findings from survey studies

Table 1. An overview of the different types of energy literacy and the findings in the literature.

	Device EL	Action EL	Financial EL	Multifaceted EL
Characterization	Ability to judge energy use of household devices	Ability to judge the impact of energy saving actions in one's home	Ability to judge financial savings of household energy saving investments	General energy knowledge, attitudes, values, energy conservation behaviour
Level in population	Inconclusive	Low	Low	Low
Predictors	- Environmental attitudes - Numeracy - Energy judgement heuristics	- Environmental attitudes - Numeracy - Age - Behaviour - Symbolic fallacy bias	-Education -Nationality	- Gender - Income - Preference for science courses - School location (urban/rural)
Link to energy use	Inconclusive	Strong	Inconclusive	Inconclusive/ N/A

Although energy literacy is often assumed a requirement for (effective) energy saving behaviour, the literature demonstrates little evidence of the impact of energy literacy on energy behaviour. The only type of energy literacy that has consistently been linked to energy behaviour is action energy literacy, which may be due to its close relation to daily energy consumption actions. Furthermore, this type of energy literacy may also be more specific, and therefore, householder's accuracy might be easier to evaluate. Hence, this type of energy literacy may provide the most promising avenue to stimulate energy saving behaviour among householders.

Considering the low levels of energy literacy reported across the energy literacy literature, and important question is how policy makers could increase energy literacy among householders. Household energy consumption has been targeted using information

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Heuristics in energy judgement tasks

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ABSTRACT

To save energy effectively, householders need to be aware of the energy consumption in their homes, in particular the energy use of their household appliances. People's perception of the energy use of their appliances has been found to be influenced by the use of heuristics (simple rules for making quick decisions), yet these heuristics have received little research attention. Three studies investigated the use of these energy judgement heuristics using mixed methods. Findings show that 1) participants used as many as twenty-four different heuristics in an energy judgement task – an order of magnitude more than identified in existing literature; 2) participants are aware they use the heuristics, but awareness varies per heuristic; 3) the use of these heuristics can be changed and this in turn can improve energy literacy. These studies demonstrate for the first time that the energy judgement process is much more complex than previously thought and provides a promising starting point for future research to uncover opportunities to improve energy literacy.

1. Introduction

Due to the methods of generation, energy use is associated with various societal problems, including climate change (Myhre et al., 2013), fuel poverty (DECC, 2015) and the global energy crisis (Buchan, 2010). Despite householders reporting that saving energy is the most important strategy to reduce their impact on environmental problems (Semenza et al., 2008), householders do not currently save energy efficiently in their homes (Ehrhardt-Martinez, Donnelly, & John, 2010), suggesting an opportunity to improve this energy conservation behaviour. Fortunately, householders also report being willing to reduce their energy use (Mansouri, Newborough, & Probert, 1996), and when this motivation is low, research provides insights on how to increase such motivations (e.g. van den Broek, Bolderdijk, & Steg, 2017). However, willingness to save energy is of no use without the knowledge of how to do so effectively. In other words, are householders energy literate? Individuals with a good understanding of energy consumption, or high-level energy literacy, are able to make informed decisions and know how to save energy efficiently and effectively; people lacking such literacy will be held back from reaching what energy-saving goals they may have. Indeed: householders with a better understanding of domestic energy use tend to use energy more efficiently and consume less electricity (Blasch, Boogen Filippini, & Kumar, 2017; Kempton, 1986).

1.1. Device energy literacy

Different types of energy literacy have been identified in previous research. Some research has conceptualised energy literacy in a scientific sense (i.e. an energy literate person understands energy production and supply, the environmental and societal impact of energy production and consumption etc.; DeWaters & Powers, 2011). Other researchers have used the term to cover understanding of the energy consumption of domestic activities (Attari, Dekay, Davidson, Bruine, & Bruin, 2010), still others focus on what we have termed device energy literacy. This paper will focus on the latter type of energy literacy as householders report being willing to reduce the use of household appliances (Gatersleben & Vlek, 1998).

