

**Using Alternative Data Visualization Formats to Impact Residents Energy
Awareness**

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ABSTRACT

Data visualization has the power to portray an informative message when designed with the end user in mind. Energy data visualizations must be tailored to the resident's energy, graphical, and data literacy level. A resident's energy, graphical, and data literacy level depicts their understanding and life experience with energy. Current utility companies standardize data visualization formats for all customers, regardless of their literacy level. My aim for this dissertation is to evaluate how data visualization mediums (2D chart types and virtual reality visual aids) aid residents when reading, working with, analyzing, and arguing energy consumption data of household appliance pairs. The data visualization chart types explored include the area, bar, and circular column charts. The visual aids displayed in the virtual environment explored include color coding, electricity flow, and the power meter. The energy data of the household appliances is embedded within the visual aids without displaying energy metrics. The household appliances include lighting (LED vs incandescent bulb), cooking (air fryer and stove), and heating appliances (heat pump and space heater). The participants included 32 graduate students from Virginia Tech engineering programs. Results from the study showed that some participants had a hard time interpreting axis unit metrics energy such as watts, watt*minutes, and kWhs in all three 2D chart types. If participants could not read and work with the units on charts, their ability to analyze and argue about the energy data was diminished quickly. In addition, when participants were interacting with the visual aids, researchers discovered that the power meter was the easiest to convey because it provided participants with a way to qualitatively and quantitatively answer the questions presented by the questionnaire. This

dissertation provides insights for researchers, utility companies, and policymakers to move away from standardized data visualizations and utilize alternative visuals for reading, working with, analyzing, and arguing residential energy consumption data. Researchers can utilize the dissertation insights to explore other data visualization mediums that have the potential to convey energy insights. Utility companies can begin implementing these alternatives data visualization in pilot programs to test their effectiveness with the public. And lastly policymakers can enforce utility companies to prioritize customers literacy levels when administering utility bills.

Using Alternative Data Visualization Formats to Impact Residents Energy Awareness

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GENERAL AUDIENCE ABSTRACT

Data visualization has the power to tell a wonderful, meaningful, and thoughtful story when created with the end user in mind. The same thing can be said about visualizations on utility bills when tailored to a resident's energy, graphical, and data literacy level. A resident's literacy level results from their life experiences and circumstances dealing with energy data. Currently, data visualizations are standardized by utility companies, meaning that all individuals receive the same energy data visualization no matter their literacy level. My aim for this dissertation is to evaluate which data visualization chart types and VR visual aids enable reading, working with, analyzing, and arguing energy consumption data of household appliance pairs for residents. The data visualization chart types explored include the area, bar, and circular column charts. The visual aids explored include color coding, electricity flow, and the power meter. The household appliances include lighting (LED vs incandescent bulb), cooking (air fryer and stove), and heating appliances (heat pump and space heater). The participants included 32 graduate students from Virginia Tech engineering programs. Results from the study showed that some participants had difficulty reading and working with energy metrics on all three 2D chart types. If participants did not understand the units when reading and working with the charts their ability to analyze and argue the energy data was insufficient. In addition, when participants were interacting with the visual aids, researchers discovered that the power meter was the easiest to convey because it provided participants with a way to qualitatively and quantitatively answer the questions presented by the questionnaire. This dissertation provides insights for researchers, utility companies, and policymakers to move away from standardized data visualizations and

utilize alternatives that enable reading, working with, analyzing, and arguing residential energy consumption data.

Dedication

This dissertation is dedicated to the past generations and future generations to come. I am who I am today because of my ancestors who came before me and blazed the trail for me to obtain my education and utilize the special, unique characteristics that were instilled in me from a young age: determination, curiosity, patience, dedication, humor, and being tireless. First, I would like to honor my father, Andrew James, who is in heaven watching down on me along with my grandmothers' mother side (Essis Titus) father side (Ludell Garrick), grandfathers' mother side (James T Cantey) father side (Joseph Garrick), and my Uncle Gerald Cantey who was the original engineer of the family. My ancestors inspired me to keep pushing forward no matter what obstacle has come along my path. Even my grandparents that passed away before I was born this dissertation is for you. A shoe is just a shoe until someone steps into it. A family lineage is just a family tree until you instill purpose and values that can be passed down from generation to generation, destroying negative cruses and building up positive generational curses.

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Next, I would like to thank my family for instilling in me the importance of obtaining a education. My mother and father for raising me to become the man I am today. My father taught me a lot about cars and working with my hands at a very young age, and I still carry that knowledge with me today. My mother taught me about working hard, kindness and how to give unconditional love. Even though my father is not long here today, I still feel his presence with me daily. I want to also thank my sister, who has taught me how to fight through tough situations and never give up. I want to thank you all for believing in me when I did not believe in myself.

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CHAPTER 1: INTRODUCTION

There is an opportunity to present energy data through another lens, painting a new picture to impact residents' energy awareness. Utility companies are starting to move towards paperless billing, increasing the need for digital technology. Utility companies now provide residents one access to utility bills in a PDF or digital dashboard format. The PDF is the same document residents would receive in the mail. However, the digital dashboard gives residents more control over seeing historical energy data information, which is a step in the right direction towards improving residents' energy-data literacy levels. But residents may still not fully understand the digital dashboards just as the utility bills because of the use of standardized practices used by utility companies. Standardized design practices in the residential energy domain are unreliable because residents' energy-data literacy levels differ.

To combat the standardized practices of utility companies I'm proposing the use for alternative data visualizations mediums such as virtual reality. Virtual reality has the power to create an immersive experience for residents to gain energy awareness of household consumption in a non-standardized format. As defined by (Witmer and Singer 1998), "Immersion is a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences." (Fauville n.d.) Benefits of continuous stream or stimuli and experience in the virtual reality environment could lead to residents improving their energy literacy levels on their own by interacting with components insides of the virtual environment. The interactable components would be but are not limited to HVAC system, lights, water heater, washer, dryer, etc. Studies have shown that they are multiple proposed methods in which a virtual reality environment can be designed to increase energy

awareness (Bühling et al. 2012; Hoffmann et al. 2011; Fredericks et al. 2019; García-Manzano et al. 2019; Tagliabue 2020). Therefore, the creation of virtual reality environments can be designed around the individual's energy and data literacy levels and not be generalized for a standard.

1.1 An example that there is no standardized way to create a virtual environment

For example, in the summer of 2022, I collaborated with Radford high school educators. The majority of the high school teachers had never experienced VR before, which allowed them to have limitless imagination when it came to brainstorming ideas. The educators and I meet bi-weekly throughout the summer. As a result, from collaborating with the educators, I was able to create ENERGY-VR. ENERGY-VR is a learning platform for computer science skill development based on intelligent infrastructure and residential energy monitoring systems. The virtual environment was design to provides two options learning options for students (1) they can follow the instructions spoken by the avatars guiding them from start to finish, or (2) they can have the ability to roam throughout the virtual environment learning at their own pace. This virtual environment will be the foundation for the virtual experience I'm using to educate residents on how common household appliances consume energy.

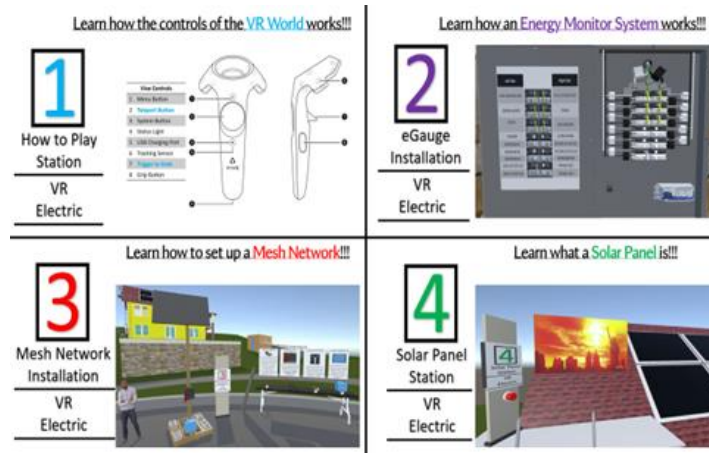


Figure 1: Displays the four different phases students encountered when navigating throughout the ENERGY VR learning experience.

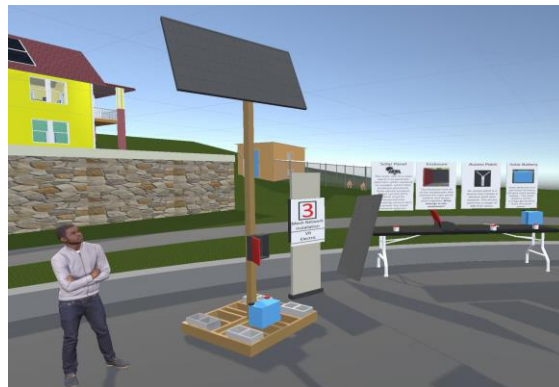


Figure 2: Displays the solar power mesh network building station.

1.2 Data visualization Convey Information

Currently, data visualization tools are being created to put the power back into the hands of the users, allowing users to fully be aware and in control (Azzam et al. 2013). Making data accessible to the public is one thing, but making sure people understand what the data is saying is essential.

A person's understanding of data depends on their data literacy level. Data literacy defined by (Bhargava 2015), discuss a person's ability to read, work with, analyze, and argue data. "Data literacy also includes a person's ability to: formulate and answer questions using data as part of evidence-based thinking; use appropriate data, tools, and representations to support this thinking; interpret information from data; develop and evaluate data-based inferences and explanations; and use data to solve real problems and communicate their solutions" (Vahey et al. 2006). A person's data literacy level is a result of their educational and life experiences with data. Therefore, different conclusions can be drawn from individuals viewing the same data visualizations because of their data literacy level.

1.3 The current way in which energy data is presented to residents.

Presenting energy data to residents in a general schematic limits their understanding of household energy consumption. Utility companies have standardized how energy consumption data is shared with residents. Standardization prevents residents from fully comprehending the energy data displayed on utility bills. There are tradeoffs between customers comprehension of the visualization chart type and the precision of what is shown on the visualization (Egan et al. 1996). For example, "a bar graph is mainly understood by most individuals than bell curves, but abnormal data points cause miscommunication of the bar graph's intended purpose" (Egan et al. 1996). However, utility companies only use a subset of the available data visualization chart types to represent residents' energy data. Results from my master's work involving a content analysis identified four commonly used charts in utility bills. Besides those four chart types discovered, eight additional chart types were uncovered during the literature review that could visualize energy data.

Table 1: Displays the four chart types discovered from the utility bill along with the eight additional chart types uncovered doing the literature review.

Current Chart Types	Additional Chart Types
Vertical Bar	Horizontal Stack Bar
Vertical Stacked Bar	Scatter
Line	Funnel
Doughnut	Bullet
	Heatmap
	Boxplot
	Treemap
	Radar

Residents have the desire to understand why their monthly utility bill is the amount it is. According to (Foster and Alschuler 2011), 41% of residents reviewed graphs to compare energy consumption from their previous months when receiving uncommon bills to understand their energy consumption. While customers are looking at graphs displaying energy data, another study by (Egan et al. 1996) discovered at least half of the participants had confusion while trying to understanding energy data charts. Even if utility companies choose to incorporate the additional chart types discovered from the content analysis, residents may still have trouble understanding the energy consumption data, because of their energy-graphical-data literacy levels. Data visualization must also be chosen to meet residents’ current energy-graphical-data literacy level to

have complete comprehension with the resident. The aim of this dissertation determines how participants are reading, working with, analyzing, and arguing energy data embedded within 2D data visualizations and visual aids in the virtual environment, shown in Table 1.

Motivation

Motivation sentence for Manuscript 1.

There is a need to understand how residents interact with and draw conclusions from reading, working with, analyzing, and arguing energy data embedded within 2D data visualizations.

Motivation sentence for Manuscript 2.

There is a need to understand how residents are reading, working with, analyzing, and arguing with energy data embedded within visual aids inside of a virtual environment.

Motivation sentence for Manuscript 3.

There is an opportunity to gather feedback to understand the advantages and challenges of embedding energy data within visual aids, as well as to explore residents' recommendations for creating more informative data visualizations.

Research Purpose and Objectives for each Manuscript

Manuscript #1

Title: Resident Engagement with Energy Data: Examining How 2D Visualizations Support Interpretation and Decision-Making.

Research Objective: Determine how residents are reading, working with, analyzing, and arguing energy data embedded with an area, bar, and circular column chart.

Research Question: How are residents reading, working with, analyzing, and arguing with 2-dimensional data visualizations containing household energy consumption data?

Manuscript #2

Title: Decoding Energy Data: How Residents Use Visual Aids in Virtual Environments to Understand Household Energy Insights.

Research Objective: Determine how residents can read, work with, analyze, and argue energy data embedded with three visual aids: color coding, electricity flowing, and power meter within a virtual reality environment.

Research Question: How can displaying energy data using alternative visual aids in the virtual environment impact a resident's ability to read, work with, analyze, and argue about energy consumption data?

Manuscript #3

Title: Effectiveness of Visual Aids in Virtual Environments for Conveying Household Appliance Energy Data.

Research Objective: Determine how effective the energy consumption data of household appliances were able to be embedded into the visual aids in the virtual environment.

Research Questions: How can constructivist learning theory be implemented to impact a residents ability understand three visual aids in the virtual environment?

Sub-question: How effective were the visual aids sufficient at revealing energy data insights?

Sub-question: How could the visual aids be altered to improve the align with participants perceptions or ways of learning?}}

Research Scope

This dissertation is tailored towards residents who are considered low-income earning individuals, who are spending outrageous amounts on utility bills and want to reduce their bills but do not know where to start. Residents are spending too much money on utility bills which, in

return, limits the amount of money they spend on necessities like doctor visits, groceries, and emergency savings. Energy insights need to be displayed in a way that's understood and related to the resident's energy, graphical, and data literacy levels. The intended message is not conveyed when data visualizations do not align with residents' literacy levels. Chapter 3 of the dissertation examines how individuals read, work with, analyze, and argue 2D data visualization chart types consisting of the area, bar (one of the most common chart types displayed on utility bills), and the circular column chart. The results from Chapter 3 provide new insights on what data visualization components individuals are utilizing when reading, working with, analyzing, and arguing residential energy data embedded within the charts.

There is a need to utilize a different data visualization medium to showcase a different perspective for individuals to understand energy insights. It is one thing to say that this energy behavior change would decrease energy consumption levels by 30%; it is another thing to showcase how different energy behaviors consume different amounts of energy. In Chapter 4, energy insights are showcased through 3 visual aids: color coding, electricity flow, and power meter. Results from Chapter 4 provide evidence on how well or unwell individuals were reading, working with, analyzing, and arguing the energy data embedded within the visual aids. Finally, Chapter 5 examines how individuals were able to construct knowledge from observing the feature changes within the visual aids. Results from chapter 5 inform future designers of what visual aid features were beneficial and what features were a distraction.

The participants for this research study consisted of 32 graduate students from Virginia Tech. Graduate students are consisted low income due to their salary amount. The data visualization used throughout this study consists of 2D chart types and virtual reality visual aids.

The 2D data visualization the area, bar, and circular column chart was examined. For the virtual reality environment energy was embedded into three visual aids: color coding, electricity flowing, and power meter. Participants were interviewed as they were interacting the data visualizations and answered the question verbally. The participants' responses were recorded using a voice recorder.

Dissertation Structure

This dissertation is organized into five chapters. The first chapter includes the introduction describing the problem and motivation behind the research study, research questions and the research scope. Chapter Two includes the first manuscript on “Resident Engagement with Energy Data: Examining How 2D Visualizations Support Interpretation and Decision-Making”. Chapter Three includes the second manuscript on “Decoding Energy Data: How Residents Use Visual Aids in the Virtual Environments to Understand Household Energy Insights”. Chapter Four include the third manuscript on “Effectiveness of Visual Aids in Virtual Environments for Conveying Household Appliance Energy Data”. And lastly, Chapter Five contains conclusions, major takeaways and implications for each manuscript and provides recommendations for future research.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

1.1 Introduction to Current Problem

Energy is an element that is needed to produce life, and for residents to have access to energy they are presented with a bill from the utility company. The current format of data visualizations on utility bills limit residents' energy awareness of household energy consumption, resulting in residents not having actionable behaviors to take to reduce their electricity bill. There are 5.3 million residents in the United States experience energy poverty, meaning that they are paying more than 6% of their monthly income on energy expenditures (Bell-Pasht 2024; Scheier and Kittner 2022). Residents are spending extra money on utility bills which cause them to cut back on necessities like doctor visits, education advances, and lifesaving (Doremus et al. 2022; Greenstone and Looney 2012; Shepard and Davis 2023). Residents have a desire to understand why their utility bill is the amount it is but utility companies are not designing visualizations to inform residents of household energy consumption, instead they are providing residents with aggregated energy data, which is an inefficient tactic to plotting against residents energy awareness.

1.2 Energy Data Visualization of Utility Bills















Utility companies are providing residents with aggregated energy data which contributes to having low energy awareness on household energy consumption. (Attari et al. 2010a) states that individuals underestimate appliances that consume high amounts of energy and overestimates on appliances that consume low amounts of energy. With utility companies aggregating energy data into monthly billing cycles residents are unsure on how energy is consumed throughout the home. "The standard practice elements that appear on 70-100% of utility bills include: the dollar amount due; current usage in kilowatt-hours or therms; a comparison to in usage in the same month the

previous year; the previous month's usage; grouped line items; and details of the rate (Foster and Alschuler 2011)". Nowhere in utility bills is the data disaggregated inform residents how energy is being consumed throughout their home. Forcing residents to guestimate from the total amount due and current usage in kilowatt-hours, how energy was consumed throughout rooms and appliances of the household. There is an opportunity to remove the guessing and inform residents of energy insights by restructuring the utility bill, using alternative data visualization and disaggregating energy data.

1.3 The Current Way Utility Bills Display Residential Energy Consumption Data

Utilize companies are only using a subset of data visualization chart types to display energy insights, limiting residents' ability to comprehend. The top 11 utility companies in the United States are using 4 different chart types (vertical bar, vertically stacked bar, doughnut, and line) to display energy data, shown in Table 2.

Table 2: Displays that there are four common chart types used between all the 11 utility companies' bills.

Vertical Bar	Vertical Stacked Bar	Doughnut	Line	Utility Companies
				AEP (American Electric Power)
				BG&E (Exelon)
				Consolidate Edison
				DTE
				Duke Energy
				Edison International Compant Utility
				NextEra Energy (Florida Power and Light Company)
				Pepco
				PG&E (Pacific Gas & Electric)
				PPL (Pennsylvania Power & Light)
				Southern Company (Georgia Power)

Another eight data visualization chart types outside of the energy domain from academic literature have the ability to display energy data, shown in Table 2. With the new chart types identified in literature there is an opportunity to remove confusion felt by residents and allow for complete understanding to occur. Not all chart types are understood in the same manner by residents, due to differences in literacy levels. For example, “majority of individuals understands bar graphs than bell curves, but abnormal distributions causes miscommunication about the bar graph's intended purpose” (Egan et al. 1996). Certain data visualizations align better with residents understanding, that’s the importance and power of utilizing alternative chart types than the current four types used by utility companies.

1.4 The Power of Data Visualizations

A data visualization transforms raw data into a conveying message where insights can be revealed. Data visualizations have been around since 200 BC where Egyptians were using cartography and astronomy to lay out towns (Azzam et al. 2013). “Data visualization is defined as the process of representing data in a graphical or pictorial way in a clear and effective manner (Sadiku et al. 2016)”. Data visualization relies on three criteria: (a) is it qualitative or quantitative based data, (b) are the results an image that represents the raw data, which then (c) is it readable to support exploration, examination, and communication? (Azzam et al. 2013). These three questions must be answered and evaluated when creating data visualizations. Data visualizations are needed to communicate data insights to the masses. Currently, data visualization tools are being created to put the power back into the hands of the users, allowing users to fully be aware and in control (Azzam et al. 2013). Making data accessible to the public is one thing, but making sure people understand what the data is saying is essential to conveying energy insights.

