**Supplemental Text for**

**Better rules for judging joules:**

**Exploring how experts make decisions about household energy use**

Joseph Kantenbacher and Shahzeen Z. Attari

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# Supplementary Methods 1: Expert interview materials and protocol

## Study information sheet

**INDIANA UNIVERSITY STUDY INFORMATION SHEET**

**Energy Use and Perception**

You are invited to participate in a research study on energy and energy use, conducted by Dr. Shahzeen Attari of the School of Public and Environmental Affairs and Dr. David Landy in the Department of Psychological and Brain Sciences. You have been recruited to participate based on your public profile and expertise within your professional field. Please read this form and ask any questions before agreeing to be in the study.

**STUDY PURPOSE**:

The purpose of this study is to better understand how different forms of expertise and professional experience influence how people think about and approach the topic of energy use in the home.

**NUMBER OF PEOPLE TAKING PART IN THE STUDY:**

If you agree to participate, you will be one of approximately 50 people who will be participating in this research.

**PROCEDURES FOR THE STUDY:**

If you agree to be in the study, you will be asked questions about energy use. In addition, you will be with presented two tasks to complete either verbally or by inputting responses into a computer. These tasks include making judgments about the energy use of household goods. The study will conclude with a set of questions about your background. The entire session should take a maximum of 45 minutes.

**RISKS OF TAKING PART IN THE STUDY:**

Participation in this study involves making judgments about energy use in the home, and may prompt participants to reflect critically on their patterns of private energy use.

**BENEFITS OF TAKING PART IN THE STUDY:**

An understanding of how people think about energy can help us understand how to improve energy perceptions and use. You benefit from this experience because you may learn something about the nature of energy use by common appliances and other household items.

**ALTERNATIVES TO TAKING PART IN THE STUDY:**

An alternative to participating in the study is to choose not to participate.

**PAYMENT:**

This interview will take no longer than 45 minutes. For participating in this study, you will receive a payment of $20.00.

**CONTACTS FOR QUESTIONS OR PROBLEMS**:

For questions about the study, contact the researcher Dr. Shahzeen Attari at sattari@indiana.edu.

For questions about your rights as a research participant or to discuss problems, complaints or concerns about a research study, or to obtain information, or offer input, contact the IU Human Subjects Office: (812) 856-4242 or irb@iu.edu

**VOLUNTARY NATURE OF STUDY:**

Taking part in this study is voluntary. You may choose not to take part or may leave the study at any time. Leaving the study will not result in any penalty or loss of benefits to which you are entitled and you will be compensated for your time up to that point. Your decision whether or not to participate in this study will not affect your current or future relations with the investigator(s).

**HOW WILL MY INFORMATION BE PROTECTED?**

Efforts will be made to keep your personal information confidential. We cannot guarantee absolute confidentiality. Your personal information may be disclosed if required by law. No information which could identify you will be shared in publications about this study.

Organizations that may inspect and/or copy your research records for quality assurance and data analysis include groups such as the study investigator and his/her research associates, the Indiana University Institutional Review Board or its designees, and state or federal agencies who may need to access the research records (as allowed by law).

## Introduction to participants

We are interested in how people with different forms of expertise and professional experience think about and approach the topic of energy use in the home.

In the course of this interview, I will be asking you different types of questions to access your thinking about different facets of energy use in the home. The questions will be delivered and answered orally. The two mains tasks for this session are:

1. A behavior choice task, where I will ask you to think through the relative energy costs or savings potential of various routine appliances and activities
2. An estimation task, wherein you will provide an estimate of the energy consumed by various household appliances

After completing these tasks, I will ask that you share some reflections on the tasks and the ways that your experience and expertise informed your approaches. We will finish with a brief final set of questions about your background.

## Open-ended questions

1. How much do you think about the amount of energy you use on a day-to-day basis?
2. How does thinking about energy use factor into your professional life?
3. What actions have you taken in the past to reduce your personal energy consumption?

## Talk-aloud protocol warm-up1

We are interested in what you say to yourself as you perform the next task. I will ask you to talk aloud as you work on the problems. What I mean by talk aloud is that I want you to say out loud *everything* that you that you say yourself silently. Just act as if you are alone in the room, speaking to yourself. If you are silent for any length of time, I will remind you to keep talking aloud.

Before we turn to the main task, we will start with a couple of practice problems. I want you to talk aloud while you do these problems.

* First, I want to ask you to add 82 and 18 in your head.
* Next, I would like you to tell me how many windows are in your house.