Device energy literacy reflects people's ability to estimate the energy consumption of household devices accurately. Unfortunately, the literature currently presents no consensus on the nature or degree of such literacy. There are indications people tend to use a conservative range when judging the energy consumption of household appliances; the energy use of high energy consuming devices is underestimated while the energy use of low consuming appliances is overestimated (Attari et al., 2010; Schuitema & Steg, 2005). However, the methodology of such studies, in which participants rated the energy consumption of appliances in comparison to a reference point, has been criticised because of its susceptibility to the anchoring-and-adjustment

pliances (e.g. Chisik, 2011; Pierce & Paulos, 2010).

1.2. Heuristics in energy judgement

Some of the aforementioned studies found participants employed *heuristics* when judging the energy consumption of household appliances (Baird & Brier, 1981; Chisik, 2011; Cowen & Gatersleben, 2017; Schuitema & Steg, 2005). Heuristics are simple rules used to reduce the cognitive load of decision-making and prevent information overload (Chaiken, 1980). Heuristics are a result of a process of attribute substitution in which people tend to use an alternative attribute to infer the target attribute (Kahneman & Frederick, 2002). The use of these heuristics will be helpful for estimating the energy consumption of appliances when the alternative attribute is a valid indicator of energy consumption but will, of course, be unhelpful when this is not the case.

To date, research has identified three types of heuristics that are employed to judge the energy consumption of household devices. First, participants have been found to use a *size heuristic* (Baird & Brier, 1981; Chisik, 2011; Cowen & Gatersleben, 2017; Schuitema & Steg, 2005). Here, large devices are thought to use more energy in comparison to small devices, which implies that the energy consumption of small devices tends to be underestimated whereas the energy consumption of large devices is overestimated.

Second, people have been found to employ a *usage pattern heuristic* (Chisik, 2011). With this heuristic, devices that are used frequently or for long periods are thought to use a lot of energy per year whereas devices that are rarely used and for a short amount of time are thought to consume low levels of energy. Therefore, the use of this heuristic may mean that the energy use of devices that consume high levels of energy per fixed time unit and are rarely or shortly used may be underestimated and vice versa.

Furthermore, the visibility of the appliance has been suggested to be considered when judging the energy use of home appliance systems (Bodzin, 2012; DeWaters & Powers, 2011), which we might link to the well-known *availability heuristic* (Tversky & Kahneman, 1973). However, the only study that has investigated the use of this potential heuristic with experimental methods did not provide sufficient evidence for the use of this heuristic, nor was the heuristic used in a consistent manner (Schuitema & Steg, 2005). Similarly, householders may consider the household domain (e.g. cooking, entertainment) of the appliances when judging the energy use of an appliance, as this is a salient feature when householders group appliances (Gabe-Thomas, Walker, Verplanken, & Shaddick, 2016).

Evidently, the current literature suggests that heuristics directly underpin a householder's energy literacy. Considering energy literacy in turn affects energy behaviour and consumption (Blasch, Boogen Filippini, &

2. Study 1

The first study took an exploratory approach to provide a more comprehensive search for different energy judgement heuristics than the previous literature. Moreover, this study also included a first exploration of participants' awareness of the use of the heuristics.

2.1. Method

A qualitative approach was taken to map the energy judgement heuristics, potentially allowing any heuristic to be uncovered in this study. This is in contrast with previous studies that assessed whether the rating of an attribute could be statistically related to the energy judgement (Attari et al., 2010; Baird & Brier, 1981; Cowen & Gatersleben, 2017; Schuitema & Steg, 2005), and thereby only investigated the use of heuristics that were hypothesised a priori.

To prompt the use of energy judgement heuristics, groups of participants conducted a task in which household appliances were ranked by their perceived energy use. Participants were instructed to only consider the energy use of each appliance when in use for one minute, thereby factoring out differences in the frequency and duration for which the appliances tend to be used. It is acknowledged that the energy use of appliances is also strongly determined by the use of the appliance, potentially limiting the ecological validity of the decision-making process in this task. However, the fixed-time instructions were necessary to avoid extensive discussions on the use of the appliance, as this is likely to differ across participants. The current task was therefore the preferred method to measure which other factors are considered when judging energy use of appliances.