1.5 Data visualizations for Residential Energy Data

There is an opening to introduce new alternative data visualization mediums to the energy domain, to improve residents’ energy awareness. Of the many data visualization chart types in existence utility companies only utilize 4 chart types which limits residents’ ability to understand. Utilizing other chart types to display residents’ energy data will allow residents to find the chart type that aligns with their understanding. When creating the charts there are five functionality elements that serve as the foundation. The five main functionality elements are color, marker shape, marker size, axis titles, and background formatting (Hyndman et al. 2018; Lauer and O’Brien 2020). These elements must be understood for a resident to convey energy insights. The way residents interact

and interpret energy data visualizations is a contribution of their life and educational experiences with energy, graphs, and data.

1.6 Energy Literacy

Energy literacy is defined as having basic energy awareness, which includes having the ability to identify the impacts of energy production and consumption on the environment, from one's energy behaviors. (DeWaters and Powers 2011). "An individual's energy ability is beyond their scientific understand of energy, it includes having a clear understanding of energy systems and the aptitude and willingness to use that knowledge" (DeWaters et al. 2013). One's energy literacy level consists of three parts: knowledge, attitude, and behavior (Martins et al. 2020).

- Knowledge is a person's understanding of energy scientific concepts.
- Attitude is a person's mindset for making decisions about energy.
- Behavior is the way a person produces and consumes energy through usage.

1.7 Graphical Literacy

"Graphical literacy is defined as one's ability to understand a graphical representation" (Fry 1981; Ozmen et al. 2020). Graphical literacy is also defined as "the visual decoding of information encoded on graphs" (Cleveland and McGILL 1984). Therefore, different conclusions can be drawn from individuals analyzing the same visualization based on their internal decoding process. A comprehensive visualization of energy data is critical for residents to understand first where, how, and when they are consuming energy, with the intention of later going back and changing their

energy consumption behaviors to reduce energy consumption. However, “there are no clear design requirements to develop an energy monitoring visualization” (Murugesan et al. 2014).

Operational Component

- A person’s ability to read energy consumption graphs involves a resident understanding the information presented on a graph.
- A person’s ability to work with energy consumption graphs involves a resident using a graph to understand consumption patterns.
- A person’s ability to analyze energy consumption graphs involves a resident gathering conclusions from the graph.
- A person’s ability to argue energy consumption graphs involves using a graph as evidence to justify your proposal on how much energy is consumed by household appliances.

1.8 Data Literacy

The textual and numerical values of an energy data visualization must be understood for residents to completely understand the intent message within the visual. (Bhargava 2015; Wolff et al. 2016) have defined data literacy from many domains. However, no definition of data literacy fits contains the use of residential energy data. Earlier in research (Bhargava 2015) “first defined data literacy as the a person ability for reading, working with, analyzing, and arguing with data”. Later on (Bhargava 2015) newly definition of data literacy which is “the desire and ability to constructively engage in society through or about data” is moving closer to encompassing resident energy data. Another author’s (Wolff and Kortuem 2015), definition moves evener closer to discussing

residential energy data, by discussing reading graphs and charts to draw conclusions and recognize errors in the data. With academia literature not having a definition of data literacy in relation to residential energy data, I will coin data literacy in relation to the residential energy data domain as a person's ability to read, work with, analyze and argue. There is currently no definition that encompasses all three theories of energy, graphical, and data literacy. I am creating a conceptual framework for defining a resident's **reading, working with, analyzing, and arguing** ability residential energy consumption data. The format of defining residential energy consumption data is based on (Bhargava 2015) definition of data literacy.

1.9 Operationalization of residential energy consumption data

1.9.1 Reading residential energy consumption data is defined as ...

First, starting with the category reading. Before processing occurs, a person must be able to read information on the data visualization. “Reading data involves understanding what data is according” to (Bhargava 2015). Reading in relation to an energy data visualization involves identifying the axis titles, marker shape and sizes, legend, colors, or energy metrics. Reading the data on the visualization involves “lifting” information from a graph to answer an explicit question, in which the answer is obviously on the graph (Curcio 1987). (Wainer 1992) conducted a study that focuses on reading the graph as data extraction when answering elementary format questions. Elementary format questions only introduce a single element of a component (Bertin 1983). In this study, participants will be asked elementary style questions to read the energy data within the visualization, to identify a single specifier, just as (Carswell 1992) conducted, example question:

What is the value of pie slice B? Then after reading the data, participants will be working with the data to create insights based on the values identified within the chart.

1.9.2 Working with residential energy consumption data is defined as ...

Working with energy data embedded within a visualization reveals more in-depth energy insights than just reading the data. “Working with data involves creating, acquiring, cleaning, and managing the data (Bhargava 2015)”. A study conducted by (Gillan and Lewis 1994) “from their Mixed Arithmetic Perceptual (MA-P) model principle # 2 states that interacting with graphs is the search, encoding, arithmetic operation, and response components on a task that requires the users to calculate a value based on data identified from the graph.” In working with graphs, the user can interpolate the data. “For interpolation of the data, one must not only process information in the documents but also make document-based inference or draw on person background knowledge of the data presented (Friel et al. 2001)”, in the context of this research study data visualization will serve as document. A person’s background knowledge of energy, data, and graphical literacy levels plays a significant role in understanding the importance of energy data embedded within the data visualization.

1.9.3 Analyzing residential energy consumption data is defined as ...

A person must have an understanding of the energy data before they are able to analyze the data. Meaning that (1) they must be able to read and work with the data, and (2) their energy, graphical, and data literacy level enables them to interpret the results they received from reading and working with the energy data. Analyzing data was once defined by (Bhargava 2015) as utilizing an analytic

operation such as filtering, sorting, aggregating, comparing data. “Currently (Bhargava 2019) defines analyzing data as the ability to take a data set and perform algorithmic operations on it, both simple and complex.” Five of the algorithmic operations for performing analyses are five types of analyses “statistical analysis (e.g., to order, rank, or sort); temporal analysis answering “when” questions (e.g., to identify distributions over space); geospatial analysis answering “where” questions (e.g., to identify distributions over space); topical analysis answering “what” questions (e.g., to examine the composition of text); and relational analysis answering “with whom” questions (e.g., to examine relations; also called network analysis)” (Börner et al. 2019). These are five of the analysis process residents could utilize when performing algorithmic operations such as filtering, sorting, aggregating, or comparing the energy data. After analyzing, the final step is to argue the energy data, bring every category of reading, working with, and analyzing together creating a final narrative.

1.9.4 Arguing residential energy consumption data is defined as ...

A resident must have a holist understanding of reading, working with, and analyzing energy data embedded within a data visualization before they can argue the energy data. Arguing with data is defined as using data as evidence to support a narrative to communicate a message, draw conclusions, and compare from the data to a particular audience (Bhargava 2015, 2019; Wolff and Kortuem 2015). Arguing with energy data embedded within visualizations is an unfamiliar practice in the residential energy domain. Residents rarely argue with their energy provider, they may complain to themselves or their neighbors but never to the provider. Because residents cannot gather a narrative due to the energy, graphical, and data literacy misalign with the data visualization showcasing the energy data. Creating graphs that put residents in the position to argue

their energy data is needed to bridge the gap between residents understanding how energy is consumed throughout their home and learning actionable steps to take reducing their energy consumption usage. Besides using 2D chart types to make residents read, work with, analyze, and argue energy data, there is another data visualization medium that can be utilized virtual reality. With energy being invisible to the human eye, there is an opportunity to leverage the power of virtual reality to display energy insights.

1.10 Using Virtual Reality to Display Residential Energy Consumption Data

Virtual Reality (VR) adds another dimension and perspective for residents to understand household energy consumption. VR is used for many different applications from “entertainment, focusing on simulations, video games, 3D cinema, to virtual social worlds” (“Benefits of virtual reality in the classroom” 2017). But VR potential goes beyond these realms. “VR has infiltrated into the education system, providing alternative methods for teaching various concepts” (Kavanagh et al. 2017). I propose that VR can be used as an alternative teaching method to educate residents on household energy consumption. This dissertation is composed of three visual aids (a visual feature used to embed energy data) in the virtual environment. The visual aids are color coding, electricity flow, and a power meter. The color-coding visual aid changes colors in relation to the amount of energy being consumed low, medium, and high energy consumption is depicted by green, yellow, and red, respectively. The electricity flow visual aids depict energy flowing from the circuit outlet to the appliance. The flow speed is in direct relationship to the amount of energy being consumed, low to high, slow to fast flow speed respectively. The last visual aid, the power meter uses 5 boxes to depict energy consumption, using a direct relation between the number of

boxes lit in red to the amount of energy consumed by the appliance. Placing an individual inside of a virtual reality environment with visual aids and expecting them to learn is like placing an individual in a classroom with learning materials without a teacher. There must be a learning process in place to ensure that learning occurs in the virtual environment. There are many ways in which an individual can acquire new knowledge. This dissertation study will explore three learning styles: constructivist, social constructivism, and experiential learning.

1.11 Theories for Learning Experience

Presenting information to an individual and expecting them to learn might not adhere to the way that individual constructs new knowledge. There are numerous ways in which an individual can acquire new knowledge, meaning that there is no real one true answer or theory that summarizes how we learn. This research study will be grounded on three learning theories, constructivist, sociocultural, and experiential learning theory. Kolb, Piaget, Dewey, and Vygotsky are the fathers of experiential, constructivist, sociocultural learning theories.

1.11.1 Sociocultural Theory

Individuals can also create knowledge from social interactions with humans and environments. Vygotsky is a constructivist, however his theory of sociocultural is grounded on the social environment as a facilitator of development and learning (Zimmerman and Schunk 2014). Vygotsky believes that when an individual interacts with a social environment critical for learning, social interactions transform learning experiences (Kolb and Kolb 2011). And depending on how individuals interact with people, objects, and institutions, their way of thinking can be transformed. That transformation of learning is transmitted through language. “Language is the most critical

tool, which is developed from social speech, to private speech, to convert (inner) speech (Meece 2002).” Individuals can also construct knowledge through the transformation of experiences (Kolb 1984).

1.11.2 Experiential Learning Theory

Learning is a process whereby knowledge is created through the transformation of experience (Kolb 1984). Experiential learning theory was developed as a result of “Dewey’s philosophical pragmatism, Lewin’s social psychology, and Piaget’s cognitive development genetic epistemology to form a unique perspective on learning and development” (Kolb 1984). Experiential learning promotes experience, learning, and development across the social spectrum (Kolb et al. 2014). “Experiential learning theory integrates the foundational experiential learning scholars into six principles: (1) Learning is best conceived as a process, not in terms of outcome, (2) All learning is re-learning, (3) Learning requires the resolution of conflicts between dialectically opposed models of adaptation to the world, (4) Learning is a holistic process of adaption, (5) Learning results from synergetic transactions between the person and the environment, and (6) Learning is the process of creating knowledge” (Kolb and Kolb 2011).

1.11.3 Constructivist Theory

Constructivist theory states that individuals construct their understanding of knowledge through interaction. Learning occurs through the construction of meaning not through passive reception. Individuals acquire new knowledge when meaningful and important experiences are happening to the learner (Popkewitz 1998; Ültanır 2012). As a result of those experiences, the learning process starts, enabling an individual to recognize and evaluate what they just experienced. Piaget states

that learning is “understanding the process of discovery or re-construction by re-discovery. In this regard, training as an individual and future individual creativity is important in the construction of knowledge” (Piaget and Coltman 1970). Constructivist learning theory was explored through residents’ interaction with the three visual aids in the virtual environment.

1.12 Conceptual Framework

Energy data must be visualized in a particular format, tailored to residents understanding, for new knowledge to be acquired. Energy, graphical, and data literacy are the main theories grouped together for a resident to understand the energy data embedded within the data visualization. While understanding occurs, new knowledge is formed from a resident utilizing their learning style of choice. While there are many different learning styles such as social constructivism and experiential learning for this dissertation the learning style of focus is constructivist learning. Constructivist learning involves understanding how residents are reading, working with, analyzing, and arguing with the visual aids in the virtual environment to construct new knowledge. The conceptual framework below shown in **Figure 3**, maps out the critical path for understanding data visualization with residential energy consumption data embedded.



A Framework for Interpreting Energy Data Through Data Visualizations

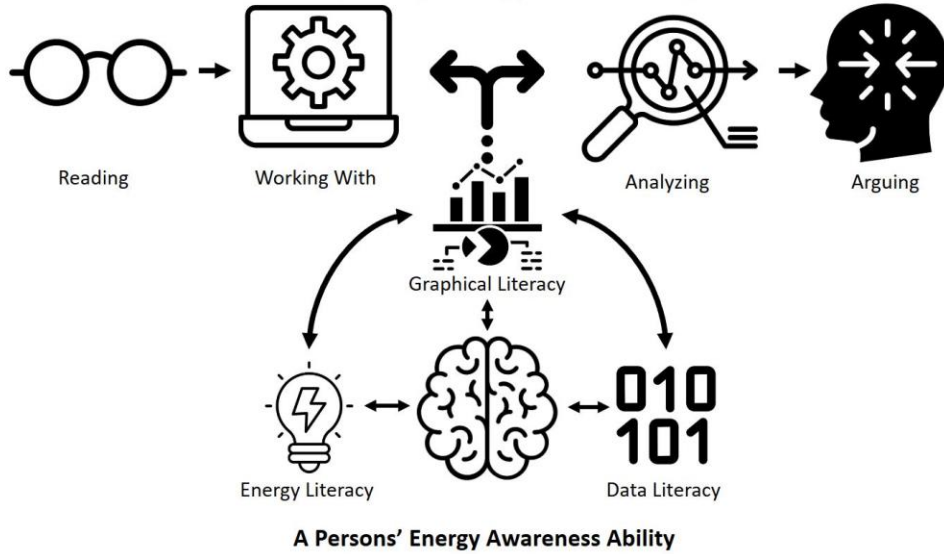


Figure 3: This conceptual framework illustrates how an individual's ability to interpret data visualizations—through reading, working with, analyzing, and arguing—is influenced by their energy awareness, which encompasses their energy, graphical, and data literacy levels.

CHAPTER 3: MANUSCRIPT 1 - RESIDENT ENGAGEMENT WITH ENERGY DATA: EXAMINING HOW 2D VISUALIZATIONS SUPPORT INTERPRETATION AND DECISION-MAKING

Abstract

Utility companies limit how residential energy data is displayed on utility bills minimizing residents understanding of household energy consumption. Utility companies only utilize a subset of data visualization chart types those being a vertical bar, vertical stacked bar, doughnut, and line chart, even though there are other chart types available to convey energy insights. With their being a limited number of chart types exercised; comprehension might not occur due to the person literacy levels. Data visualization used of utility bill should be tailored towards individuals' energy, graphical, and data literacy levels to impact their energy awareness ability. The main goal of this study is to determine how participants are reading, working with, analyzing, and arguing residential energy data embedded within the three 2D chart types: area, bar, and line charts. The data collection method used included a questionnaire which included four questions for each chart type on reading, working with, analyzing, and arguing. The participants chosen for this study involved 32 graduate students from various majors at Virginia Tech University. The results from this study describe the how participants utilized the data visualization components for reading, working with, analyzing, and arguing energy data embedded within. For reading, participants referred to the marker color or legend to extract information. For working with the energy data, participants had trouble computing an answer if they did not understand the energy metric present. For analyzing, participants utilized the axis titles and intervals to compute the answer. And lastly, arguing, participants identified the peaks and valleys, color changes, and on and off periods as

evidence when creating a narrative to support or go against the statement. These operational insights are foundational for utility companies to improve the design of data visualization on utility bills.

1 Introduction

1.1 Data Visualization of Residential Energy Consumption Data

Utility bills data visualizations should be tailored to an individual understanding rather than being standardized. The standardization of data visualization depicts that everyone is going to gather the same conclusion, however that is not reality. There is a need to understand how residents interact with standard data visualizations on utility bills to see where the confusion lies (Egan et al. 1996). There are several components on a 2D data visualization which a person can use to determine the energy consumption insights. A residents' ability to interact with a 2D energy data visualization is a result of their energy, graphical, and data literacy level. A person's energy literacy is built upon their life experience regarding their knowledge, attitude, and behavior towards energy. A person's graphical literacy level is defined as a person's ability to decode information embedded within a visual. And lastly a resident's data literacy involves their ability to understand how the data is produced and what it represents. With individuals having different energy, data, and graphical literacy levels, data visualization must be selected to encompass a person's ability to understand them. Currently utility companies' standard the way energy data is displayed to their customers, which is not inclusive and leaves some residents in the dark. Aggregating energy data and presenting it to customers at monthly intervals is not enabling them to understand how energy is truly consumed throughout their home. Disaggregating the energy data into the circuit level and

visualizing the energy data in a way that is understood by the residents is the first step to create awareness.

Using different data visualizations can create energy awareness for residents to understand how energy is consumed throughout their home. Increasing/impacting a resident's energy awareness enables them to live a life where they know exactly how energy is and should be consumed throughout their home. There is still the narrative going around saying cut those lights up their running up my utility bill, while less attention is applied to that space heater or the constant changing of the thermostat for personal comfort. Those actions really encompass more utilized more energy than keeping the light on. However, residents are not awareness because the energy insights haven't been visualized in a way that inclusive to a resident's level of understanding. These actions need to be visualized in a way so residents can clearly see and recognize the true intended energy consumption of such actions, new mindset can be created to shift energy perspectives.

There is an opportunity to capture the way residents interact with energy data visualizations. The goal of this research study is to determine how individuals are reading, working with, analyzing, and arguing energy data embedded with three 2D data visualizations chart types. The data visualizations include an area, bar, and circular column chart. The energy data compared the energy consumption of pairs of three appliance types. For the lighting appliance, the comparison is between an incandescent bulb and an LED bulb. For the cooking appliance, the comparison is between an air fryer and stove. For the heating appliance, the comparison is between a space heater and heat pump. Different appliance types were used to see if there was a difference in a person's ability to read, work with, analyze, and argue static (lighting appliance) versus dynamic (cooking and heating appliance) energy data. The residents were randomly assigned an appliance type and

asked four questions pertaining to their ability to read, work with, analyze, and argue, each of the three 2D chart types.

Results displayed that individuals who viewed the area chart utilizing the static energy data from the lighting appliance were able to read, work with, analyze, and argue the energy data. Unlike those given the dynamic energy data of the cooking or heating appliance, it was difficult to determine the answers using the area chart. Other insights like the mentioned above are uncovered in the results and discussion section of this paper. This research attempts to identify which of the three data visualization chart types or components of a chart are assist in determining energy consumption insights of appliances.

1.2 Broader Impacts

The way data is visualized creates a direct path to the intended message or an infinite loop where no conclusions can be discovered. In this case energy data is commonly displayed utilizing only a subset of chart types available in the data visualization domain. Those common chart types are line, bar, and doughnut/pie charts. In which residents have difficulty understanding the energy insights embedded with the chart types. Introducing new chart types and even going to the 3D and VR dimension provides residents with new perspectives for revealing energy insights within the energy data. Showcasing new perspectives will align with residents' literacy levels promoting energy awareness/understanding. Aside from the energy domain, these new discoveries will be beneficial to water utilities, financial, and even the healthcare industry. An example for the healthcare industry, what if doctors revealed health insights using a virtual model of oneself. Stating that if you continue your same healthy or unhealthy lifestyle choices, this will be the state of your health in the future, data visualization has the power to do so.

1.3 Intellectual Merit

Residents can acquire different conclusions from reading, working with, analyzing and arguing the same data visualization. This phenomenon is due to residents' energy, graphical, and data literacy level. A residents' energy, graphical, and data literacy level is created and shaped by educational backgrounds and life experiences. The majority of residents do not understand the energy data embedded within the current chart types utilized by the utility companies to showcase monthly energy expenditures on their utility bills. Leaving residents in the dark about how and why they're being charged for their utility bill. Utilizing chart types that aligns with a resident's ability to read, work with, analyze, and argue the energy consumption data will increase the resident's energy awareness. Impacting/increasing the residents' energy awareness will empower them to understand energy utilization in their home with the hope of enabling them to save energy. In addition, utility companies, government agencies, and civil society can adopt these findings to create new policies that revise the way data visualizations are presented to residents, transforming the utility bill.