## Choice task

[The instructions and each of the choice sets will be presented to the participant on a single sheet in landscape format if in person; if interview is remote, then each item will be presented on a separate screen on Qualtrics; correct values are provided in parentheses and were not included in the original document]

In the following sets, please choose the option that **uses the least amount of energy**. Assume typical appliance usage. Unless otherwise stated, please assume that the 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  (3938 Wh) | Washing machine  (478 Wh) | Dishwasher  (1201 Wh) |

**Which uses the least energy?**

|  |  |  |
| --- | --- | --- |
| Microwave  (1101 Wh) | Toaster oven  (1450 Wh) | Electric kettle  (1390 Wh) |

**Which uses less energy?**

|  |  |
| --- | --- |
| Watching a movie on a  40” flat screen TV  (145 Wh) | Watching a movie with a  digital projector  (225 Wh) |

**Which uses less energy?**

|  |  |
| --- | --- |
| A ceiling fan  (69 Wh) | A tube fluorescent light  (39 Wh) |

## 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?**

**How would you describe your expertise in your field as being relevant for estimating energy consumption of home appliances?** *Please circle the number that best fits your response.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Not at all relevant | Mostly irrelevant | Somewhat irrelevant | Somewhat relevant | Mostly relevant | Highly relevant |
| 1 | 2 | 3 | 4 | 5 | 6 |

**How many years of professional experience do you have in your field (excluding time spent pursuing certifications or academic degrees)?**

**What is the highest level of education you have attained?**

☐ Some schooling, but no diploma or degree

☐ High school diploma or GED

☐ Some college

☐ College degree

☐ Some graduate school

☐ Graduate degree

**Do you have a graduate degree (master's or doctorate) in any of the following fields?** Please check all that apply.

☐ Physics

☐ Electrical engineering

☐ Mechanical engineering

☐ Other engineering (not electrical or mechanical)

☐ Mathematics/Statistics

☐ Economics/Business

**Have you ever been certified as a home energy auditor?**

☐ Yes

☐ No

**Have you received any training as an electrician?**

☐ Yes

☐ No

**Have you ever been certified as a professional engineer by the National Society of Professional Engineers?**

☐ Yes

☐ No

**How often do you engage with members of the general public on issues related to personal energy use?** *Please circle the number that best fits your response.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Never | Yearly | A few times per year | Monthly | Weekly | Daily or almost daily |
| 1 | 2 | 3 | 4 | 5 | 6 |

**Do you rent or own your residence?**

☐ Rent

☐ Own

☐ Other \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Have you ever had an energy audit performed at your residence?**

☐ Yes

☐ No

**What is your gender?**

☐ Male

☐ Female

☐ Other \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**What is your age (in years)?**

**What is your ZIP code?**

**Do you have any additional thoughts or comments about our interview that you would like to share with me?**

# 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) |  |  |  |  |
| It takes less energy to heat something with microwaves than with heating elements (12) |  |  |  |  |
| Devices that need to be cooled while they are working use a lot of energy (13) |  |  |  |  |
| Devices that can run on batteries are low energy consumers (14) |  |  |  |  |
| Insulation helps to reduce the energy use of devices that heat and cool (15) |  |  |  |  |
| A device that runs on its own circuit uses a lot of energy (16) |  |  |  |  |
| LED lights do not use a lot of energy (18) |  |  |  |  |
| Devices that either make lights dim/flicker or trip circuits when turned on use a lot of energy (19) |  |  |  |  |
| The larger the plug a device has, the more energy it will use (20) |  |  |  |  |
| Devices that plug into a 240-volt outlet use more energy than devices that plug into a standard 120-volt outlet (21) |  |  |  |  |
| Thicker power cords are associated with more energy consumption (22) |  |  |  |  |
| Quieter devices use less energy than ones that make noise (for example, a rattle or hum) when they are in operation (23) |  |  |  |  |
| Devices that become hot to the touch use more energy than similar devices that don’t (24) |  |  |  |  |
| Devices that have an energy label use more energy (28) |  |  |  |  |
| Devices with a lot of components use more energy (29) |  |  |  |  |
| Larger devices consume more energy (30) |  |  |  |  |
| Devices that charge other devices use more energy (31) |  |  |  |  |
| Devices that 'keep up the heat' or movement consume more energy (32) |  |  |  |  |
| Devices use less energy in the use phase compared to its use in a 'preparation phase' (33) |  |  |  |  |
| Devices that have an initial heating up period consume more energy than devices that do not (34) |  |  |  |  |
| Devices that are related to each other (for example, DVD players and televisions) use similar amounts of energy (35) |  |  |  |  |

Q2 Do you have any additional rules about home energy use that you would like to see added to the above set of rules?