The rank-order task was designed to not include a reference point, as this was found to be problematic in previous research due to the use of an anchoring and adjustment heuristic (Frederick et al., 2011). Furthermore, this task allowed the use of heuristics to occur spontaneously without explicitly prompting participants to use certain heuristics, which could make participants aware of the observation of their decision-making process and the research objectives. Participants were instructed to conduct the task together, meaning the rank-order task functioned to generate discussion about the methods that could be used to estimate the relative energy consumption of the household appliances and to make implicit ideas about energy consumption explicit through interpersonal debate. Note that we do not claim this method captures all participants' heuristics, as participants may not report on heuristics that they are not aware of using or that they do not perceive as valid heuristics. However, this was not the goal; rather, we sought to estimate the overall extent of heuristic use rather than a firm quantification.

Kumar, 2017; Kempton, 1986), the use of heuristics is likely to affect energy use. Heuristics may differ in their impact on energy literacy, meaning some heuristics can result in more accurate energy perceptions than others. Hence, the use of less beneficial heuristics may negatively impact energy saving while employing more helpful heuristics may empower householders to reduce their energy use. Given the limited state of the current energy heuristic literature, it is important to further investigate these heuristics and

2.1.1. Sample

Participants ($N = 26$, age $M = 18.96$, $SD = 1.11$, 57.7% female) were first-year undergraduates who participated in the study in return for course credit or a financial reward. Participants were recruited through online and offline advertising that did not mention the focus on environmental behaviour in the study, to avoid sampling bias. The

Table 1
Overview of themes and codes (number of instances OBSERVED/NUMBER OF INSTANCES SELF-REPORTED).

Theme	Description	Subthemes	Description	Example
Task (36/5)	Aspects of the device's task(s) are employed	• Task complexity (6/1) • Task size (30/4)	• Devices that carry out complex tasks consume more energy • Devices that complete several tasks (either simultaneous or successive), or large tasks, consume more energy	• "Uhm, phone charger, not much? It's easy isn't it?" • "But then, surely, coffee machine, has gotta be above kettle, because it's doing more things, than a kettle"
Knowledge (24/1)	Prior understanding of the energy use	• Wattage (5/1) • Received wisdom (18/0) • Energy label (1/0)	• Devices that use a lot of Wattage consume more energy • Knowledge about the energy consumption of the device that stems from public discourse or an unspecified source • Devices that have an energy label use more energy	• "A microwave is about 800 Watt, that's the only thing I know." • "Portable heater take up loads of energy, someone told me that." • "Because fridges have those things where they have to tell you how much energy they use and stuff whereas phone chargers … you know"
Force (21/10)	Perception of the force of the device	• Perceived energy intensity (8/5) • Perceived power (4/1) • Activity (8/3) • Task/size ratio (1/1)	• Devices that are less energy intense use less energy • Devices that are more powerful use more energy • More active devices use more energy • Devices that are small but conduct a large task use a lot of energy	• "I think they'll be quite energy intensive so let's put it there [pointing to the top of the ranking-order]." • "Toothbrush is quite powerful" • "They are not quite, if you know what I mean, they are not active as these things" • "Because that heats up everything around it, and it's only a small thing, so it's probably more likely to create more heat quicker [others agree] than'"
Physical features (48/5)	Physical characteristics of the device	• No. of components (7/0) • Type (24/0) • Size (9/5) • Charging needs (8/0)	• Devices with a lot of components use more energy • Devices from some brands or certain type of devices are more energy consuming • Larger devices consume more energy • Devices that charge other devices use more energy	• "Because you have a DVD player in your laptop, so a laptop with a disc driver is going to have more than a DVD player." • "Yes, it depends on the hoover. [..] Maybe a Henry hoover wouldn't be quite as bad" • "Well, maybe the smallest things use the least" • "Phone charger, well chargers might need quite a bit because they're charging something."
Relative standing (53/2)	The energy use of the device is compared to other devices	• Category (29/0) • Function (24/2)	• Appliances that are semantically related to each other consume similar levels of energy use • Devices with similar functions consume same levels of energy while devices with different functions consume different levels of energy.	• "DVD player and TV would be quite similar I think" • "Uh, I don't think an iron is too bad, because it's just heating up like straighteners, and hair straighteners aren't too bad."
Temporal patterns (49/4)	Time-based aspects of the appliance are used	• Speed (12/2) • Time switched on (37/2)	• The faster the device completes its task, the more energy the device consumes • Devices that are switched on for a longer period of time consume low levels of energy	• "Kettle would, kettle would use a lot. Because it heats up water really quickly doesn't it?" • "I think, it must be like, fridge freezer, must not use a lot because they are on all the time"
Multiple consumption modes (37/0)	Consideration of the variability of the process of the task of the devices	• Sustenance (9/0) • Utility phase (2/0) • Settings (8/0) • Heating up phase (18/0)	• Devices that 'keep up the heat' or movement consume more energy • Device use less energy in the utility phase compared to its use in a 'preparation phase' • When the device can be set on a higher unit (e.g. higher temperature) the device uses more energy • Devices that have an initial heating up phase consume more energy than devices that do not	• "Yeah, they have to like keep up the heat" • "Because you have to warm up the iron, and then you stop kind of" • "Yes, it really depends on what temperature you are using it at" • "Yeah, because that just goes like instantly hot, doesn't it? So shall we put electric hob up a bit?"
Temperature (33/4)	Temperature features of the appliance are employed	• Heat (31/4) • Cold (2/0)	• The more a device produces heat to heat up air or water or itself, the more energy it consumes • Devices that reduce the temperature of an element such as air or water were consume high levels of energy	• The ones that produce heat, are gonna be high up, aren't they, they use a lot of energy, like things that produce heat use the most, so that's going to be high up." • "They have to keep it at a very cold temperature"
Experience (4/0)	Considering the experience with the device	• Cuts out the fuser (4/0)	• Devices that have previously cut out the fuse box consume a lot of energy.	• "So I [think] high, because in my room, always, it always cut's out the fuse … so …"