2. Background

2.1 The current way in which energy data is presented to residents.

Presenting energy data to residents in a general schematic limits their understanding of how energy is consumed in their homes. Utility companies have standardized how energy consumption data is shared with residents. Standardization prevents residents from fully being able to comprehend the energy data displayed on the utility bills. There are tradeoffs between customers' comprehension of the visualization chart type and the accuracy of what is shown/said in the visualization (Egan et

al. 1996). For example, “a bar graph is mainly understood by a larger audience than bell curves, but irregular distributions can result in miscommunication of the bar graph's intended purpose” (Egan et al. 1996). However, utility companies only use a subset of the available data visualization chart types to represent residents' energy data. Results from (James, 2024 insert my paper) involving a content analysis identified four commonly used charts in utility bills (vertical bar, vertically stacked bar, doughnut, line. Besides those four chart types discovered, eight additional chart types were uncovered in searching through literature outside of the energy domain that have the potential to visualize energy data which were the Boxplot, Bullet, Funnel, Heatmap, Horizontal Stack Bar, Radar, Scatter, and Treemap.

2.2 Residents Have the Desire to Understand their Energy Consumption

Residents have the desire to understand why their monthly utility bill is the amount it is. According to (Foster and Alschuler 2011), “41% of customers looked at a table or graph to compare consumption from their previous months to understand unusual bills”. While customers are looking at graphs displaying energy data, another study by (Egan et al. 1996), “discovered that at least half of the participants had problems understanding charts displaying energy data”. Even if utility companies choose to incorporate the additional chart types discovered from the content analysis, residents may still have trouble understanding the energy consumption insights, because of their ability interact and comprehend with the energy data embedded with the data visualization.

2.3 Understanding how individuals Interact with Energy Data Visualizations

A person's ability to interpret and comprehend energy data on a visualization to split into four categories: **Reading, working with, analyzing,** and **arguing**. There is a uniform chain effect with each of the categories, meaning that a person could utilize another category while answering a

question dealing with another category. And within the four categories are three subcategories depict a person's reasoning behind working, analyzing, and argue, those subcategories are: graphical, energy, and data literacy.

2.3.1 Reading

First starting with the category reading. Before processing occurs, a person must be able to read information on the data visualization. Reading data involves understanding what data is according to (Bhargava 2015). Whether that's identifying the axis titles, marker shape and sizes, legend, colors, or energy metrics. Reading the data on the visualization involves "lifting" information from a graph to answer an explicit question, for which the answer is there on the graph (Curcio 1987). (Wainer 1992) conducted a study that focuses on reading the graph as data extraction when answering elementary format questions. Elementary format questions only introduce a single element of component (Bertin 1983). In this study participants will be asked using elementary format questions to read the energy data within the visualization, to identify a single specifier, just as (Carswell 1992) conducted, example question: What is the value of pie slice B? Then after reading the data, participants will be working with the data to create insights based on the values identified within the chart.

2.3.2 Working With

Working with energy data embedded within a visualization reveals more in-depth energy insights than just reading the data. "Working with data involves creating, acquiring, cleaning, and managing the data" (Bhargava 2015). A study conducted by (Gillan and Lewis 1994) "from their Mixed Arithmetic Perceptual (MA-P) model principle number two states that interacting with graphs is the search, encoding, arithmetic operation, and response components on task that require

the user to calculate a value base no data identified from the graph.” In working with graphs, the user can interpolate the data. For interpolation of the data, one must not only process information in the documents but also make document-based inference or draw on person background knowledge of the data presented (Friel et al. 2001), in the context of this research study data visualization will serve as document. A persons’ background knowledge of energy, data, and graphical literacy levels plays a significant role in understanding the importance of energy data embedded within the data visualization. Discovering the correct answer to a problem is one defeat but understanding the implications of the answer is essential.

2.3.3 Energy Literacy

Energy literacy is defined as having basic energy awareness, which includes having the ability to identify the impacts of energy production and consumption on the environment, from one’s energy behaviors. (DeWaters and Powers 2011). “An individual’s energy ability is beyond their scientific understand of energy, it includes having a clear understanding of energy systems and the aptitude and willingness to use that knowledge” (DeWaters et al. 2013). “One’s energy literacy level consists of three elements: knowledge, attitude, and behavior” (Martins et al. 2020).

- Knowledge is a person’s understanding of scientific concepts are related to energy.
- Attitude is a person’s mindset for making decisions about energy.
- Behavior is the way a person produces and consumes energy through usage.

“According to the national energy literacy survey, the average energy literacy score for high school students and recent graduates is 48.8 out of a maximum score of 100” (Richards et al. 2018). “The energy literacy score dependent on demographic differences including age, ethnicity, income, political affiliation, geography, and parent education level” (Richards et al. 2018). A study conducted by (Egan et al. 1996) discovered that half of participants had trouble understanding

energy data visualizations. Energy literacy is one form of literacy people struggle with when working energy data. Another struggle aligns with understanding the energy data embedded within graphs is also a concern.

2.3.4 Graphical Literacy

There are many ways a data visualization can be designed to display energy consumption data, but the approach needs to be tailored towards resident's graphical literacy level. "Graphical literacy is defined as the ability to read and write (or draw) graphs" (Fry 1981). Graphical literacy is also defined as "the visual decoding of information encoded on graphs" (Cleveland and McGILL 1984). Therefore, different conclusions can be drawn from two people analyzing the same visualization based on their enteral decoding process. A comprehensive visualization of energy data is critical for residents to understand where they are currently using energy and how they can change their energy consumption behaviors to reduce energy consumption. However, "are no clear design requirements to develop an energy visualization" (Murugesan et al. 2014). With there being no design requirements, visualizations are not created with the intent to convey energy insights to create a sustainable solution. Besides resident's graphical literacy of visual elements on a graph, data literacy also contributes to one's knowledge of the textual and numerical values located on data visualizations.

2.3.5 Data Literacy

The textual and numerical values on an energy data visualization must be understood for residents to fully understand the intent message on the visual. (Bhargava 2015; Wolff et al. 2016) have defined data literacy from many domains. However, no definition of data literacy fits contains the use of residential energy data. Earlier in research (Bhargava 2015) defined data literacy as the

“ability to read, work with, analyze and argue with data”. Later on (Bhargava 2015) newly definition of data literacy which is “the desire and ability to constructively engage in society through or about data” is moving closer to encompassing resident energy data. Another author’s (Wolff and Kortuem 2015), definition moves evener closer to discussing residential energy data, by discussing reading graphs and charts to draw conclusions and recognize errors in the data. Depending on a person's ability to **read, work with** along with their **energy, graphical, and data literacy** level their ability to analyze energy data may be misrepresented.

2.3.6 Analyze

A person must have an understanding of the energy data before they are able to analyze the data. Meaning that (1) they must be able to read and work with the data, and (2) their energy, graphical, and data literacy level enables them to interpret the results they received from reading and working with the energy data. Analyzing data was once defined by (Bhargava 2015) as utilizing an analytic operation such as filtering, sorting, aggregating, comparing data. Currently (Bhargava 2019) defines analyzing data as the ability to take a data set and perform algorithmic operations on it, both simple and complex. Five of the algorithmic operations for performing analyses are five types of analyses:

- “Statistical analysis (e.g., to order, rank, or sort);
 - Temporal analysis answering “when” questions (e.g., to identify distributions over space);
 - Geospatial analysis answering “where” questions (e.g., to identify distributions over space);
 - Topical analysis answering “what” questions (e.g., to examine the composition of text);
- and

- Relational analysis answering, “with whom” questions (e.g., to examine relations; also called network analysis)” (Borner et al., 20219).

These are five of the analysis process residents could utilize when performing algorithmic operations such as filtering, sorting, aggregating, or comparing the energy data. After analyzing the energy data, the final step is to argue with the energy data, bring every category of reading, working with, and analyzing together creating a final narrative.

2.3.7 Argue

A resident must have a holist understanding of reading, working with, and analyzing energy data embedded within a data visualization before they can argue the energy data. Arguing with data is defined as using data as evidence in supporting a narrative intended to communicate a message, draw conclusions, and compare from the data to a particular audience (Bhargava 2015, 2019; Wolff and Kortuem 2015). Arguing with energy data embedded within visualizations is an unfamiliar practice in the residential energy domain. Residents rarely argue with their energy provider, they may complain to themselves or their neighbors but never to the provider. Because residents cannot gather a narrative due to the energy, graphical, and data literacy misalign with the data visualization showcasing the energy data. Creating graphs that put residents in the position to argue their energy data is needed to bridge the gap between (1) residents understanding how energy is consumed throughout their home and (2) learning actionable steps to take reducing their energy consumption usage.

3. Conceptual Framework – Understanding Energy Insights from Data Visualizations.

Given a person's energy, graphical, and data literacy level a 2-dimensional data visualization may not align with their understanding, this is where the exploration of three different chart types will

be utilized to see how residents are **reading, working with, analyzing, arguing** energy consumption data, shown in **Figure 4**. To determine if participants are reading, working with, analyzing, and arguing the energy data, the operationalization of each must be defined.

To operationalize the read action: Reading involves extracting a single data point or elements that is an obvious answer from the graph.

To operationalize the work with action: Working with involves calculating a value from pulling two or more data visualization components from the data visualization.

To operationalize the analyze action: Analyzing involves utilizing an algorithmic operation to filter, sort, aggregate, or compare data to identify trends or relationships.

To operationalize the argue action: Arguing involves creating a narrative from the data visualization components to provide evidence to support.

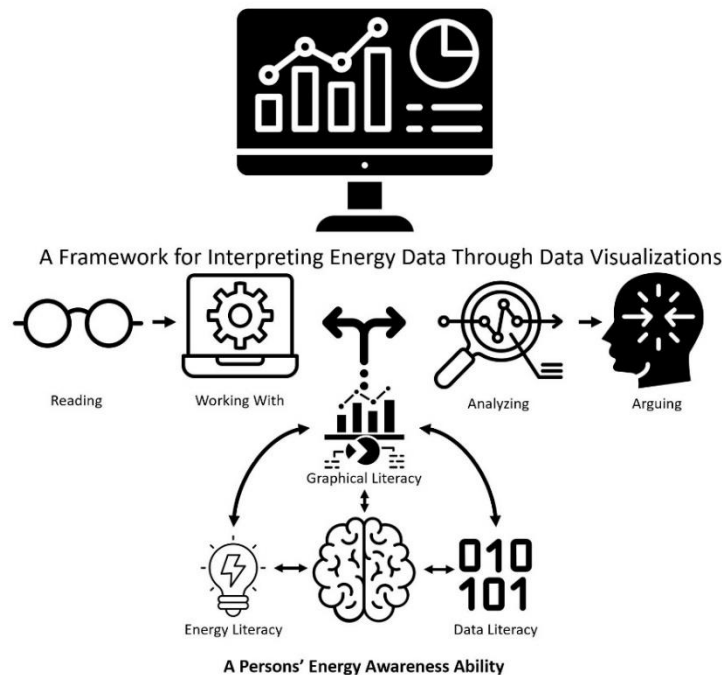


Figure 4: Conceptual framework for interpreting energy data throughout data visualizations which impacts a person's energy awareness ability.

4. Methods

Research Question #1: How do residents interact with data visualization components for reading, working with, analyzing, and arguing energy consumption data of household appliances?

Objective #1: To determine how participants are **reading, working with, analyzing, and arguing** energy consumption data embedded within three data visualization chart types.

4.1 Research Approach:

- First, I randomly assigned each participant an appliance categories lighting, cooking, or heating. Each category visualized an hour of the appliance pair's energy consumption data, on three data visualization chart types (area, bar, and circular column chart). Participants switched categories if they had no prior knowledge of the appliance type.
- Next, participants were given a semi-structured interview where they had to answer 4 questions regarding: reading, working with, analyzing, and arguing for each of the three chart types.
 - **Read:** Determine what two appliances are being compared or the units of the x and y axis.
 - **Work with:** Determine the average hourly energy consumption of the appliance.
 - **Analyze:** Determine how much total or the difference in energy was consumed from period A to period B.
 - **Argue:** How would you provide evidence to argue or justify the following statement: Johnny believes that appliance A consumes more energy than appliance *(Exact questions for each category are provided in the appendix section A.1)*
- After participants finished with the semi-structured interview, they took the post survey to see if the data visualization impacted their ability to estimate the energy consumption of

the appliance pair, shown in **Figure 5**. The sample size was 32, 11 participants for the lighting, 11 participants for cooking, and the remaining 10 participants were assigned to the heating category.

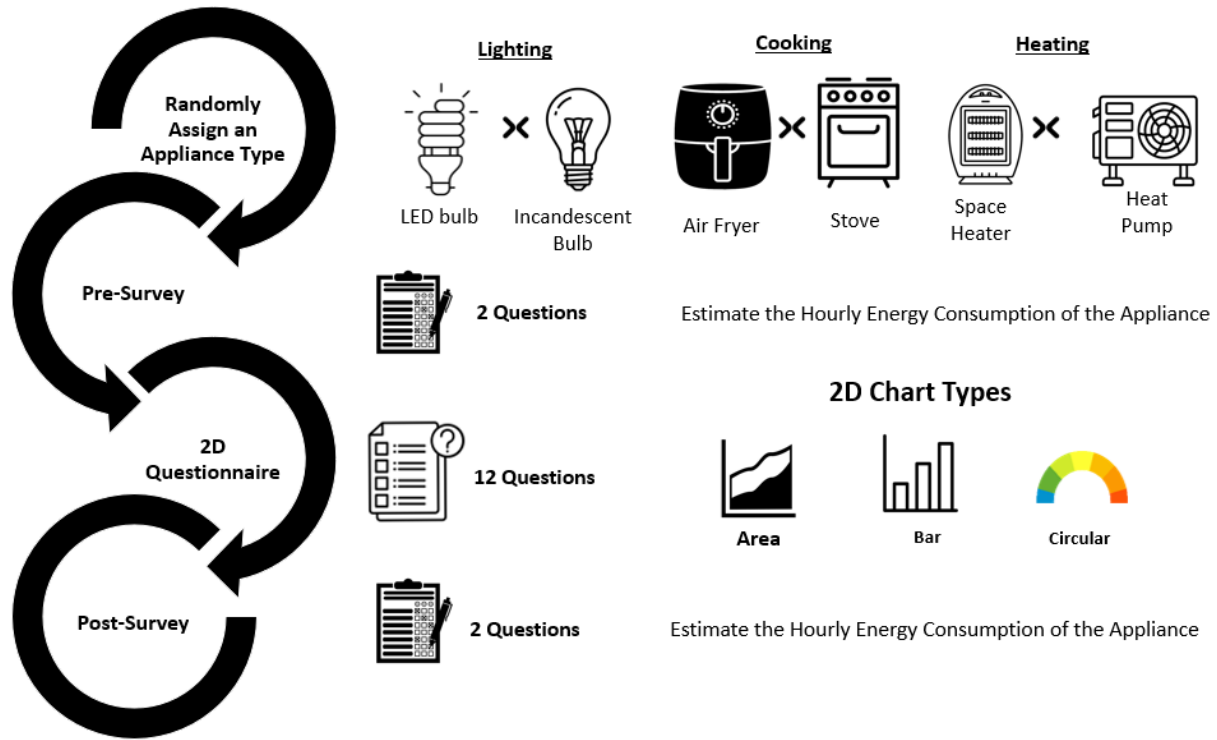


Figure 5: Displays the four steps in the research experiment.

4.2 Research Material

4.2.1 Categories of Appliances:

- (1) **LED vs Incandescent light bulb**
- (2) **Space Heater vs Air Conditioner**
- (3) **Stove vs Air fryer**

4.2.2 Data Visualization 2D chart Types

- The **2D** data format utilized three different chart types to compare the energy consumption of the 3 pair appliances. The area and bar chart were chosen because utility companies

utilize these charts to show case time series energy data, shown in **Figures 6 and 7**. Utility companies utilize these chart types because they display historical comparisons, show changes over time, and display distributions (Egan et al. 1996; Foster and Alschuler 2011; Herrmann et al. 2018). While these bar charts are used by utility companies (Egan et al. 1996) found that at least half of participants had problems comprehending them. And the circular column chart, shown in **Figure 8** was chosen because its similar to the shape on the speedometer in cars, which is familiar to a large audience of people. In addition, with the circular column chart changing color intensity, shape, and size our brain immediately recognizes the changes (Cleveland and McGILL 1984; Ware 2004; Archambault et al. 2015).

Lighting Category

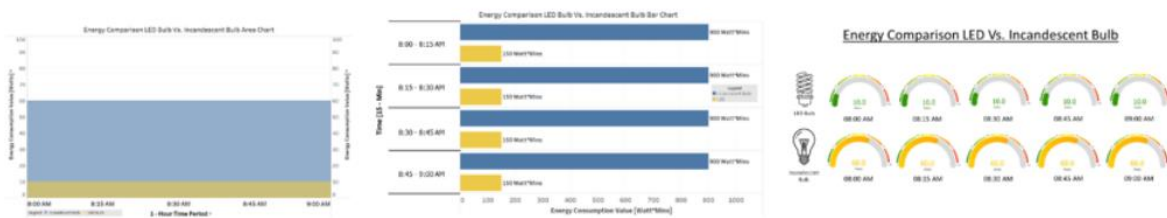


Figure 6: The three chart types utilizing the lighting appliances energy data. (Larger print graphs are displayed in the appendix section A.2)

Cooking Category

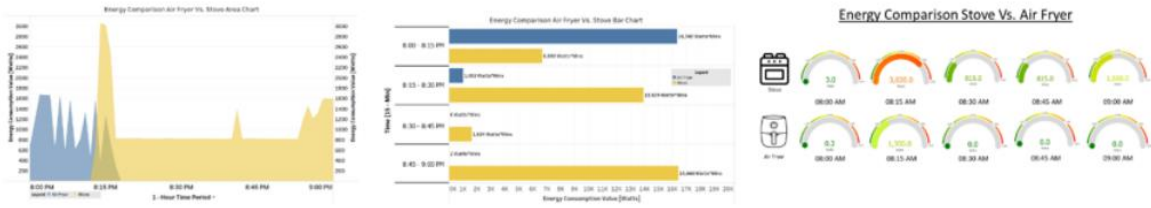


Figure 7: The three chart types utilizing the cooking appliances energy data. (Larger print graphs are displayed in the appendix section A.2)

Heating Category

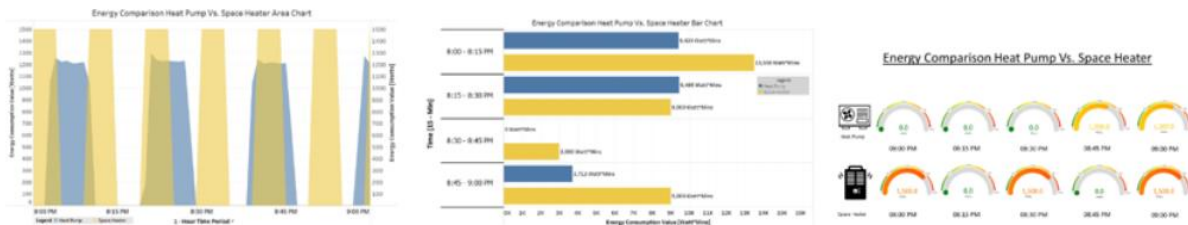


Figure 8: The three chart types utilizing the heating appliances energy data. (Larger print graphs are displayed in the appendix section A.2)

4.3 Data Collection

4.3.1 Pre-Post Survey

Pre-Post Survey was utilized to evaluate residents' energy estimation of the household appliance pair they were assigned before and after interacting with the three data visualization chart formats. The survey will be built upon (Attari et al. 2010b) work that focuses on public perceptions of energy consumption and savings. Results from Attari study revealed that participants had very minor overestimates when actual energy use was low and large underestimates when actual energy use was high (Attari et al. 2010b). The survey will ask participants to estimate the amount of wattage consumed within one hour by choosing a whole number between 0 and 3000 watts. After

participants took the pre-survey, they interacted with three chart types displaying 1 hour of energy data for the appliance pair they were assigned.

4.3.2 Semi-Structured Interview

I conducted semi-structure interviews to ask participants questions about reading, working with, analyzing, and arguing the energy consumption data of the appliance pair for each of the three chart types, asking 12 questions. Semi-structured interviews provide an opportunity for the interviewer to ask questions to uncover critical information from the participants' experience in the research study. "Semi-structured interviews enable researchers to ask questions like 'What happened then/before/after,' or 'can you say a bit more about...?'" (Anderson and Kirkpatrick 2016). For example, one question was "Determine what two appliance are being compared, and after the answer was received". The follow up question was "what component of the chart did you use to determine your answer?"