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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Q3 What is your name? (Your answers are confidential. We ask for the purpose of linking your response here to your previous interview.)

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Q5 Do you have any additional comments for us?

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

# 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 |
|  | Fan | Notes that the device has a fan or circulates air, though is not itself a fan |
|  | Forced-air cooling | Notes the presence or absence of forced-air cooling |
|  | Insulation | Notes the presence, absence, or degree of insulation |
|  | Light | Notes the presence of a light or display system, though not as the primary or secondary function of the device |
|  | Magnetron | Notes that the device contains a magnetron or otherwise generates microwaves |
|  | Motor/compressor | Notes that a device has a motor, compressor, engine or cognate term |
|  | Resistive coil | Notes that a device has a resistive coil, heating element, or cognate term |

# 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 |
| 1. The more a device produces heat to heat up air or water or itself, the more energy it consumes |
| 1. The fast a device completes its task, the more energy the device consumes |
| 1. More active devices use more energy |
| 1. **Larger devices consume more energy** |
| 1. Knowledge about the energy consumption of the device that stems from public discourse or an unspecified sources |
| 1. Devices with similar functions consume same levels of energy while devices with different functions consume different levels of energy |
| 1. **Devices with a lot of components use more energy** |
| 1. **Devices use less energy in the utility phase compared to its use in a 'preparation phase'** |
| 1. Devices that use a lot of Wattage consume more energy |
| 1. Devices that reduce the temperature of an element such as air or water will consume high levels of energy |
| 1. Devices that have previously cut out the fuse box consume a lot of energy |
| 1. **Devices that have an initial heating up period consume more energy than devices that do not** |
| 1. **Devices that have an energy label use more energy** |
| 1. Devices that complete several tasks (either simultaneous or successive), or large tasks, consume more energy |
| 1. **Devices that charge other devices use more energy** |
| 1. Devices that carry out complex tasks consume more energy |
| 1. Devices that are switched on for a longer period of time consume low levels of energy |
| 1. Devices that are small but conduct a large task use a lot of energy |
| 1. Devices that are more powerful use more energy |
| 1. Devices that are less energy intense use less energy |
| 1. **Devices that 'keep up the heat' or movement consume more energy** |
| 1. Devices from some brands or certain type of devices are more energy consuming |
| 1. **Appliances that are semantically related to each other consume similar levels of energy** |

# Supplementary Analysis

## Power Analysis

Power analysis performed with G\*Power (v3.1; (3)) indicates that a sample size of 67 experts would have been suitable to detect correlations with medium effect sizes (r = 0.3) at 1 – β = 0.80. Given this study’s sample of 30 experts, the effect size would have needed to be 0.45 or so to have a reasonable chance of detecting a significant correlation between the various measure of expert performance on the estimation task and experts’ self-assessed relevance of their expertise (see Section 3.1).

## Correctness as a Function of Wattage Proximity

To test whether expert performance on the choice task was dependent on the magnitude of difference between devices, we examined the correlation between these two terms. Expert performance was measured in terms of the number of experts (out of 30) who correctly selected the appliance with the lowest energy use. Wattage difference was assessed by taking the logarithmic difference between the device with the second-lowest wattage and the device with the lowest wattage within each choice set (see Table S1 below). The correlation between expert performance and wattage difference (r = 0.14, *p* = 0.72) was small and non-significant, suggesting that expert choice performance was not dependent on the magnitude between choice wattages.

**Table S1. Wattage values, wattage difference values, and count of**

**correct experts for each choice task**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Choice task | Lowest wattage (α) | Second-lowest wattage(β) | Log10(β/α) | Number of correct expert choices (out of 30 total) |
| 1 | 1157 | 3050 | 0.421 | 20 |
| 2 | 363 | 809 | 0.348 | 18 |
| 3 | 197 | 967 | 0.691 | 22 |
| 4 | 185 | 358 | 0.287 | 17 |
| 5 | 27 | 33 | 0.087 | 23 |
| 6 | 478 | 1201 | 0.400 | 14 |
| 7 | 1101 | 1390 | 0.101 | 18 |
| 8 | 145 | 225 | 0.191 | 9 |
| 9 | 39 | 69 | 0.248 | 24 |

# References

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3. Faul, F., Erdfelder, E., Buchner, A. & Lang, A.-G. Statistical power analyses using G\*Power 3.1: Tests for correlation and regression analyses. *Behav. Res. Methods* **41**, 1149–1160 (2009).