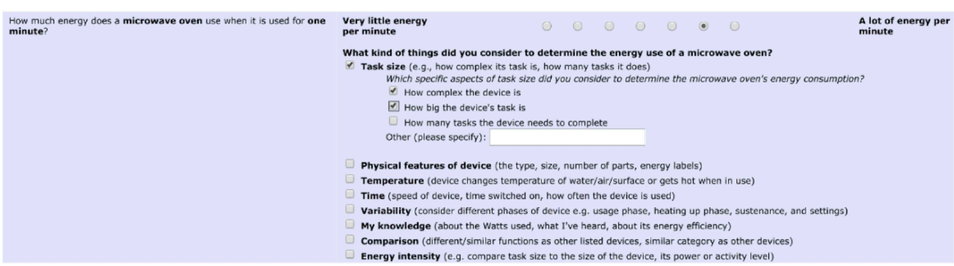

Fig. 1. Screenshot of an energy judgement task in the survey and the presentation of the energy judgement heuristics.

3.1.2. Materials and procedure

Ten devices (laptop, kettle, light bulb, oven, mobile phone charger, tumble dryer, hair dryer, microwave, toaster, fridge freezer) were selected to represent common daily household appliances, to cover a range of energy consumption levels and possibility to apply the different heuristics to (i.e. they varied in size, tasks etc.). For each appliance, participants were first asked to rate the energy consumption of the household device, again considering its energy use for one minute of continuous use. Participants indicated their energy judgement on a seven point Likert scale (1 = *uses very little energy per minute*, 7 = *uses a lot of energy per minute*). Each energy judgement task was followed up with a question assessing which heuristics they had used in the energy estimation of the device just considered (e.g. "*What kind of things did you consider to determine the energy use of the fridge-freezer?*"; see Fig. 1).