4.4 Data Analysis

4.4.1 Analyze Semi-Structured Interview - Qualitative Coding

Process Coding

To determine how participants interacted with the data visualizations process coding was used as the first cycle coding method. Process Coding – uses gerunds("ing" words) exclusively to connote observable and conceptual action in the data (Elliott, 2018). Processing coding was utilized to review the actions participants performed to answer the questions regarding reading, working with, analyzing, and arguing using the data visualization chart types.

Pattern Coding

Pattern coding validates the first-round process coding process by looking at the “bigger picture” configuration. “Pattern coding has four important functions: (1) it condenses large amounts of data into smaller number of analytic units, (2) it gets the researcher into analysis during the data collection stage, (3) it helps the researcher elaborate a cognitive network, and (4) it lays the groundwork for cross-case analysis surfacing common themes and directional processes” (Miles et al. 2020). For example, the qualitative data collected shows evidence that the participant always compares the sizes of markers when arguing or justifying their response to a particular question. Therefore, we can include that the participant focusing on marker size when arguing with a data visualization.

4.5 Validity and Reliability

The validity and reliability of this research design are critical to confirming that the conclusions gathered are accurate and verified. I utilized the Q3 framework to guide my justifications for (1) procedural validity, (2) ethical validity, and (3) process reliability within the research design.

“**Procedural validation** concerns feature of the research design that inherently improves the fit between the reality studied and the theory generated (Walther and Sochacka 2014)”. To ensure procedural validation, I administered a questionnaire to identify participants' ability for **reading**, **working with**, **analyzing**, and **arguing** energy data embedded within three different chart types. The three different chart types are area, bar, and circular column chart. Utilizing three different chart types enables an authentic view of a participant's ability to answer the questions. For example, participants may excel at reading, working with, analyzing and arguing energy data when using an area chart but have complications utilizing a circular column chart. Having three different chart types creates a wide representation of participants' ability to understand different data visualizations format using energy data.

“**Ethical validation** is defined as the concerns aspects of integrity and responsibility throughout the research process (Walther and Sochacka 2014)”. To ensure ethical validation I will keep the motivation and intentions clear. The motivation for this study is to determine how participants are reading, working with, analyzing, and arguing energy data embedded within different data visualization chart types. Capturing this qualitative data helps achieve the end goal, which is to create energy data visualization that adheres to a person's energy, graphical, and data literacy levels.

“**Process Reliability** concerns the mitigation of random influences on the research process (Walther and Sochacka 2014)”. To ensure process reliability, I utilized intercoder reliability. “Intercoder reliability improves the systematicity, communicability, and transparency of the coding process” (O’Connor and Joffe 2020). Intercoder reliability is measured by having two or more coders use the same codebook to code the content using transcripts from the semi-structured interviews then calculate the level of agreement among coders (Mao 2017). The first author developed the codebook to evaluate and identify themes. Dr. Paige and members of my research team reviewed the codebooks too while navigating throughout the semi-structured interview transcript search for themes. Having another researcher check and review codes in the process will support the validity of this research study. Validation in the early generation of codes ensures reliability for identifying themes throughout the pattern coding process.

Intercoder Reliability Protocol

- 1) Select two or more coder
- 2) Provide instructions for understanding the coding process.
 - a) Include and review codebook with coders
 - b) Include semi-structure interview transcript

- c) Include document for coders to write down their results.
 - i) 0 (no agreement) to 1 (perfect agreement)
- 3) Compare the agreement the coders
- 4) Insert results into the percent of agreement and intercoder reliability formulas.

5. Results

5.1 Pre-Post Survey Results

5.1.1 Lighting Appliance Results

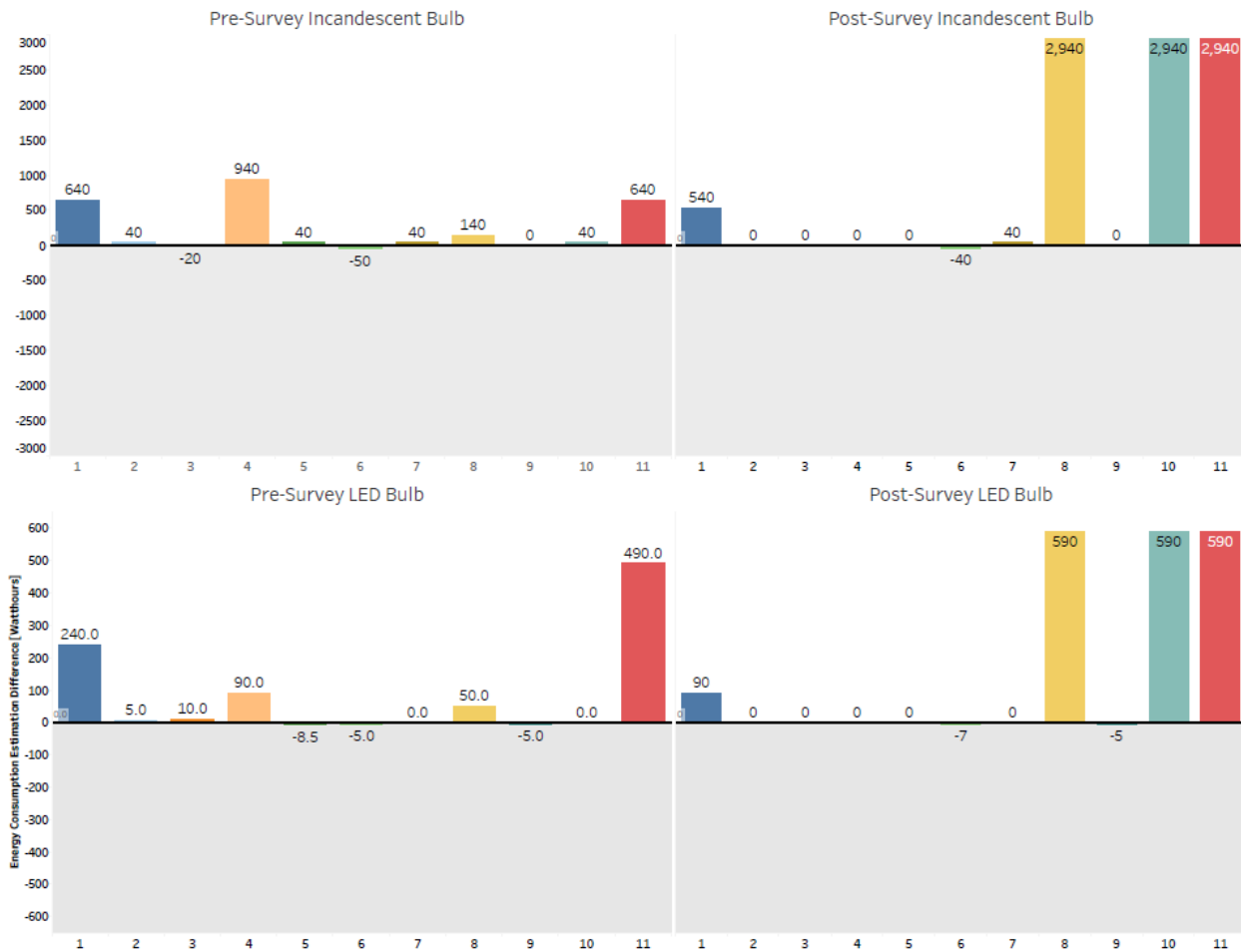


Figure 9: Displays the results of the pre-survey on the left side and the post survey results on the right side of the figure. The incandescent bulb is on the top and the LED is on the bottom of the figure.

5.1.2 Cooking Appliance Results

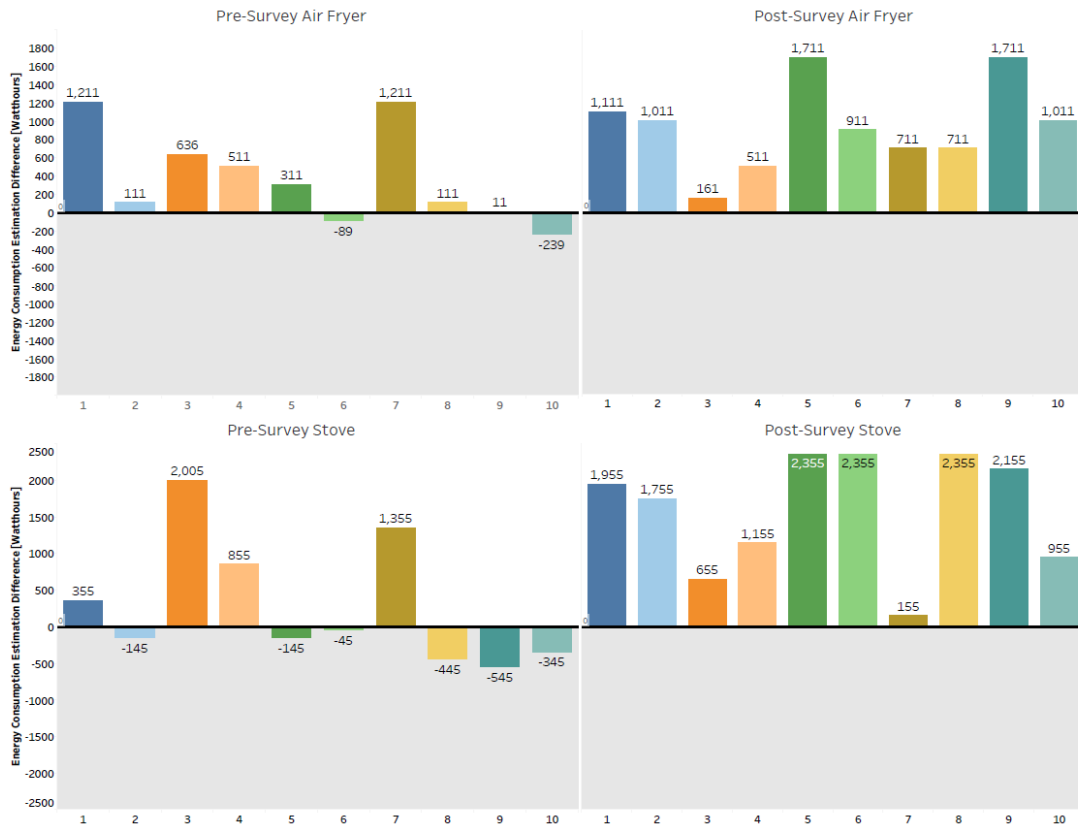


Figure 10: Displays the results of the pre-survey on the left side and the post survey results on the right side of the figure. The air fryer is on the top and the stove is on the bottom of the figure.

5.1.3 Heating Appliance Results

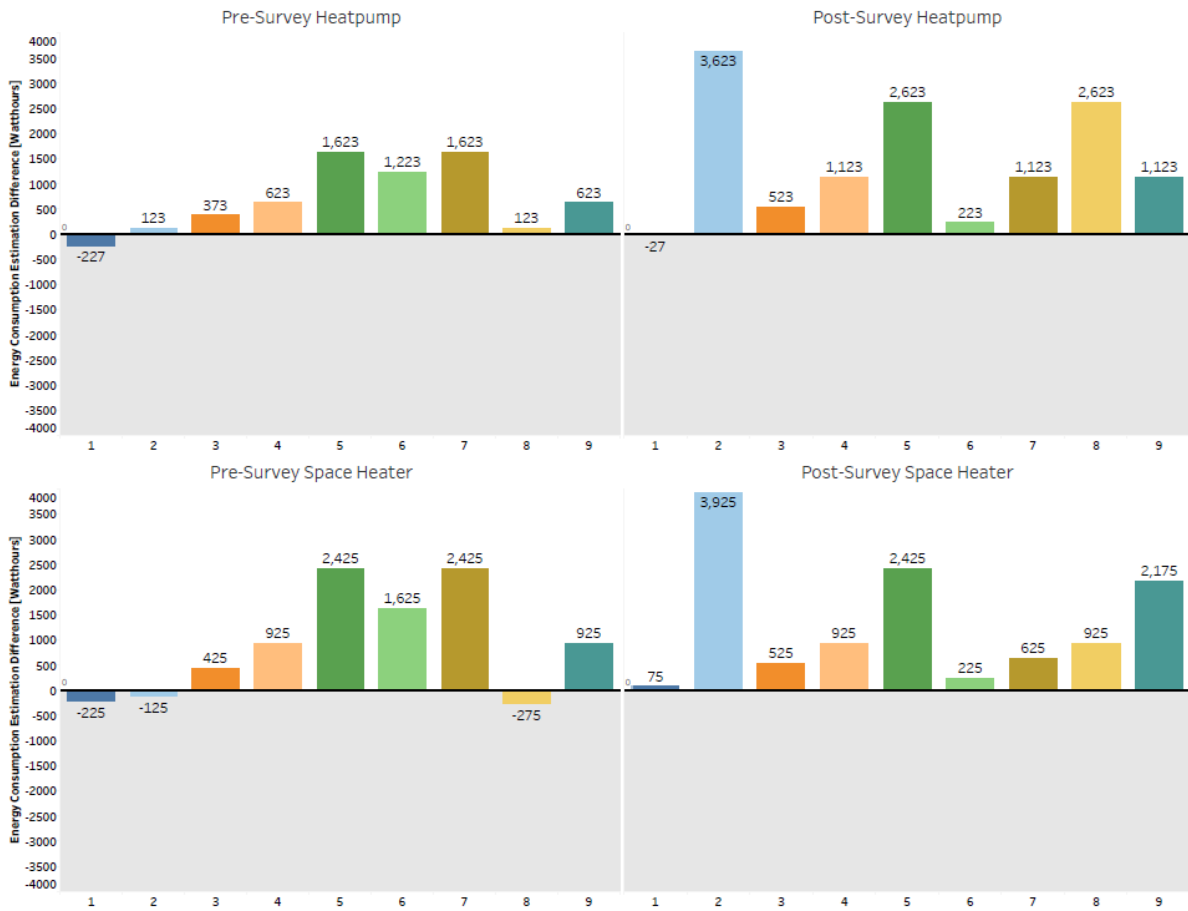


Figure 11: Displays the results of the pre-survey on the left side and the post survey results on the right side of the figure. The heat pump is on the top and the space heater is on the bottom of the figure.

5.2 Qualitative Coding Results

1st Round Process Coding and 2nd Round Pattern Coding Results

5.2.1 Reading

5.2.1.1 Process Codes

Identifying ...

time interval, title, marker color, marker shape, marker size, legend and axis title.

5.2.1.2 Pattern Code

When participants were asked to read the energy data within the visualization to determine which two appliances are being compared and the units on the x and y axis, **participants extracted information from the graphical and textual components** (Farahani et al. 2023).

5.2.2 Working with

5.2.2.1 Process Codes

Identifying ...

peaks and valleys, marker color, constant energy consumption, and axis time intervals.

Utilizing ...

addition, division, and multiplication.

5.2.2.2 Pattern Codes

When participants were asked to work with the energy data within the visualization to determine the average hourly energy consumption of the appliances, **participants extracted information from the graphical and textual components and calculated the value using mathematical operations.**

5.2.3 Analyzing

5.2.3.1 Process Codes

Identifying...

color, time interval, energy consumption units.

Utilizing ...

addition, subtraction, division, multiplication, and scaling.

5.2.3.2 Pattern Codes

When participants were asked to analyze the energy data within the visualization to determine the total energy consumption and energy difference between two-time values, **participants extracted information from the graphical and textual components and calculated the value using mathematical operations.**

5.2.4 Arguing

5.2.4.1 Process Codes

Comparing ...

energy consumption scale, marker size, area size, time interval, energy metrics, hour energy consumption totals, peaks, and graphs curves.

5.2.4.2 Pattern Codes

When participants were asked to argue the energy data within the visualization to provide evidence to argue or justify the following state: Johnny believes that appliance A consumes more energy than appliance B, **participants utilized the graphical and textual components as evidence in creating a narrative to support or go against the statement.**

6. Discussion

6.1 Pre-Post Survey

The pre and post survey results informed the researchers that some participants were able to understand the energy data embedded within the three chart types by their ability to underestimate or overestimate the energy consumption within an hour. The majority of participants were able to identify the correct amount of energy consumption by the lighting appliances. These results let us know two things participants had a well understanding on the amount of energy a LED and incandescent bulb consumed within one hour due the light over estimation as a whole on the pre-

survey, shown in **Figure 9**. And second the scores of 0, shown in **Figure 9** on the post-survey results side inform the researchers that majority of participants understood were able to read, work with, analyze, and argue the 3 chart types to gather the correct energy consumption of the lighting appliances within one hour. In addition, there were three participants that overestimated tremendously during the post-survey, displaying that when **working with** the energy data to determine the average they used addition solely instead addition and division to determine the average.

Participants overestimated the hourly energy consumption more after viewing the three chart types of cooking and heating appliances. This informs the researchers that the three chart types skewed participants hourly energy consumption understanding. One cause and effect is that the cooking and heating appliances energy data is dynamic rather than static like the lighting appliance data, should in **Figure 10 and 11**. Dynamic energy data causes the markers on the chart to have various sizes and shapes characterized, shown in **Figure 7 and 8**, which affects a participant's ability to compute the average utilizing the chart types. Another cause and effect are the time duration period of the appliances, for example the air fryer appliance was only on for a duration of 18 minutes. And depending on the chart types of different calculations had to be performed to determine the average. For the area chart, to determine the average the participant needed to compute the area under the curve in that hour interval. For the bar chart to determine the average, the participant needed to use addition to add the energy consumption of the bars. For the circular column chart to determine the average, participants needed to use addition to add the energy consumption of the 5-time intervals and divide by 5. The next section will discuss how participants were reading, working with, analyzing, and arguing the energy data embedded within the three chart types, which

is another source of evidence to explain the over estimation of the post survey results of the lighting, cooking, and heating appliances.

All four of the categories reading, working with, analyzing, and arguing stemmed from one another. First category of **reading** the energy consumption data involves extracting a single data point or elements that is an obvious answer from the graph, second **working with** is defined as involves calculating a value from pulling two or more data visualization components from the data visualization, and **analyzing** involves utilizing an algorithmic operation to filter, sort, aggregate, or compare data to identify trends or relationships. And finally, **arguing** involves creating a narrative from the data visualization components to provide evidence to support. The discussion section will explain how the process and pattern coding reveal insights from the participants transcripts for each of the four categories.

6.2 Reading

Reading is the first fundamental basic operation that needs to take close for an individual to understand what information is presented on a graph. Reading symbolizes identifying what data or information is represented on the data visualization. For reading participants were asked three different questions related to the three chart types. For the area chart participants were asked to **determine what two appliances were being compared**. For the bar chart participants were asked to **determine the units on the y-axis**. For the circular column chart participants were asked to **determine the units on the x-axis**. When answering the questions, participants identified the legend when determining what appliances are being compared. Legends are a crucial bridge

between data and marker shown of the visualization (Liu et al. 2024), a participants must understand the legend to identify meanings of the markers.

Participant #18 - *It's the heat pump versus the space heater.*

Joseph James - *Okay, and then how did you find that answer?*

Participant #18 - *using the legend that we have here and the different colors.*

Participants also referenced the marker's color, but still needed to read the legend to identify what colors represented the appliances. Therefore, a legend is always needed when comparing two or more appliances/variables. When participants were asked to determine the units on the x or y axis, many identified the axis title on the chart types. Other participants went a step further and identified the actual time series interval.

Participant #26 - *Okay, so the x axis, it refers to the time... So, like time difference increasing with the positive axis. So, for each 15 minutes, there are the records for energy consumed in a circular graph. So, the first one is for LED, consumes 10 watts at 8pm and for 815 it's also 10 hours. 830 it's 10 hours. So, in each 15 minutes is consuming the same amount of watts, okay? 10 hours. And for incandescent bulbs it consumes 60 watts for each 15 minutes.*

Extracting the axis time interval and not just the axis title enables participants to better understand the context of the visualization, which is needed when a resident begins working with the energy data.