To reduce information overload in the survey, the heuristic themes that were created in the last study were presented, accompanied by keywords of the relevant heuristics in brackets (see Fig. 1). When the overarching theme was selected, the specific heuristics of the respective theme would appear. Participants indicated which of these heuristics

case participants might devise the heuristics after they have estimated the energy consumption. Therefore, this measure was instead to reflect participants' ability to recognise their use of the energy judgement heuristic, which reflects their awareness of the use of the energy judgement heuristic as awareness is a requirement for the recognition of the energy judgement heuristic. The relative frequency with which each heuristic was selected was therefore assumed to reflect participants' relative awareness of the use of the energy judgement heuristic. Because recognising the energy judgement heuristics requires lower levels of awareness than recalling the heuristics, participants were expected to recognise more heuristics than they could spontaneously recall in Study 1.

It needs to be noted that the selection of these heuristics may also be an indicator of what heuristics are seen as more or less socially desirable or what heuristics were perceived to be plausible strategies to judge the energy use of the appliance after the judgement was established. Furthermore, the use of the heuristics, and with that, the awareness of the use of the heuristics, is likely to vary with the appliance that is to be evaluated. Therefore, this study will focus on how

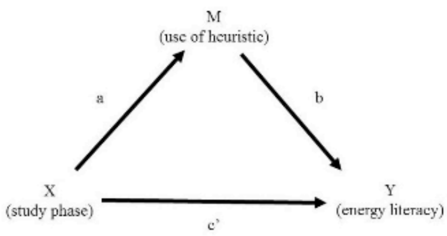

Fig. 4. Illustration of a mediation design.

bootstraps with replacement were performed to obtain a confidence interval around the regression coefficient of this path (Preacher & Hayes, 2008).

The mediation analyses explored if this change in energy literacy could be explained by the changes in the use of the heuristics as a result of the manipulation. Therefore, only the heat and time switched on heuristics were expected to mediate the change in device energy literacy. However, a mediation analysis for each heuristic was performed to confirm that only the use of these two heuristics mediated the improved device energy literacy and thereby served as a test that any changes might reasonably be attributed to the information provision in this study. Furthermore, for these analyses we excluded the rating of the appliances that were displayed on the posters (fridge, tumble dryer, hairdryer and laptop) to investigate if participants were able to extrapolate the use of the heuristics to other appliances.

Table 3
Results of mediation analyses for each heuristic.

Coefficient	Size	Intensity	Activity	Heat	Speed	Time switched on
a	**0.39** ($\chi^2(1) = 8.48$, $p = .004$)	−0.07 ($\chi^2(1) = 0.62$, $p = .43$)	−0.08 ($\chi^2(1) = 0.52$, $p = .47$)	**0.44** ($\chi^2(1) = 8.14$, $p = .004$)	0.00 ($\chi^2(1) = 0.00$, $p = .99$)	−0.20 ($\chi^2(1) = 1.97$, $p = .16$)
b	**0.08** ($\chi^2(1) = 4.17$, $p = .04$)	− 0.001 ($\chi^2(1) = 0.01$, $p = .91$)	**−0.12** ($\chi^2(1) = 8.00$, $p = .004$)	**0.10** ($\chi^2(1) = 7.20$, $p = .007$)	−0.01 ($\chi^2(1) = 0.26$, $p = .87$)	−0.06 ($\chi^2(1) = 2.56$, $p = .10$)
ab	0.03 (95%CI [-0.01, 0.07])	0.00 (95% CI [-0.02, 0.01])	0.01 (95% CI [-0.02, 0.04])	**0.04** (95% CI [0.02, 0.08])	0.00 (95% CI [-0.01, 0.01])	0.01 (95% CI [-0.02, 0.04])
c'	**0.45** (95% CI [0.28, 0.62])	**0.48** (95% CI [0.32, 0.66])	**0.47** (95% CI [0.31, 0.64])	**0.44** (95% CI [0.26, 0.60])	**0.48** (95% CI [0.31, 0.65])	**0.47** (95% CI [0.31, 0.64])

Appendix A

Table 1
Percentage of selection of heuristics, mean number and standard deviation (SD) of selected heuristics per participant and total number of selections per appliance