6.3 Working with

For an individual to work with energy data they must first **read** the energy data embedded with the data visualization. After a participant reads the data next, they can determine what operation method they will utilize to work with the data. In working with graphs, participants extrapolated or interpolated the energy data to answer the questions (Friel et al. 2001). The question for the working with energy data category was to **determine the average hourly energy consumption of a given appliance**. This question made sure the participants observed the entire data visualization to compute the answer. When computing the average, participants utilized the mathematical *operations of addition, multiplication, and division*. For computing the average depending on the chart type some participants had difficulty due to the units being displayed. The area chart displayed 1-hour period on the x-axis and watts on the y-axis, the bar chart displayed watt*mins on the x-axis and 15-minute period of the y-axis, and the circular column chart displayed watts and instantaneous time on the x-axis. The difficulty stems from the participants' energy-graphical-data literacy levels, even though the question clearly states determine the average **hourly** energy consumption. Some participants converted the calculated answer into hourly units, while others were amazed at the average they calculated and disregarded the units all together.

Participant #14 - *So first I was just checking that my units are all the same for the stove. So, which is good. And then to compute the average, I'm going to sum up all the time bars. So that's 6690, plus 13,929, plus 1634, plus 16444, that gives me like a little over 380,000 divided by four is 16,486 watts per minute.*

Using energy metrics align with a participant understanding enables accurate operations to be performed when calculating averages. Understanding how residents work with the energy data embedded with the graphical and contextual visualization components to calculate the average is essential, when moving to the next category analyzing energy data. This sequence is a ripple effect

for example, if a person can't read the visualization, their percent of successfully work with the data decrease, which leads to more decreasing ability for the resident to analyze the energy data.

6.4 Analyze

For an individual to analyze energy data they must be able to **read** and **work with** the energy data. The question for analyzing the energy data was to **determine the total or energy consumption difference between a specific time window**. Most participants utilized the *mathematical operations of subtraction or addition*. Before they performed the mathematical operations the participant read the chart to extract the specific appliance and time window. Multiple participants first identified the axis interval on the chart types to determine the energy consumption level for the given appliance. For the bar and circular column chart calculating the energy consumption difference between two time periods was easy because x and y-axis respectively are broken down into specific time intervals.

Participant #6 - *Written here on the graph, 815 to 830.*

Participant #9 - *815 to 830 I already have it given here, so it's 9000 more.*

Unlike the area chart where participants had to determine the area under the curve to calculate the total energy consumption. When there is a need to show the total or difference in energy consumption a bar or circular column chart is the obvious choice because the charts are easily readable for quick analysis.

Participant #25 - *See, so obviously the units here are watts per minute. So here it there are 15 minutes.*

So, I will use the 1003 to multiple 15. Then we can calculate the total usage three, multiple 15 equals to 15,045, the new unit is watts. However, if the energy data is constant then an area chart would be another

valid option for calculating the total or difference in energy consumption because to discover the answer the participants would simply have to calculate the area of a rectangle. However, the participant may not know how to calculate the area, if this is the case a bar or circular column chart will suffice. And lastly tying everything together the argue category.

6.5 Argue

For an individual to argue the energy consumption data within the visualization they must have been able to **read**, **work with**, and **analyze** the data previously. The prompt given to the participants stated that Johnny believes that one appliance consumes more energy than the other appliance. Next the participant had to provide evidence from the data visualization to argue or justify the prompt. Even though the category **analyze** definitions contains operation compare, participants also compared the graphical and contextual components to provide evidence when arguing their case creating a narrative for support. Tracing the pattern of the area chart allowed participants to compare the peaks and valleys of the appliance pair to determine which appliance consumed the most energy. In addition, participants compared the timeframe in which appliances are turned on and off was another guiding principle for stating the case.

Participant #23 - *So, I agree with him, since the stove consumes more energy. So, I would show him this energy comparison chart for the stove. And the stove turned on at 815 it went up to almost 3000 watts. And then he used air fryer at the same time, and then it just went up to 1300 watts. So, the difference is almost double. So that's why I would agree that the stove uses more.*

The chart types that displayed this principle the most explicitly was the area and circular column chart, displaying the minute interval and instantaneous time data respectively for an hour period, provided evidence for the participant to argue or justify. And finally, participants used color to justify residents' response for supporting or going against the prompt. The use of color was an

obvious comparison on the bar and circular column chart. For the bar chart one can easily compare the amount of color shown to determine which appliance consumes more energy. For the circular column chart, one can compare the frequency of colors shown, regarding the green, yellow, and red colors, increasing in amount of energy consumed, respectively.

7. Conclusion

A person's energy, graphical, and data literacy level is based upon their educational and life experiences, meaning that one can obtain different results when reading, working with, analyzing, and arguing the energy consumption data embedded within the chart. It is unfair to use standard data visualization because individuals will arrive at different conclusions from the intended message based upon their literacy level. The key finding for this study are:

- When **reading** a data visualization, participants utilized important data visualization components such as the legend and marker colors to compare the variables. Therefore, all data visualizations should have a legend and marker colors to differentiate between the variables.
- When **working with** the data visualizations, participants were confused when they discovered how the energy metrics were presented, particularly when computing the average. To minimize confusion, units must be associated with a resident's energy, graphical, and data literacy level to ensure complete understanding, when calculating the average. For constant consuming appliances like lighting, participants could easily determine the average by reading the value from the any of the three chart types. However,

for dynamic consuming appliances like the heating and cooking appliances, additional effort was needed to be done to determine the average.

- When **analyzing** the data visualizations, participants successfully determined the energy total or different over a given period. It is important to ensure that the axis title aligns with the participants understanding and is formatted in a way that facilitates quick calculations.
- When **arguing** the data visualization, participants mention the utilization of outlining the chart to identify peaks and valleys, look for the on and off periods, and they point out of color. For example, when creating a data visualization to argue energy consumption trends utilize an area chart with meaning time intervals, and colors should be applied to distinguish peaks and valleys for quick observations.

The study was constructed by certain limitations. First, the scope of the study was intended to target residents of affordable housing. Collaborating with affordable housing residents was desired because there is a need to reduce spending on utility bills to fund essential areas in their lives, such as healthcare and savings (Hernández and Phillips 2015). However, due to time and management conflicts, graduate school students were chosen as participants. Additionally, we only chose to focus on three chart types to establish a baseline of understanding before introducing more advanced data visualization chart types and techniques. Gathering qualitative data on how participants read, worked with, analyzed, and argued the energy data provides insights for moving forward to developing a residential energy data visualization framework.

Implications and Future Work

The results of the study contributed to the evidence supporting the residential energy data visualization framework. The first piece of evidence was identified during the content analysis of the 11 largest utility companies where 4 chart types were identified in utility bill and 8 other chart types were uncovered in data visualization literature outside of the energy domain, that have the capacity to visualize energy consumption data. The goal of the Residential Energy Chart Framework (RECF) is to create a data visualization framework, where charts can be developed to match a person's current energy-graphical-data literacy level, revealing how energy is being consumed throughout the home, resulting in complete understanding. Future collaboration with a utility company is valuable and needed to prototype and further evaluate the three chart types and as well as other chart types, to determine if the results from the study can be expanded across different demographics. Creating data visualization with the end user in mind is needed to convey transparent messages allowing the reader to read, work with, analyze and argue the energy data.

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CHAPTER 4: MANUSCRIPT 2 - DECODING ENERGY DATA: HOW RESIDENTS USE VISUAL AIDS IN VIRTUAL ENVIRONMENTS TO UNDERSTAND HOUSEHOLD ENERGY INSIGHTS

Abstract

Since energy is invisible to the human eye, misconceptions about its utilization can easily go unnoticed, leading to miscalculations. There is an opportunity to reimagine how energy data is displayed to residents, through the use of virtual reality. Energy data can be embedded within visual aids in the virtual environment to showcase how energy is consumed throughout household appliances. This study aims to determine how participants interact with energy data embedded within visual aids in the virtual environment looking at their ability to read, work with, analyze, and argue energy data. Research has shown that our brain immediately processes color, shape, size, and orientation when viewing a visualization, which informed the design of the three visual aids used in this study: (1) color coding, (2) electricity flow, and (3) power meter. The appliances used include lighting (LED vs Incandescent Bulb), cooking (Air fryer vs Stove), and heating (Space heater vs Heat pump). Participants utilized a questionnaire to answer questions regarding reading, working with, analyzing, and arguing the energy data of the household appliance pair they were randomly assigned. The results of the questionnaire showcased that a resident's ability to read, work with, analyze, and argue differed from the visual aid and appliance type. For reading, participants understood the color coding and power meter visual aids but had trouble understanding the direction due to the wagon wheel effect. For working with, participants could compute the average utilizing the color coding and power meter. Still, they had trouble with the electricity flow due to not having a reference point. For analyzing, participants were able to understand how the

electricity flow speed and the power meter blocks related to energy consumption usage, but for the color-coding, participants' ability to relate was subjective to participants understanding. Finally, for arguing, participants were able to create a narrative using evidence from the power meter, while the color coding and electricity flow were difficult because it was subjective to the participants understanding. This study contributes to understanding what visual aids are effective for visualizing residential energy data of household appliances in the virtual environment.

1.Introduction

1.1 Using Alternative Data Visualizations to Display Energy Insights

Visual aids assist an individual in understanding the purpose of the intended message. Traditional residential energy data is displayed on utility bills utilizing a line, bar, or pie chart with energy metrics outlined in kWhs, even though many data visualization chart types and mediums can display energy data. This paper highlights two of the many problems with how current utility bills display energy data. First, not everyone adheres to a line, bar, or pie chart due to a person's energy, graphical, or data literacy level. A person's energy, graphical, and data literacy level defines a person's understanding of energy data embedded within a data visualization. Second, individuals do not understand or cannot determine what a kWh is. Studies have shown that residents need help understanding a kWh (Anderson & White, 2009; Costanza et al., 2012). If energy data were displayed using alternative data visualization and energy metrics, residents could identify energy insights from a new perspective, impacting their energy awareness level.

There is an opportunity to utilize an alternative data visualization medium such as virtual reality to identify energy insights to residents. Virtual reality gives residents a new perspective on energy

insights. It adds another dimension to showcase energy that is not visible in reality. For example, energy is invisible to the human eye. However, with virtual reality, energy can be rendered as electricity flowing through circuits and appliances in a home. For this research energy insights will be three visual aids: color, electricity flow, and power meter blocks in the virtual environment. Additionally, instead of using kWhs to display energy metrics, they were embedded within the visual aids. The color, the electricity flow speed, and power meter blocks lit up, according to the energy being consumed at that moment. The goal of this research is to determine how individuals are **reading, working with, analyzing, and arguing** energy data embedded with 3 visual aids in the virtual environment. The energy data is of three pairs of appliance types. For the lighting appliance, the comparison is between an incandescent bulb and an LED bulb. For the cooking appliance, the comparison is between an air fryer and a stove. For the heating appliance, the comparison is between a space heater and a heat pump. Researchers used different appliance types to determine if it affects a person's ability to read, work with, analyze, and argue static and dynamic energy data. 32 participants were randomly assigned an appliance type and asked four questions pertaining to their ability to **read, work with, analyze, and argue** each of the three visual aids.

The study's results were mixed depending on the chosen appliance type and visual aid. The power meter visual aid was the most understood due to the residents' ability to quantify energy consumption in blocks/boxes. On the flip side, residents had trouble quantifying the electricity flow speed due to the speed of motion because there was no reference point to follow. The participants needed clarification when answering questions using the color gradient to show static lighting energy data. However, participants were spot on when answering questions using dynamic cooking and heating energy data, using the visual aid. This paper's results and discussion sections

discuss other takeaways from the experiment. This research attempts to showcase the power of visual aids in virtual reality, creating a new perspective that cannot be displayed feasibly in reality.

1.2 Boarder Impacts

Showcasing energy from a new perspective removes the complexity once carried by outside opinion. Creating a visual aid tailored to an individual's understanding removes the gray areas and includes everyone. Using alternative visual aids creates inclusion between the energy provider (**who supplies the energy**) and the residents (**who consume the energy**). Displaying energy data in an understandable format build trust between individuals. The customer understands the energy charges and is “not in the dark”. And the energy provider has evidence to show they charged the customer that amount. Creating accessibility and transparency in energy data visualization can build partnerships when all stakeholders are present.

1.3 Intellectual Merit

This research will advance the utilization of visual aids in the energy domain. To impact a resident's energy, graphical, and data literacy level, one must first understand their current level of understanding. It is essential to meet residents at their level of awareness, valuing their knowledge and life experiences associated with energy, graphs, and data. This research will create new data visualization methods for utility companies to display energy insights. Instead of standardized utility bills, tailored data visualizations will be administered from utility companies to residents. Creating data visualization that complements residents' literacy levels, impacts their ability to understand energy consumption in their homes. The first goal of this research is to create energy awareness, followed by implementing new behavior changes to reduce energy consumption usage.

This approach can benefit other areas where societal change is needed. Other areas where societal changes are needed are with utilities such as water and even the financial domain dealing with rent, mortgages, and banking information. Displaying insights in a way that complements an individual's literacy level promotes comprehension.

1.4 Research Question:

How can displaying energy data using alternative visual aids in the virtual environment impact a resident's ability to **read, work with, analyze, and argue** about energy consumption data?

1.5 Sub Research Questions:

Read: How do participants describe the functionality of virtual visual aids?

Work with: Determine the average energy consumption utilizing the virtual visual aid?

Analyze: How are the participants relating the virtual visual aids back to energy consumption amounts?

Argue: How are the participants utilizing the virtual visual aid to argue or justify a statement?

2. Background

2.1 Understanding Energy Data

Presenting energy data to residents in a general schematic limit understanding of energy consumption throughout their home. Utility companies have standardized the way in which energy consumption data is shared to residents. Standardization prevents residents from fully being able to comprehend the energy data displayed on the utility bills because residents' interpretation differs based on literacy levels. Energy, graphical, and data literacy contribute to a person's ability to read, work with, analyze, and argue energy data to make informed decisions. Energy literacy is the

domain of basic energy knowledge, and understanding the impacts of energy production and consumption on the environment. (DeWaters and Powers 2011). Graphical literacy is defined as “the visual decoding of information encoded on graphs” (Cleveland & McGILL, 1984). And data literacy is defined as “the desire and ability to constructively engage in society through or about data” (Bhargava, 2015). These are the main branches of literacy that enable a person to read, work with, analyze, and argue energy data embedded within data visualization. Below I have operationalized the four categories:

- **To operationalize the read action:** Reading involves extracting a single data point or element that is an obvious answer from the data visualization.
- **To operationalize the work with action:** Working with involves calculating a value from pulling two or more data visualization components from the data visualization.
- **To operationalize the analyze action:** Analyzing involves utilizing an algorithmic operation to filter, sort, aggregate, or compare data to identify trends or relationships.
- **To operationalize the argue action:** Arguing involves creating a narrative from the data visualization components to provide evidence to support.

If utility companies would expand the possibilities of using other data visualization mediums that align with a resident's energy, graphical, and data literacy levels, residents' retention and comprehension would increase. Impacting how residents read, work with, analyze and argue the data visualization displaying the energy data. Many individuals lack the technical expertise to understand energy data charts (Mataloto et al. 2021). There is an opportunity to use virtual reality as another data visualization medium to create a new perspective for residents to view energy insights. Virtual Reality (VR) adds another dimension and perspective for residents to understand how energy is consumed in their homes. VR is mainly used for entertainment,

focusing on simulations, video games, 3D cinema, and virtual social worlds (vradmin 2017). But VRs potential does not and has not stopped there. VR has infiltrated into the education system, providing alternative methods for teaching various concepts (Kavanagh et al. 2017). I propose that VR can be used as an alternative teaching method to educate residents on how energy is consumed throughout their homes. Energy, which is invisible to the human eye, can be represented and seen in virtual space, this is the power of virtual reality. However, the effectiveness of displaying energy in the virtual environment must be experimented. To determine the effectiveness of showing energy in the virtual environment, I utilized three visual aids to display energy data insights.

2.2 Functionality Elements in the Virtual Environment Space

Our brain immediately processes color, size, and orientation when viewing a visualization (Archambault et al., 2015; Ware, 2004; Cleveland & McGill, 1986). For the research study I used three visual aids to display and compare the energy consumption of 3 pairs of appliances. The three visual aids are color coding, electricity flow, and power meter. The three visual aids utilize three functionality elements to convey the energy insights. Those three functionality elements are color, size, and orientation. The color functionality elements aligns with the color coding, the size elements align with the power meter, and lastly the orientation elements align with the electricity flow visual aid.

2.3 Color

Unlike energy, which is invisible to the human eye, color is a substance human can see and differentiate given the correct circumstances. “Color is the most valuable characteristic in appreciating and responding to the visual world. (Adkins & Pease, 1991)” Color can be a

representation of many different meanings. For example, (1) red on the traffic light means to stop, (2) green on our cell phone indicates our batteries are fully charged, and (3) yellow on fruit reveals you are observing a banana. Utilizing color in the energy domain can provide the same alert effect that individuals experience in the real world. Every time a color changes, this informs the user that a significant change has occurred with the energy consumption of the appliances (Wong, 2010). Color is a channel to convey information. In the energy domain color captures the residents' attention and impacts understanding when comparing the energy consumption of the appliances (Bonino et al., 2012). To convey energy insights to residents I will utilize color coding. Color coding has been proven to be effective in eco-feedback studies for helping individuals understand energy performance in buildings (Bonino et al., 2012). This research study utilizes green, yellow, and red for low, medium, and high energy consumption respectively. Depending on participants' preconceived notions of color determines what conclusion is regarding energy consumption levels. Along with color, shape and size are two other elements our brain immediately processes when viewing a visualization.

2.4 Size

Depending on the size of an object conclusions can be made without the need for metrics. Embedding metric within the size of an object allows for quick observations to be made. To convey the insights of energy data to residents, I utilized a power energy meter in the virtual environment. A power energy meter represents an animated bar chart in the virtual reality environment. The height of the power energy meter corresponds to the amount of energy consumed at that time and moment by the appliance, which resembles a bar chart. (Croxtan & Stein, 1932) stated that size is more accurately represented in bar charts than circles or squares. Even though the power meter is made from individual squares, when participants view the visual

aid, they see a bar. The bar sizes allow quick height observations to be made when comparing two or more appliances. And lastly, orientation is the last element our brain immediately processes when looking at a visualization.

2.5 Orientation and Movement

Circuits in our home provide a pathway for energy to move throughout a home delivering electricity to appliances. However, that movement of electricity is invisible to the human eye. With virtual reality that pathway can be revealed, exposing electricity flows to residential enables them to see how much energy appliances consume. I utilized an electricity flowing visual aid in the virtual environment to visualize the movement of energy consumption data. The electricity flow visual aid mirrors the energy flow through a wire, which is what happens when energy is flowing from the outlet to the appliance. The electricity flow is speed dependent, slow, medium, and fast pace will respond to low, medium, and high energy consumption level respectively. With virtual reality, energy insights can be observed by the human eye, creating awareness for residents to understand how energy is consumed throughout household appliances.

3. Conceptual Framework

Utilizing virtual reality to display visual aids can assist or hinder residents' understanding of energy consumption data depending on:

- Residents' familiarity with virtual reality environments.
- Residents' ability to read, work with, analyze, and argue the effects of color change in relation to the energy consumption amount.
- Residents' ability to read, work with, analyze, and argue changes in movement as electricity flows through a wire as it relates back to energy consumption amounts.

- Residents' ability to read, work with, analyze, and argue changes in size of the power meter as it relates back to energy consumption amounts.

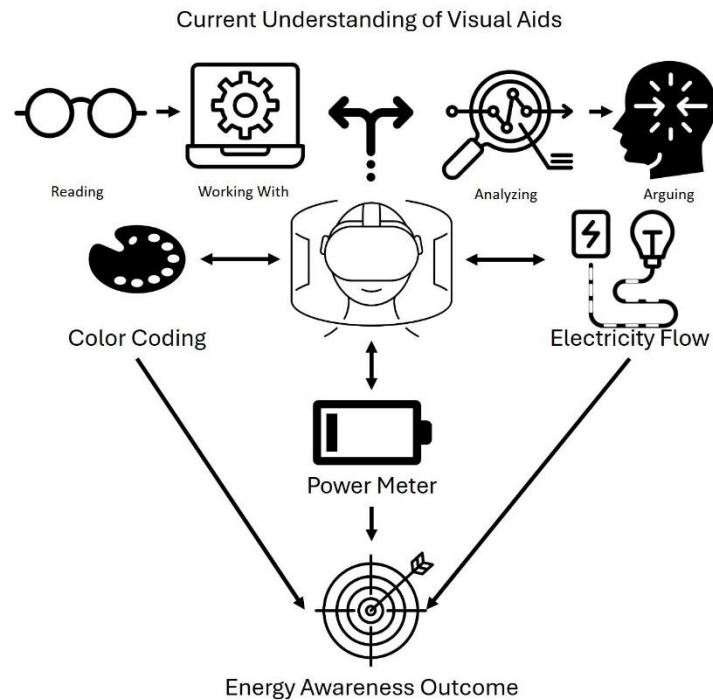


Figure 12: Displays the connection between using visual aids to impacts residents' energy awareness.

4. Methods

4.1 Participants

A total of 32 participants were recruited through Virginia Tech University Graduate School Department. Participants received a \$25 Amazon gift card once they completed the study.

4.2 Research Material:

4.2.1 Virtual Reality Environment:

The foundation of the virtual environment is from a VR project I conducted with Radford high school designed to teach students how to install an energy monitoring device inside of a home.

The virtual environment was created in Unity, a game engine, including a fully furnished 2-bedroom 2-bathroom house. Participants experience the virtual environment utilizing the Meta Quest VR headset. The teleportation technique was employed to allow participants to walk freely in the virtual environment. I designed the virtual environment to include 3 pairs of appliances, while displaying energy consumption data in three different ways: (1) **color coding**, (2) **electricity flowing**, and (3) **power meter**. The three pairs of appliances included lighting (LED vs incandescent bulb), cooking (air fryer vs stove), and heating (space heater vs heat pump). The appliance energy consumption values were recorded at 15-minute intervals for one hour, shown in **Table 3**. In the virtual environment the appliances energy consumption values update every second in the virtual environment.



Figure 13: Displays the outside of the home, which resembling Annie House a home from an organization called Sustaining Way located in Greenville, SC dedicated for educating residents on energy insights.



Figure 14: Displays the inside of Annie House.

Table 3: Displays the raw 15-minute snapshot energy consumption wattage values of the 3 appliance pairs.

	Lighting		Cooking		Heating	
	LED	Incandescent	Stove	Air Fryer	Space Heater	Heat Pump
0:00 min	10	60	3	0	1500	0
0:15 min	10	60	3020	3	0	0
0:30 min	10	60	815	1300	1500	0
0:45 min	10	60	815	0	0	1200
1:00 min	10	60	1600	0	1500	1207

4.2.2 Color Coding

For the color coding the appliances change from green displaying low to no, yellow displaying medium, to red displaying high energy consumption (Mataloto et al. 2021). Since appliances consumed energy differently specific intervals had to be assigned in relation to the color coding.

The energy consumption values associated with the change in color are listed in **Table 4**.

Table 4: Displays the direct correlation between the color and the energy consumption values of the appliances.

Color Coding	Lighting	Cooking	Heating
Green	0 – 33 Watts	0 - 1166	0 - 667
Yellow	34 - 66	1167 - 2333	668 - 1333
Red	67 - 100	2334 - 3500	1334 - 2000

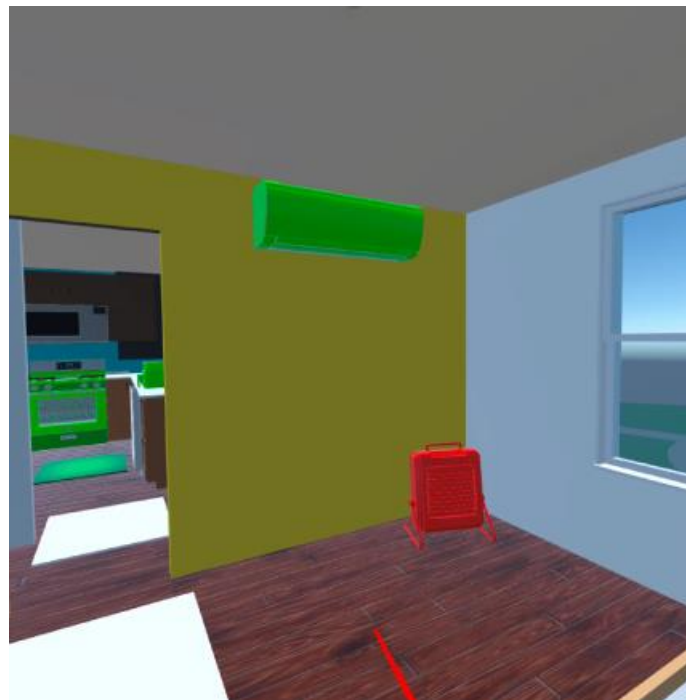


Figure 15: Displays the color-coding visual aid. showing three levels of energy consumption indicated by green, yellow, and red for low, medium, and high energy levels respectively.

4.2.3 Electricity Flow

For the electricity flow, the speed changed according to the amount of energy consumed. The energy consumption values associated with the flow speed are listed in **Table 3**. The electricity

flow visualize aid represents the streamline of energy flowing. A streamline which is a integral curve that is tangent to a given 2D vector field (Turk and Banks 1996), was utilized to display energy in the three dimensional space. The electricity flowing visual aid, is made up of a 2D image displaying an arrow. The 2D image is wrapped onto the wire in the virtual environment as a material. Then the 2D image is animated to create movement, portraying to represent energy flowing through a wire. The animated movement of the 2D image is connected to the amount of energy being consumed by the appliance.



Figure 16: Displays the electricity flow visual aid shown as the wire going from the outlet to the incandescent bulb.

4.2.4 Power Meter

For the power meter the number of blocks lit up matched the energy consumption level of the appliance. Since the appliances consumed energy differently specific intervals had to be assigned in relation to the power meter. The energy consumption values associated with the number of blocks lit are listed in **Table 5**.

Table 5: Displays the direct correlation between the number of blocks lit and the energy consumption values of the appliances.

Appliance Type	Lighting	Cooking	Heating
1 st Block Lit	0 – 20 Watts	0 - 700	0 - 400
2 nd Block Lit	21 - 40	701 - 1400	401 - 800
3 rd Block Lit	41 - 60	1401 - 2100	801 - 1200
4 th Block Lit	61 - 80	2101 - 2800	1201 - 1600
5 th Block Lit	81 - 100	2801 - 3500	1601 - 2000



Figure 17: Displays the power meter visual aid, showing five levels of energy consumption indicated by the number of red blocks lit.

4.3 Research Approach:

- First, participants were randomly assigned appliance categories lighting, cooking, or heating. Participants switched categories if they had no prior knowledge of the appliance type. 11 participants for the lighting, 11 participants for cooking, and the remaining 10 participants were assigned to the heating category.
- Next, participants encountered three 2D data visualization chart types (area, bar, and circular column) one at a time and answered interview questions retaining to reading, working with, analyzing, and arguing the energy data embedded within. The researcher read the interview questions while the participant was interacting with the 2D data visualizations. **(This step was analyzed in another manuscript, (James, 2025))**
- Then participants encountered the three visual aids (color coding, electricity flow, and power meter) in the virtual environment one at a time and answered interview questions retaining to **reading, working with, analyzing, and arguing** the energy data embedded within. The researcher read the interview questions while the participants answered the questions while interacting with the virtual environment.
- After the participant finished with one virtual aid, the Oculus Quest headset was removed, and the researcher loaded the next virtual aid.

- And finally, after the participant encountered the last virtual aid, participants were asked to remove the headset.

4.4 Data Collection

4.4.1 Semi-structured interview

I conducted semi-structured interviews to capture the residents' experience with the visual aids in the virtual environment. Semi-structured interviews allow the interviewer to direct the conversation by asking the interviewee questions in a semi-structured manner. The goal of using semi-structured interviews is to discover critical experiences from the residents' interactions with the data visualization format. In addition, semi-structured interviews allow residents to answer freely so they don't like restricted with their responses. Also, conducting semi-structured interviews allows me to ask questions like 'What happened then/before/after,' or 'Can you say a bit more about...?' to help residents elaborate on their reflections (Anderson & Kirkpatrick, 2015). For example, one question I will ask the resident is, "How would you provide evidence to argue or justify the following statement: Johnny believes that the incandescent bulb consumes more energy than the LED bulb?". Please see appendix B for the complete list of interview questions.

4.5 Data Analyzing

4.5.1 Descriptive Coding

Insights must be searched and analyzed from the semi-structure interview transcripts to reveal how residents were able to read, work with, analyze, and argue the energy data embedded within the three visual aids. To reveal the residents' discernment, descriptive coding was utilized for the first

cycle coding method. Descriptive coding summarizes in a word or short phrase – most often as a noun – the basic topic of a passage of qualitative data (Saldaña, 2013). Descriptive coding is the groundwork needed before a researcher proceeds to the second round. Description is the foundation for qualitative coding analysis, its purpose is to assist the reader to see what you saw and to hear what you heard (Wolcott, 1994). After the initial descriptive codes have been collected, the second coding method pattern coding was utilized to create themes.

4.5.2 Pattern Coding

Themes are needed to convey important insights for participants reading, working with, analyzing, and arguing the energy data, which was done using pattern coding for the second cycle coding method. Pattern coding groups summaries into a smaller number of sets, theme, or constructions. (Miles, Huberman, 1994, p.69) Pattern codes pull together material into a smaller number of more meaningful units. (Punch, 2024,p.174) “Pattern coding has four important functions: (1) it condenses large amounts of data into smaller number of analytic units, (2) it gets the researcher into analysis during the data collection stage, (3) it helps the researcher elaborate a cognitive network, and (4) it lays the groundwork for cross-case analysis surfacing common themes and directional processes” (Miles et al., 2020). For example, the qualitative data collected shows evidence that the participant always compares the sizes of markers when arguing or justifying their response to a particular question. Therefore, we can include that the participant focusing on identifying marker sizes when arguing with a data visualization.

4.5.3 Protocol for Pattern Coding:

1. Search the answers to the questions for rules, causes, and explanations.
2. Create initial pattern codes.
3. Then group initial codes together to create themes.

(Elliott, 2018), (Miles & Huberman, 1994),

4.6 Validity and Reliability

4.6.1 Intercoder reliability

Intercoder reliability will improve the systematicity, communicability, and transparency of the coding process [27]. Intercoder reliability is measured by having two or more coders use the same codebook to code the content using transcripts from the semi-structured interviews then calculate the level of agreement among coders (“Intercoder Reliability Techniques,” 2017). I will be responsible for developing the codebook to evaluate and identify themes. Dr. Paige and members of my research team will assist by reviewing my codebooks to discover the unidentified themes. Involving other researchers in the coding process creates validation to ensure accuracy and reliability for the themes generated from pattern coding.

4.6.2 Intercoder Reliability Protocol

1. Select two or more coder
2. Provide instructions for understanding the coding process.
 - a. Include and review codebook with coders
 - b. Include semi-structure interview transcript
 - c. Include document for coders to write down their results.
 - i. 0 (no agreement) to 1 (perfect agreement)
3. Compare the agreement the coders
4. Insert results into the percent of agreement and intercoder reliability formulas.

5. Qualitative Coding Results

Table 6: VisualAids_Lighting_CodeBook

Name	Description
Appliance Type:	Cooking (LED and Incandescent Bulb)
Visual Aid:	Color Coding
Category: Read	
Pattern Code:	Color Extraction.
Descriptive Code:	Definition
Identified the correct colors	Was able to view the specific colors shown on the lights
Category: Work with	
Pattern Code:	Misdirected Time Calculation
Descriptive Codes:	Definition
Confusion	Due to the static energy data
Identified the time	Said the number of seconds the color stayed the same
No color change	Notice that the color remained the same
Category: Analyze	
Pattern Code:	Identified Color Relationship to Energy
Descriptive Codes:	Definition
Compare Bulb sizes	Compare physical Size
Compare Scientific Reasoning	Mentions scientific reasoning
Direct Relationship	Direct Correlation Between Color and Energy usage
No Correlation	No relationship energy consumption and color
Category: Argue	
Pattern Code:	Color is not always substantial to provide evidence.
Descriptive Codes:	Definition

Evidence from Life Experience	own personal preference
Not enough information to Argue	Could not justify or argue
Size comparison	Compare the physical size of the two bulbs
Utilizes Color as Evidence	Mentions color for evidence when justifying their statement.

Visual Aid:	Electricity Flow
Category: Read	
Pattern Code:	Extract Electricity Wire Characteristics
Descriptive Codes:	Definition
Identifies Speed	Comparing speeds
Identify Colors	Describe color
Identify Direction	Describing a path travelled
Identify Scientific	Describe Scientific relationship
Category: Work with	
Pattern Code:	Indecisiveness in Calculations
Descriptive Codes:	Definition
No Difference Detected	Can't tell difference in speed
Not enough information Present	Need a reference point
Qualitative Observation	visual comparison of how energy is consumed
Quantitative Average	Able to determine quantitative average
Category: Analyze	

Pattern Code:	Identified Flow Relationship to Energy
Descriptive Codes:	Definition
Direct Correlation Between Speed and Energy	Faster speed means more energy consumed
No Conclusion	Not enough information to make a comparison
Size of the bulb	Compare the size of the bulb
Category Argue	
Pattern Code:	Multiple Electricity Characteristic Utilized for evidence
Descriptive Codes:	Definitions
Compare size	Mentions the size of the wire supplying electricity to the appliance.
Comparing Flow Speed	Incandescent bulb electricity is flowing faster
Comparing Scientifically	Mention scientific terms in comparison
No Able	Not enough information to Compare
Visual Aid:	Power Meter
Category: Read	
Pattern Code:	Extract Number of Boxes
Descriptive Codes:	Definitions
Observe number of boxes lit	Identifies the number of boxes shown
Category: Work with	
Pattern Code:	Calculate Block Average
Descriptive Codes:	Definitions

Assign Value to Boxes	Determine that each red block is 4 watts
Identified Average for Incandescent	Quantitative average
Identified Average for LED	Quantitative average
Category: Analyze	
Pattern Code:	Identified Box Relationship with Energy
Descriptive Codes:	Definitions
Direct Correlation Between Boxes and Energy	The higher number of lights show the more energy consumed
The Color Red	red relates to the amount of energy consumed
Time depends	Time is also a factor to consider when discussing energy consumption related to boxes
Category: Argue	
Pattern Code:	Box Pattern Characteristics Provides Evidence
Descriptive Codes:	Definitions
Assigning Values to Boxes	each box consumes about 10 watts of energy
Comparing Peaks	compare the max number of boxes used
Comparing the use of Red	compare the number of red boxes used

Table 7: VisualAids_Cooking_CodeBook

Name	Description
Appliance Type:	Cooking (Air Fryer and Stove)

Visual Aid: Color Coding

Category: Read	
Pattern Code:	Color Extraction.
Descriptive Code:	Definition
Did not identify all the color for the air fryer	did not mention green and yellow
Did not identify all the color for the stove	do not mention red, green and yellow
Identified all the color of the air Fryer	identify the color yellow and green
Identified all the color on the stove	Identify the color red, yellow, and green
Category: Work with	
Pattern Code:	Time value calculated.
Descriptive Code:	Definition
For the Air fryer each color is shown at the same amount of time.	The number of seconds shown green = yellow
For the air fryer the green color was display longer than the color yellow	The number of seconds the green color > yellow color
For the Stove all color shown for the same amount of time	color time equals each other
For the stove all color varies in time	colors vary in time
For the stove The color green time interval was different from red and yellow.	The green color time interval is X while the red and yellow time interval is Y and Y
Category: Analyze	
Pattern Code:	Identified Color Relationship to Energy
Descriptive Codes:	Definition
High Energy Consumption	Mention the color red, high energy consumption

Low Energy Consumption	Mentions the color green, low energy,
Medium Energy Consumption	Yellow Color represent energy consumption levels between green and red
More Color More Energy Consumed	Compare number of color used to energy consumption amount
Traffic Light Comparison	Mentions the colors in relationship to traffic light
Category: Argue	
Pattern Code:	Color characteristics provide evidence
Descriptive Codes:	Definition
Comparing size of appliance	When the appliance size as evidence
Comparing the frequency change in colors	Participants mentions the changes in color for providing evidence to which appliance consumes more energy
Red color indicates More energy consumed by the stove,	The red color being shown by the stove means that the stove is using more energy than the air fryer

Visual Aid:	Electricity Flow
Category: Read	
Pattern Code:	Extract Flowrate Conditions
Descriptive Codes:	Definition
Flowing Direction	Direction of electricity
Recognize Fluctuations Speed	The speed of the electricity flow
Category: Work with	
Pattern Code:	Uncertainty in Calculation.
Descriptive Codes:	Definition
Able to determine quantitative Average	Used mathematical process to compute the average.
Not enough information present	Can not determine the average

Observe energy consumption pattern	description of the flow speed
Category: Analyze	
Pattern Code:	Identified Speed Relationship
Descriptive Codes:	Definition
Speed corresponds to Energy Consumption Level	the faster the flow the more energy being consumed
Category Argue	
Pattern Code:	Various electricity wire flow conditions for evidence.
Descriptive Codes:	Definitions
Can't differentiate	can't compare the flow looks the same
Size Comparison	Comparing the size of the electricity flow
Time interval comparison	Comparing time interval
Velocity comparison	Comparing speed

Visual Aid:	Power Meter
Category: Read	
Pattern Code:	Extract Block Sequence
Descriptive Codes:	Definitions
Observes the pattern changes in the power meter	Identifies the number of block/boxes shown
Category: Work with	
Pattern Code:	Calculate Block Average
Descriptive Codes:	Definitions
air fryer	

Calculates Average verbally	Use two values to create an average
Determine an Average	Guess a number, not working out how they discovered the average
Stove	
Calculates average verbally	Use three values to create an average
Determine the Average	Guess a number, not working out how they discovered the average

Category: Analyze

Pattern Code:	Identified Box Relationship with Energy
Descriptive Codes:	Definitions
Compare fluctuations	Comparing the number of boxes used during a time.
Direct Correlation Between Boxes and Energy Consumed	More boxes more energy consumed
Red signifies High energy consumption	The color red equals high energy consumed
Unclear on the relation to energy	identifies that there is a relationship but is unclear

Category: Argue

Pattern Code:	Box Patterns Provide Evidence
Descriptive Codes:	Definitions
Comparing Peaks of energy consumption	Identifies high energy consumption values of appliances.
Comparing the average hourly energy consumption	Identifies average hourly energy consumption of appliances
Comparing the number of block/boxes lit	Compares the frequently of blocks/boxes lit up

Table 8: VisualAids_Heating_CodeBook

Name	Description
Appliance Type:	Heating (Heat Pump and Space Heater)
Visual Aid:	Color Coding
Category: Read	
Pattern Code:	Color Extraction.
Descriptive Code:	Definition
Identify colors	Identify all the colors of the appliances
Category: Work with	
Pattern Code:	Color Calculation is inconsistent
Descriptive Code:	Definition
Heat pump changes at consistent intervals	Stay one color for the same amount of time as another color.
Heat Pump Color Change Interval Differs	The color represent are present for different amount of times.
Space Heater changes at Consistent Intervals	Stay one color for the same amount of time as another color.
Space Heater Color Change Interval Differs	Stay one color for the same amount of time as another color.
Category: Analyze	
Pattern Code:	Utilized color describe energy consumption
Descriptive Codes:	Definition
Describes the pattern of the energy consumption	Describe the color sequence.
Green - The appliance is ON	Green means that the appliance is turned on

Green No Energy Consumption	Mention green equals no energy consumption
High Energy Consumption	Red is more energy consumption
Low Energy Consumption	Mentions Green for low energy consumption
Medium Energy Consumption	Yellow is less than red but more than green energy consumption
No Energy Consumption	No energy being consumed
No connection	No relationship to energy consumption
Identifies Red	Red indicates energy consumption
Identifies Yellow	Yellow means that the appliance is turned off
Category: Argue	
Pattern Code:	Color characteristics provide evidence
Descriptive Codes:	Definition
Comparing ON_OFF cycles	The frequently of the space heater mean more energy is consumed
Comparing the Frequency Color Change	The space heater shows red which consumes more than the yellow of the heat pump.
Comparison of maximums	Identifying the highest energy consumption color for each appliance.
Not enough information to compare	Can not draw a conclusion from color.