	Fridge	Oven	Phone charger	Microwave	Lightbulb	Hair dryer	Kettle	Tumble dryer	Laptop	Washing machine
Task complexity	2.13	1.53	6.07	4.43	5.26	2.96	1.95	4.39	10.57	5.34
Task size	4.51	3.06	11.39	4.43	4.24	3.55	6.17	7.84	5.65	8.26
Number of tasks	1.88	2.00	2.28	1.33	1.53	1.18	0.97	2.26	5.95	3.94
Energy label	6.14	2.47	1.90	2.36	5.43	1.48	1.62	3.44	2.53	4.32
Brand	1.75	1.18	1.33	1.62	3.90	2.66	2.11	2.02	3.42	3.05
Number of components	1.63	0.94	2.28	1.62	1.70	1.48	1.30	2.49	4.17	1.65
Size	8.77	4.00	9.30	3.10	5.77	3.25	3.41	7.96	3.42	5.59
Heat	3.51	16.49	0.76	11.52	5.26	15.98	17.69	10.93	2.38	7.75

Table 1 (*continued*)

	Fridge	Oven	Phone charger	Microwave	Lightbulb	Hair dryer	Kettle	Tumble dryer	Laptop	Washing machine
Cold	14.29	1.30	0.19	1.92	0.34	0.89	0.65	0.59	0.45	1.40
Hot device	4.51	6.60	3.04	3.69	7.81	8.43	4.87	2.73	7.74	1.78
Speed	2.38	6.95	10.06	10.34	1.87	6.21	10.71	5.82	3.42	6.23
Time switched on	8.65	9.54	11.76	9.60	12.73	10.06	6.01	8.43	10.71	9.53
Necessity	2.76	2.47	3.42	1.62	4.58	2.51	2.27	2.26	3.87	2.67
Costs	1.38	1.18	0.57	1.03	1.87	0.74	1.46	1.90	1.04	1.52
Phase	2.76	3.18	0.38	0.74	0.34	1.33	1.79	0.95	0.74	1.78
Heat-up time	0.88	5.18	0.57	2.95	0.85	3.85	5.84	2.26	1.04	1.78
Heat-up	0.50	3.06	0.38	1.03	0.17	1.92	1.14	1.78	0.89	1.65
Usage pattern	1.13	3.42	2.85	3.10	4.07	3.55	3.08	3.21	4.91	3.05
Sustenance	2.01	2.47	0.38	1.18	0.68	2.22	0.81	2.14	0.89	3.43
Watt	1.63	1.18	2.66	4.28	7.64	2.51	3.41	1.31	1.64	1.40
Received wisdom	3.51	3.18	2.66	2.66	4.07	2.81	5.19	4.87	2.08	2.92
Energy efficiency	2.76	1.18	1.14	1.33	3.40	0.30	0.97	1.78	1.49	1.65
Unknown source	2.26	1.77	3.61	1.77	2.38	1.92	1.46	2.14	2.53	1.65
Function dissimilarity	1.88	1.41	2.66	1.33	1.02	1.63	0.81	1.31	1.34	0.76
Function similarity	1.13	1.30	0.57	2.07	1.02	0.89	1.30	1.07	0.45	1.78
Category	0.25	0.35	0.57	0.44	0.17	0.30	0.16	0.36	0.45	0.13
Perceived energy intensity	5.39	4.95	6.64	8.12	6.28	6.21	5.52	4.99	4.76	4.45
Task/size ratio	2.38	1.88	3.61	2.36	1.36	1.92	1.62	1.66	2.68	1.65
Perceived power	3.88	4.12	4.74	6.35	3.06	5.33	4.22	4.16	4.32	4.45
Activity	3.38	1.65	2.28	1.62	1.19	1.92	1.46	2.97	4.46	4.45
Mean number of heuristics (SD)	3.29 (2.55)	3.48 (3.14)	2.13 (2.14)	2.73 (2.70)	2.41 (2.32)	2.73 (2.90)	2.48 (2.55)	3.40 (3.51)	2.71 (3.00)	3.27 (3.62)
Total count	798	849	527	677	589	676	616	842	672	787