Visual Aid:	Electricity Flow
Category: Read	
Pattern Code:	Identified electricity flow characteristics
Descriptive Codes:	Definition
Compare Light Motion	Describes the light pattern seen

Identify direction	Describes the direction of the electricity flow.
Identify velocity	Describes the speed of the electricity flow.
Category: Work with	
Pattern Code:	Observe the flow speed
Descriptive Codes:	Definition
Qualitative Response	faster than the space heater
Quantitative Average	Able to quantify a value
Category: Analyze	
Pattern Code:	Identified Speed Relationship
Descriptive Codes:	Definition
Direct Correlation	The more electricity flows the more electricity consumed
Category: Argue	
Pattern Code:	Flow speed provide evidence
Descriptive Codes:	Definitions
Compare Energy Flow	Compares the energy flow time to state evidence
Compare Timeframe	Compares the time rate of high and low intensity
Comparing velocity	Visibly identifies flow speed
Visual Aid:	Power Meter
Category: Read	
Pattern Code:	Identified Boxes
Descriptive Codes:	Definitions
Identified the Blocks	Counted the total number of blocks seen

Category: Work with	
Pattern Code:	Utilizing the pattern to compute an average.
Descriptive Codes:	Definitions
Describe Process for computing the average	Identifies the box pattern and provides an average.
Guess the Average	Guess a number, not working out how they discovered the average
Category: Analyze	
Pattern Code:	Number of boxes corresponds to energy consumption
Descriptive Codes:	Definitions
Direct Correlation	The boxes are being filled up
Unclear on the relation to energy	Identifies that there is a relationship but is unclear
Category: Argue	
Pattern Code:	Providing evidence using boxes.
Descriptive Codes:	Definitions
Comparing Averages	Remembering the average from the work with questions
Comparing Block fluctuation	Describes the number of boxes used
Timeframe	Same based on timeframe

6. Discussion

6.1 Overview

To enhance alternative data visualizations, it's essential to reveal how participants were able to **read**, **work with**, **analyze**, and **argue** the energy data embedded with the visual aids. **Reading**

involves extracting a single data point or element that is an obvious answer from the data visualization. Next **working with** involves calculating a value from pulling two or more data visualization components from the data visualization. Then **analyzing** involves utilizing an algorithmic operation to filter, sort, aggregate, or compare data to identify trends or relationships. And finally, **arguing** involves creating a narrative from the data visualization components to provide evidence to support. This process will be further explored in the discussion explaining how participants responded to each category involving the three visual aids: **color coding**, **electricity flow**, and the **power meter**.

6.2 Read

Reading is the first step in creating awareness for utilizing visual aids, if participants could not identify the visual changing features, the visual is worthless. For the color-coding visual aid participants were able to identify all the colors when viewing the appliances. Some participants experience confusion when identifying the colors if the entire appliance was not color coded. For example, on the lighting appliance the bulb was the only source of color change. Meaning some participants said they also identified the gray color when viewing the light appliance because of the bottom of the lamp.

Mixed options were given as participants were asked to determine how electricity was flowing through the wire of the appliance. Some participants saw the energy flowing “from the outlet to the appliance” and others saw the flow going in the opposite direction. Some participants saw the energy flow as burst of lights and energy packets.

Participant #28 - *Well, it's interesting because it like, it almost seems like it's moving in the other direction. So, where it starts at the wall, it goes to the heat pump... It's almost starting at the space heater and then going to the wall, the direction of the gray lines.*

When asked to determine how many blocks are used in the power meter for the appliance. Participants counted the total number of blocks lit up at the current moment, counted the number of white and red blocks, or mentioned all the different number of blocks shown as the energy consumption cycle repeats. Depending on which appliance participants were assigned, their ability to read differed because the lighting appliance used static energy data while the cooking and heating appliances used dynamic data. Static and dynamic energy data also affects an individual's ability to work with visual aids.

6.3 Work with

Participants were asked to work with the visual aid to **determine the average the number of seconds each color is shown, the electricity flow speed, and the number of boxes used**, participants were not informed of the proper instructions on explaining their process for commencing their answer. Therefore, participants gave quantitative answers instead how explaining the full process they took to determine the average; this was a limitation.

For the color visual aid participants had to determine the average number of seconds each color is shown in a five second time period. When viewing the lighting appliances participants were confused when answering the question because the color never changed due to the light using static energy data. For example, the LED bulb stayed green, while the incandescent bulb remained yellow. However, when answering this question with the cooking and heating appliances, participants provided quantitative responses without justification or verbally counted out the number of seconds each color was shown to determine the average.

For the electricity flow participants had to determine the average electricity flow speed. Participants were not able to quantify the average flow speed due to the lack of information presented on the visual aid. However, participants were able to provide qualitative responses to determine the average flow speed of the appliances. The qualitative responses included: **slower, pauses, fast, extremely fast.**

Participant #21 - I'd say for the air conditioner, when it starts moving, it moves really fast, but it gets stagnant for a while. In I'd say for space heater, it also gets stagnant for a while, but the flow does not look as fast as the air conditioned one.

For the power meter participants had to determine the average number of blocks shown, similar results followed from the color coding. Participants were confused with the static movement of the blocks when viewing the lighting appliances and provided quantitative and qualitative responses. Next category to discuss will be analyze which is the conclusion participants were able to gather after reading and then working with the visual aids to reveal the real implications.

6.4 Analyze

Participants were asked to analyze the visual aids by determining how the visual aid relates back to energy consumption levels. The majority of participants were able to explain the relationship between the colors, electricity flow speed, and the number of boxes to energy. The color visual aid was resourceful if the participant assumed that green was low, yellow was medium, and red was high energy usage. However, some participants had difficulties associating energy consumption levels with the colors green, yellow, and red. Which caused confusion when relating the color back to an energy consumption amount. For example, one participant stated that green, yellow, and red could be replaced by any color and the energy consumption meaning could change.

Participant #31 - *So, it's like, it's probably green for a certain level of energy usage, yellow for a certain red for certain usage, that's my assumption. Okay, so I'm guessing that every time the colors are changed, it seems arbitrary, but like, I don't think the colors are really linked to energy usage.*

For the electricity flow, participants understood the direct correlation between flow speed and energy consumption amount. The faster the electricity flow the more energy was being consumed by the appliance.

Participant #14 - *the speed is equivalent, is proportional to energy amount...So more speed, more energy...stove is probably producing more energy because it looks like it's flickering a lot faster for a longer period of time.*

And lastly the clearest visual aid was the power meter because participants could quantify the number of blocks and make the inference that the more red boxes lit up meant that appliance was consuming more energy. For example, one participant was assigned the light appliance and even assigned a number value to the blocks stating that each block represents 10 watts of energy. And finally, the last category brings **reading**, **working with**, and **analyzing** together enabling a participant to **argue** with the energy data embedded within the visual aids.

6.5 Argue

Participants were asked to argue by providing evidence using the visual aid to argue or justify an energy consumption statement comparing two appliances. Justifying or arguing the statement utilizing the colors was successful when participants associated the green, yellow, and red to corresponding energy consumption levels low, medium, and high respectively. For example, participants provide evidence such as the air fryer only displays colors of green and yellow, while the stove turns red at certain points as well, meaning that the stove consumes more energy than the air fryer.

Participant #11 - *we have red color for this stove, but there's no red color for air fryer.*

Participant #17 - The stove has a red color, so it shows that the stove has more energy consumption compared to air fryer

In addition, the findings in the analyze category for color coding were similar to the argue category. If the participant did not already have a hierarchical relationship with the colors coming into the experiment, the participants could not justify or argue the statement.

For using the electricity flow to provide evidence, participants could not always tell which appliance was consuming the most energy because the electricity flow speed looked the same at several instances. Once the electricity flow speed reached a certain threshold the human eye could not see the difference in speed. Therefore, participants compared the time interval in which the flow was **moving** versus **not moving** for evidence. In addition, if the flow never stopped (like the lighting appliances because the energy consumption is constant) participants could not create a stance to argue or justify because the flows look identical.

Participant #22 - Its blinking more, but I don't know how quantify it... if there was additional information that would be helpful, but still blinking is not really giving us a clear comparison.

And finally, using the power meter, participants compared the peak or average number of boxes for each appliance to provide evidence. Again, this was the clearest visual aid to use when arguing because participants could quantitatively compare the number of boxes used as evidence. Unlike the color-coding visual aid where participants had to already have a relationship/emotion with color and the electricity flow where participants had to guess the flow speed.

7. Conclusion

Implementing residential energy data within visual aids in the virtual environment has its pros and cons, when **reading**, **working with**, **analyzing**, and **arguing** energy data of household appliances.

7.1 Reading

For reading the visual aid, participants were asked to read the visual aids to identify the features within the visual aids. Participants were able to read the color shown for color coding and the number of blocks used by the power meter when presented in the virtual environment on the appliances. However, participants experience trouble when trying to identify the direction of which the electricity was flowing through the wire. Participants stated that the flow looked to be flowing from the appliance to the outlet at certain speed intervals. To improve the electricity flow, a different animation would need to be used or the overall speed interval from low to high needs to be reduced by a factor.

7.2 Working

For working with the visual aid, participants were asked to determine the average energy consumption amount. With the instruction not being clear participants responses varied for utilizing the color coding and power meter visual aid to determine the average. The initial plan was to gather responses that narrative residents' interaction with the visual aid to determine the average because participants just answered with quantitative values. In addition, when using the electricity flow participants were not able to determine an average because they didn't have a reference point to compare too. Utilizing a quantitative metric for time or electricity flow speed would have helped participants determine the average.

7.3 Analyzing

For analyzing the visual aid, participants were asked to determine how the visual aid relates to energy consumption amounts. Participants were able to determine that the speed of the electricity flow and number of blocks used in the power meter was proportionate to amount of energy usage. For example, "low to high" flow speed translates to "low to high" energy consumption and the

greater number of blocks there is a direct correlation with energy usage. But participants did not always associate green, yellow, and red with different levels of energy consumption. I designed the color coding to resemble the traffic light, green “go for low”, yellow “slow down for medium”, and red “stop for high energy usage”. If the participants were not thinking about this phenomenon there was no correlation between colors and energy consumption usage. Utilizing a color legend in the future will reduce the confusion participants had when correlating colors to certain energy consumption amounts.

7.4 Arguing

For arguing the visual aid, participants were asked to argue or justify Johnny’s statement comparing the energy consumption of the appliances. The power meter provided the best evidence because participants could quantify their response by comparing or averaging the number of blocks used. The electricity flow and the color-coding visual aids were difficult to use as evidence because it was subjective to the participants understanding. For example, some participants thought that the color green meant the appliance was off while others thought green was low energy consumption. And for the electricity flow some participants were able to correlate speed flow with energy consumption level to produce concrete evidence to argue or justify. While other participants were not able to create evidence because they visually could not see a difference in flow, and they did not have a reference point for comparison.

The findings suggest that utilizing visual aids to display energy insights is effective when aligned with the user preferences. Aligning visual aids with a person's understanding increases energy awareness and lessens confusion. This paper highlights the power of informing residents of energy consumption insights of appliances without the need to display confusing energy consumption

metrics. Therefore, inputting the energy consumption metrics within the visual aid's correlates in a way that understandable for residents to comprehend the energy insights. The study's finding gives new insights into the domain of energy data visualization capabilities by utilizing different visual aids (**color coding**, **electricity flow**, and **power meter**) in the virtual world. Utilizing different visual aids creates a new perspective for residents to view the energy consumption patterns or behaviors of their household appliances in the virtual world.

7.5 Future Work

The next study will evaluate how participants perceived visual aids to display energy consumption insights within the virtual environment. Perception is related to a person's ability to construct knowledge; this is where constructivist theory will be applied. "Constructivist theory states that individuals create their own new understanding, based upon the interaction of what they already know and believe, and the phenomena or ideas with which they come into contact with. (Richardson, 1997)" Constructivist theory will be explored in the next study to reveal participants perceptions of the visual aids. Along with constructivist theory, distributed cognition and activity theory will be explored. Distributed cognition theory is defined as understanding the interactions among people and technologies (Hollan et al., 2000), and is the interwoven processing of information to generate intelligent behavior (Jiajie Zhang et al., 2002). Activity theory is the understanding of the unity of consciousness and activity (Nardi, 1995). Results from the next study will reveal the pros and cons of using the three visual aids color coding, electricity flow, and power meter in the virtual environment. The goal is to leverage participants' experience to develop more effective visual aids that enhance their understanding of household energy consumption.

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CHAPTER 5: MANUSCRIPT 3 - THE EFFECTIVENESS OF VISUAL AIDS IN VIRTUAL ENVIRONMENTS DEPENDS ON RESIDENTS LEARNING STYLE

Abstract

Energy is invisible to the human eye, but virtual reality provides a perspective to visualize energy insights through visual aids. Visual aids in the virtual environment can showcase energy consumption data insights if designed to complement residents learning style. Three visual aids were used in this study to display energy insights that include color coding, electricity flowing, and power meter. There are numerous ways in which an individual can construct knowledge from visual aids. This research focuses on three theories (constructivist, distributed cognition, and activity theory) to understand how participants are interacting with the visual aids. This study aims to identify how well participants were able to understand the visual aids displaying energy insights and what recommendations participants would have to increase the effectiveness of the visual aids. A semi-structured interview data collection method was conducted to gather participants' perspectives. Results of the semi-structured interview reveal that participants greatly understood the energy power meter due to its ability to allow participants to provide qualitative and quantitative responses. For the color-coding visual aid, if participants had a preconceived notion of the colors green being low, yellow being medium, and red being high energy consumption levels, then participants understood the color-coding visual aid. If participants did not already have an established relationship with color, the color-coding visual aid was not effective at displaying energy consumption insights. And lastly for the electricity flow visual aid participants offer many recommendations to improve the accessibility and functionality, which included adding legends and metric to differentiate the flow speed. The implications from this research study have the

potential to create usable visual aids in the virtual environment to showcase energy insights impacting residents' energy awareness of household energy consumption.

1. Introduction

1.1 Virtual Reality Opens New Perspectives of Energy Consumption

Virtual reality is a powerful tool to show new perspectives and visualize insights that are invisible to the human eye. Currently, 1 in every 7 households live in energy poverty, meaning they are spending over 6 percent of their monthly income on energy expenditures (Scheier and Kittner 2022). Residents want to decrease their utility bill but are not aware of the actionable steps to take to reduce energy consumption in the home (Hernández and Phillips 2015). The first step in creating a change starts with awareness. Awareness is achieved by informing the residents of how energy is consumed through household appliances and exposing the misconceptions. As humans we know energy is needed and used to power our homes, however we cannot see it. But with virtual reality energy can be visualized through visual aids creating awareness for residents. The way a resident perceives visual aids in the virtual environment is a result of life experiences associated with the visual aids. This study is compasses three theories: constructivist, distribution cognition, and activity theory. Constructivist theory states that individuals construct their understanding of knowledge through interaction. Distribution cognition theory is understanding the interactions among people and technology. And lastly activity theory determines how individuals utilize technology to achieve an objective. A person utilizes all three theories to understand how visual aids represent energy consumption insights.

Visual aids were implemented in the virtual environment to showcase the real-time energy consumption of household appliances. Three different distinct alternatives were chosen to represent energy consumption level: color coding, electricity flowing, and power meter. Color coding was utilized as one of the virtual visual aids because individuals already have predetermined assumptions with certain colors due to life experiences. The electricity flow was utilized to portray real energy flowing from the wall outlet to the appliance. And lastly the power meter was utilized as one of the visual aids because the majority of the electronics utilize a meter to detect energy usage world include a battery or power meter. The energy consumption data included both static and dynamic data from three sets of appliances for lighting appliances (LED vs Incandescent bulb), for cooking (Air Fryer versus Stove), and for the heating appliances (Heat Pump versus Space Heater). The main goal of this study was to determine how participants understood the visual aid displaying energy consumption data and identify what changes they would recommend increasing accessibility, understanding, and functionality.

Results from this study reveal that participants better understood the power meter relationship with energy consumption because they were able to quantify the consumption. Even though participants questioned how much energy each block represented, they still preferred this visual aid. There were mixed results with the color coding, some participants had a perceived notion of the colors green, yellow, and red because of the traffic light. Green means go, relating back to good energy usage. Yellow means slow down, relating back to medium energy usage. And red means stop, relating back to high energy usage. If participants did not have a pre perceived notion of color relatability. The participants did not see how the color was related to energy consumption amounts. For the electricity flow visual aid participants concluded that the visual element of flow was not

substantial, other contextual or graphical elements are needed to gather concrete conclusions. And lastly for the power meter, was the most acceptable visual aid due to participants' ability to gather qualitative and quantitative energy insights. Using these three visual aids to visualize energy data insights is just the beginning of using alternative data visualization strategies to improve residents energy awareness.

1.2 Intellectual Merit

Energy is invisible to the human eye, so it must be visualized in a way that's understandable and relatable to residents since it's already a foreign concept to most. Understanding how energy is consumed throughout a home by utilizing different data visualization strategies has the potential to impact residents' energy awareness. An increase in energy awareness is needed; residents spend more on their utility bills each year without knowing why their bills are increasing. However, residents are expected to continue paying utility bills without context or beneficial detailed data visualization displays from utility companies. Residents want to know why their utility bill is the amount and what actionable steps they can take to reduce it. But they are unsure where to start. Virtual reality can give residents a new perspective on household energy consumption. Understanding what data visualization medium adheres to a resident's current energy, graphical, and data literacy level is key. Millions upon millions of visual aids can be created within the virtual environment, but if the visualization does not align with a person's literacy level, it's a waste. Creating personalized visual aids enables residents to understand the depth of household energy consumption, increasing their overall energy awareness level and the hope of reducing utility bills.

1.3 Broader impacts

Virtual reality has a benefit of impacting individuals understanding of energy consumption in a home when visualizing energy data. In addition, other forms of data when visualized in the virtual environment has the potential to impact an individual's ability to understand the insights of said data. For example, water utility data paired with different visual aids could impact an individual ability to understand how much water is used/wasted when performing behaviors in a home such as bathing & showers, drinking & cooking, washing clothes, etc. Creating more awareness for individuals to understand why their water utility bill is the amount it is and how appliance throughout the home consume water. The use of visual aid can also be applied to the healthcare industry utilizing confusing medical terminology. Medical terminology can be converted into visual aids to assist patients with understanding the significance of their vitals. For example, what if the doctor presented patients with a digital 3D model of the patient displaying their current health conditions, with recommendations to improve. Then the doctor could show on the model if the patient decreases this level, this will improve your blood oxygen level throughout your body, this is the power of utilizing alternative data visualization formats to display data insights.

1.4 Research Questions

Research Questions: How can constructivist learning theory be implemented to impact a residents ability understand three visual aids in the virtual environment?

Sub-question: How effective were the visual aids sufficient at revealing energy data insights?

Sub-question: How could the visual aids be altered to improve the align with participants perceptions or ways of learning?

2. Background

2.1 Theories for Human Interaction with Virtual Reality Platform

With technology advancing more and more each day, how is a human able to learn how to interact with the never-ending advanced ending of technology? As humans, how do we adapt to technology? Do we go through a period of trial and error where we must construct our own knowledge from interacting with technology to understand it? Piaget (1973) states that “understanding is the process of discovery or re-construction by re-discovery”. When humans are given technology, they must interact with it to build knowledge. To understand how participants interacted with the visual aids presented in the virtual environment, I will utilize three theories: constructivist, distributed cognition, activity theory.

2.2 Constructivist Theory

“Constructivist theory states that individuals create their own new understanding, based upon the interaction of what they already know and believe, and the phenomena or ideas with which they come into contact with. (Richardson, 1997)” Learning occurs through the construction of meaning not through passive reception. Individuals acquire new knowledge when meaningful and important experiences occur (Popkewitz, 1998; Ültanır, 2012). As a result of those experiences, the learning process starts, enabling an individual to recognize and evaluate what they just experienced. Piaget states that learning is “understanding the process of discovery or re-construction by re-discovery. In this regard, training as an individual and future individual creativity is important in the construction of knowledge” (Piaget & Coltman, 1970). Individuals can also train and encounter experiences together through social interactions to create new forms of knowledge.

2.3 Distributed Cognition Theory

Data visualization platforms are tools individuals interact with to gather insights from embedded data. There are many ways in which a human can interact with data visualizations, but why do they choose their certain way? This is where the theory of distributed cognition can be applied. The theory of distributed cognition is defined as understanding the interactions among people and technologies (Hollan et al., 2000), and is the interwoven processing of information to generate intelligent behavior (Jiajie Zhang et al., 2002). The theory of distributed cognition allows all relevant factors to be considered for completing the task bringing together people, the problem, and the tools to generate a unit of analysis (Perry, 2003). The theory of distribution cognition has been used to examine the cognitive properties of airplane cockpits, the navigation system of naval vessels, air-traffic control, shared CAD systems, shared-databased systems, the collaboration between programmers, and even a fishing community. These are all examples in which individuals are interacting with technologies to complete a goal. For this research study the cognitive properties of interest were **perceptions, learning, memory, attention, and logical reasoning**. These were included to understand how the residents interact with the visual aids to that their reasoning.

2.4 Activity Theory

The way humans interact with a piece of technology can be traced back to who they are, a piece of their consciousness. This is where activity theory can be applied. Activity theory is the understanding of the unity of consciousness and activity (Nardi, 1995). Activity theory originated from the Russian/Soviet psychology of the 1920s and 1930s (Kaptelinin & Nardi, 2012). Activity theory was introduced to human computer interaction (HCI) in the late 1980s to early 1990s (Clemmensen et al., 2016). However, the first attempt to apply activity theory in HCI was (Bødker,

1989) to argue that “people act through technology rather than interact with it”. Activity theory is used to understand the relationship between the subject and the object to achieve the outcome. Individuals can take different approaches between the subject and the object to reach the objective. Activity theory helps designers understand how to create technology tools for the specific nature of the object under scrutiny (Engestrom 1993). The specific nature under scrutiny here is a resident's ability to interpret the energy data embedded within the visual aids. Activity theory helps to reveal part of the visual aid is causing residents comprehension or confusion. For example, when I resident observes color coding comparing the energy consumption of two appliances and one appliance is green while the other is yellow, a resident might problems deciding which appliance is consuming the most energy. To one audience, red, yellow, and green relate to the traffic light system, meaning energy increasing from green to red. In another case green and yellow could have no relation to the person and they are confused by which one consumes more energy. Activity will identify the resident's roadblock and inform the designer that alterations needed to be made on color coding, which include choosing color that relational understand to residents. The goal of incorporating activity theory is to discover how individuals use visual aids in comparing the energy consumption levels of household appliances.

3. Conceptual Framework

Utilizing virtual reality to display visual aids can assist or hinder residents' understanding of energy consumption data depending on individuals learning styles and preferences. This conceptual framework outlines (1) how individuals construct knowledge through the interaction of the visual aids, which is constructivist theory, (2) how understanding the interaction between people and technologies by examining cognitive properties, which is distribution cognition theory, and (3)

observing the process that occurs between the individual and the visual aids to reach an objective, which is activity theory, shown in **Figure 18**.

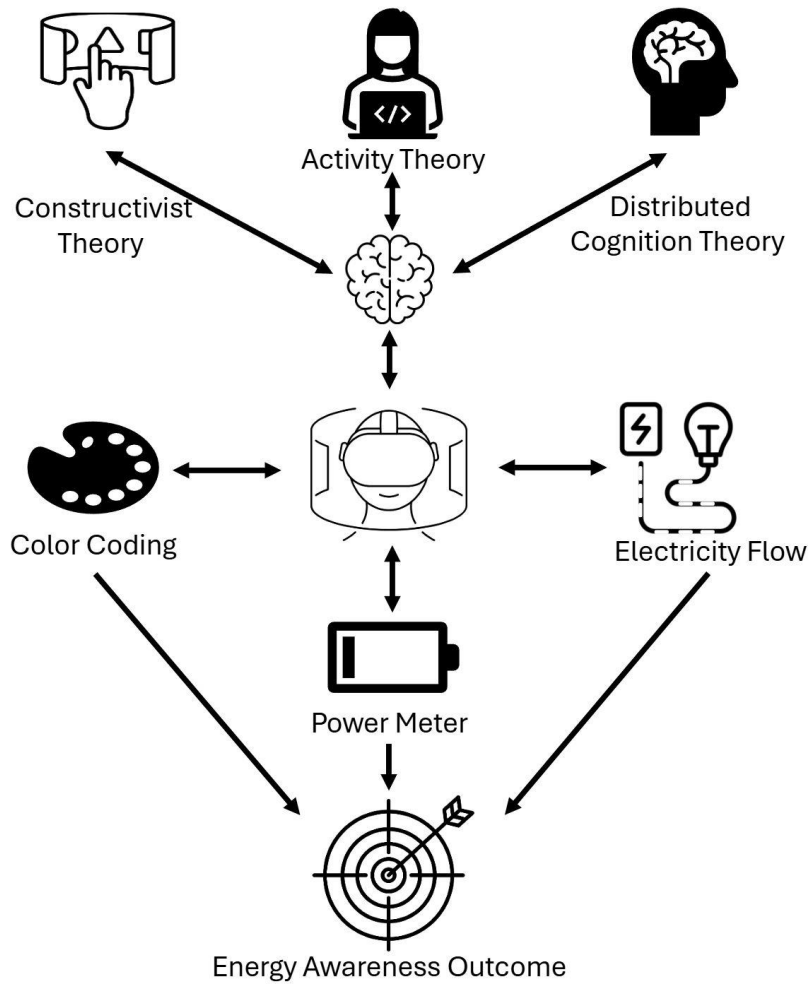


Figure 18: Display the conceptual framework used to determine the effectiveness of individuals ability to gather energy insights from the visual aids.

4.Methods

4.1 Participants

A total of 32 participants were recruited through Virginia Tech University Graduate School Department. Participants received a \$25 Amazon gift card once they completed the study.

4.2 Research Material:

4.2.1 Virtual Reality Environment:

The virtual environment was created in Unity, a game engine, including a fully furnished 2-bedroom 2-bathroom house. Participants experience the virtual environment utilizing the Meta Quest VR headset. The teleportation technique was employed to allow participants to walk freely in the virtual environment. I designed the virtual environment to include 3 pairs of appliances, while displaying energy consumption data in three different ways: (1) **color coding**, (2) **electricity flowing**, and (3) **power meter**. The three pairs of appliances included lighting (LED vs incandescent bulb), cooking (air fryer vs stove), and heating (space heater vs heat pump). The appliance energy consumption values were recorded at 15-minute intervals for one hour, shown in **Table 9**. In the virtual environment the appliances energy consumption values update every second in the virtual environment.



Figure 19: Displays the outside of the home, which resembling Annie House a home from an organization called Sustaining Way located in Greenville, SC dedicated for educating residents on energy insights.

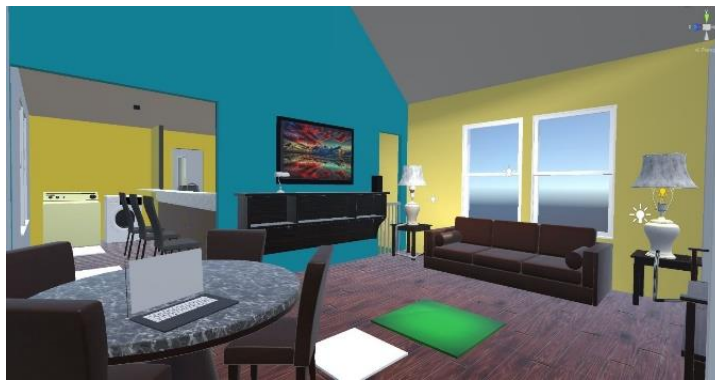


Figure 20: Displays the inside of Annie House.

Table 9: Displays the raw 15-minute snapshot energy consumption wattage values of the 3 appliance pairs.

	Lighting		Cooking		Heating	
	LED	Incandescent	Stove	Air Fryer	Space Heater	Heat Pump
0:00 min	10	60	3	0	1500	0
0:15 min	10	60	3020	3	0	0
0:30 min	10	60	815	1300	1500	0
0:45 min	10	60	815	0	0	1200
1:00 min	10	60	1600	0	1500	1207

4.2.2 Color Coding

For the color coding the appliances change from green displaying low to no, yellow displaying medium, to red displaying high energy consumption (Mataloto et al. 2021). Since appliances consumed energy differently specific intervals had to be assigned in relation to the color coding. The energy consumption values associated with the change in color are listed in **Table 10**.

Table 10: Displays the direct correlation between the color and the energy consumption values of the appliances.

Color Coding	Lighting	Cooking	Heating
Green	0 – 33 Watts	0 - 1166	0 - 667
Yellow	34 - 66	1167 - 2333	668 - 1333
Red	67 - 100	2334 - 3500	1334 - 2000

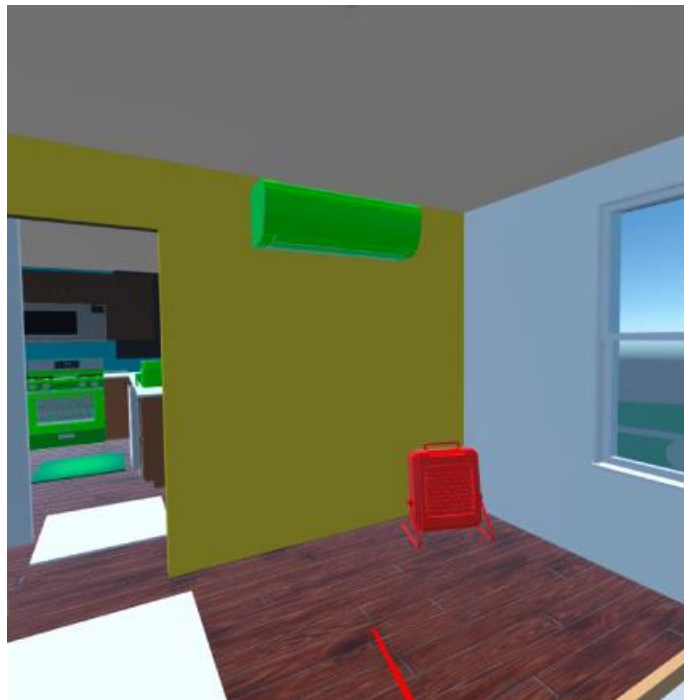


Figure 21: Displays the color-coding visual aid. showing three levels of energy consumption indicated by green, yellow, and red for low, medium, and high energy levels respectively.

4.2.3 Electricity Flow

For the electricity flow, the speed changed according to the amount of energy consumed. The energy consumption values associated with the flow speed are listed in **Table 9**. The electricity flow visualize aid represents the streamline of energy flowing. A streamline which is a integral curve that is tangent to a given 2D vector field (Turk and Banks 1996), was utilized to display energy in the three dimensional space. The electricity flowing visual aid, is made up of a 2D image displaying an arrow. The 2D image is wrapped onto the wire in the virtual environment as a material. Then the 2D image is animated to create movement, portraying to represent energy flowing through a wire. The animated movement of the 2D image is connected to the amount of energy being consumed by the appliance.



Figure 22: Displays the electricity flow visual aid shown as the wire going from the outlet to the incandescent bulb.

4.2.4 Power Meter

For the power meter the number of blocks lit up matched the energy consumption level of the appliance. Since the appliances consumed energy differently specific intervals had to be assigned in relation to the power meter. The energy consumption values associated with the number of blocks lit are listed in **Table 11**.

Table 11: Displays the direct correlation between the number of blocks lit and the energy consumption values of the appliances.

Appliance Type	Lighting	Cooking	Heating
1 st Block Lit	0 – 20 Watts	0 - 700	0 - 400
2 nd Block Lit	21 - 40	701 - 1400	401 - 800
3 rd Block Lit	41 - 60	1401 - 2100	801 - 1200
4 th Block Lit	61 - 80	2101 - 2800	1201 - 1600
5 th Block Lit	81 - 100	2801 - 3500	1601 - 2000



Figure 23: Displays the power meter visual aid, showing five levels of energy consumption indicated by the number of red blocks lit.

4.3 Research approach:

- First, participants were randomly assigned appliance categories lighting, cooking, or heating. Each category visualized an hour of the appliance pair's energy consumption data, on three data visualization chart types (area, bar, and circular column chart). Participants switched appliance categories if they had no prior knowledge of the appliance type.
- Then participants encountered visual aid in the virtual environment one at a time. First the color coding, electricity flow, followed by the power meter. The researcher read the interview questions while the participant were interacting with the virtual environment.

There were four interview questions on reading, working with, analyzing, and arguing for each visual aid. This step was analyzed and reported in manuscript (James, 2024).

- And finally, participants were asked to provide feedback on their experience in the virtual environment through a semi-structured interview. This research study explores the findings of the feedback participants provided.

4.4 Data Collection

4.4.1 Semi-structured Interviews

I conducted a semi-structured interview to capture participants' understanding of the three visual aids in the virtual environment. Semi-structured interviews let the interviewer direct the conversation by asking them semi-structured manner. In addition, semi-structured interviews allow residents to answer freely so they don't feel restricted with their responses. Also, conducting semi-structured interviews allows me to ask questions like 'What happened then/before/after,' or 'Can you say a bit more about...?' to help residents elaborate on their reflections (Anderson & Kirkpatrick, 2015). For example, one question I will ask the resident is, "Which visual aids was easy to understand? And I can follow that question up with What made that visual aid easy to comprehend?"

Participants were asked the following questions:

1. Can you name all the virtual visual aids you encountered in the virtual environment?
 - a. How was energy shown in the virtual environments?
2. Which virtual visual aid was easy to understand and what made it easy?

3. Which virtual visual aid was difficult to understand and what made it difficult to understand?
4. How would you increase the effectiveness of the virtual visual aid?
5. How would you improve the effectiveness of the virtual environment?
6. Is there any other feedback you would like to give?

4.5 Data Analysis

4.5.1 Descriptive Coding

Insights must be searched and analyzed from the semi-structure interview transcripts to reveal how participants provided feedback on the three visual aids. To reveal the participants discernment, descriptive coding was utilized for the first cycle coding method. Descriptive coding summarizes in a word or short phrase – most often as a noun – the basic topic of a passage of qualitative data (Saldaña, 2013). Descriptive coding is the groundwork needed before a researcher proceeds to the second round. Description is the foundation for qualitative coding analysis, its purpose is to assist the reader to see what you saw and to hear what you heard (Wolcott, 1994). After the initial descriptive codes have been collected, the second coding method pattern coding was utilized to create themes.

4.5.2 Pattern Coding

Themes are needed to convey important insights for participants providing feedback on the three visual aids, which was done using pattern coding for the second cycle coding method. Pattern coding groups summaries into a smaller number of sets, theme, or constructions. (Miles, Huberman, 1994, p.69) “Pattern codes pull together material into a smaller number of more meaningful units”(Punch, 2024,p.174). “Pattern coding has four important functions: (1) it

condenses large amounts of data into smaller number of analytic units, (2) it gets the researcher into analysis during the data collection stage, (3) it helps the researcher elaborate a cognitive network, and (4) it lays the groundwork for cross-case analysis surfacing common themes and directional processes” (Miles et al., 2020). For example, the qualitative data collected shows evidence that the participant always compares the sizes of markers when arguing or justifying their response to a particular question. Therefore, we can include that the participant focusing on identifying marker sizes when arguing with a data visualization.

4.5.3 Protocol for Pattern Coding:

1. Search the answers to the questions for rules, causes, and explanations.
2. Create initial pattern codes.
3. Then group initial codes together to create themes.

(Elliott, 2018), (Miles & Huberman, 1994)

4.6 Validity and Reliability

Intercoder Reliability is needed to ensure that multiple researchers can come to the same conclusion for the descriptive and pattern codes. “Intercoder reliability will improve the systematicity, communicability, and transparency of the coding process” (O’Connor and Joffe 2020). Intercoder reliability is measured by having two or more coders use the same codebook to code the content using transcripts from the semi-structured interviews then calculate the level of agreement among coders (“Intercoder Reliability Techniques,” 2017). First I will develop the code book to evaluate and record themes. Next, Dr. Paige and members of my STILE research team will review the codebooks to check the current themes and discover unidentified themes. Involving another researcher in the beginning of the coding process will ensure the validity of this research study.

5.Results

Table 12: Qualitative Coding Results from First Round Descriptive Coding and Second Round Pattern Coding.

Name	Description
Visual Aid: Color Coding	
Pattern Codes:	Color perception is key; Color contrast region must be defined; Metrics needed to deepen understanding.
Descriptive Codes:	Definitions
Add a legend	Participants suggest adding a display to link Color to energy consumption amount.
Change the Color characteristics	Participants suggest adding Color features to improve the visual aid
Color could be replaced	Participant mentions that the colors could be replaced because the Color had no significant meaning in relation to energy .
Easy Understanding	Participants were able to easily utilize the colors
Energy Relationship with Color	The participants were able to correlate the energy consumption to specific colors.
Need More information	The participants need more information than just the Color to draw conclusions.
No relationship determined	Participants could not determine the relationship between energy usage and the colors
Visual Aid: Electricity Flow	
Pattern Codes:	Flow perception depended on participant; Flow characteristics improved is needed; Metrics needed to deepen understanding.
Descriptive Codes:	Definitions

Name	Description
Add metrics to Improve	Participants suggest adding metrics to improve the visual aid
Cord Characteristics to improve	Visual suggestions to improve the Cord displaying energy
Couldn't differentiate the flow characteristics	Participant were not able to determine an answer using the visual aid
Couldn't identify direction	Participants were not able to determine the direction due to the speed of the flow.
Easy to interpret energy consumption to speed relationship	The participants were able to determine that the fast speed meant more electricity flowing
Visual Aid: Power Meter	
Pattern Codes:	Easy interpretation of relationship between boxes and energy consumption usage; Utilized the boxes to gather quantitate and qualitative reasoning; Metrics needed to deepen understanding.
Descriptive Codes:	Definitions
Add metrics	Participants suggest adding metric to improve the visual aid
Defined boxes	Participants are able to quantify the number of boxes in relations to energy consumption amounts
Easy to interpret	Participants mentioned that this visual aid was easy to interpret they could quantify the boxes.
Easy to interpret because of the bright colors	Participants mention this visual aid was easy to interpret due to the Color of the boxes
Reminds the participant of batteries	Participants relates power meter back to objects from everyday life.

6. Discussion

6.1 Color Coding

Utilizing color coding in place of energy metrics was received well by individuals who associated the color green, yellow, and red with participants energy consumption level. However if a person didn't associate colors green, yellow, and red with a particular energy consumption level the colors served no purpose. Starting with the participants that received the colors well. Participants enjoyed the straightforward fact of being able to see the color without the need of reading confusing energy metrics. Participants already had a preconceived notion for the color green, yellow, and red. Participants relationship with the colors green and red were obvious versus their relationship with the color yellow. When describing green and red participants alluded to that these colors were the extreme opposites of each other low versus high, good versus bad energy consumption level. But when describing the yellow color little to no qualitative reasoning was given. Please see the examples pulled from the interview transcripts below.

Green

Participant #9: *because I think generally in advertisements in the real world, they use different colors, so green is more like sustainable friendly red is like high voltage, danger and stuff.*

Participant #11: *So, for me, the Green was like, everything is good and energy consumption is low.*

Participant #14: *Partially because I associated green with less energy*

Red

Participant #11: *And when I saw red, You know, the energy consumption should be very high.*

Participant #14: *Partially because I associated red with more energy.*

Yellow

Participant #9: *Yellow...Not as high energy consumption as red, but not as low energy consumption as green, somewhere in between.*

Participant #23: *The color, I would say the color was pretty clear, but there is. It's hard to see how much the yellow is different than the green.*

Now moving on the participants that didn't receive the color coding well. Many participants mentioned that the color could be replaced with another color because they didn't see the significance. This is due to their energy, graphics, data life experiences with color. Many of the participants for this study were foreign students from different demographics who had different life experiences with color in relationship with energy. In addition some participants were not able to quantify the color when analyzing or arguing to justify the energy consumption insights because the color coding did not display any metrics or reference points. If there was a legend displaying that this color was linked to this amount of energy being consumed, then evidence could be established. The parameters for the color-coding visual aid used green for the energy consumption value from 0 to 33 watts for the lighting, 0 to 1166 watts for the cooking, and 0 to 667 watts for the heating appliances. Associating a color with 0 energy being consumed is misleading, one participant points out. Instead in the future researchers could utilize a different color or have the appliance transparent representing the appliance using zero amounts of energy. Speaking transparently since energy is invisible to the human eye in the virtual environment, we utilize the electricity flow visual aid to showcase energy.

6.2 Electricity Flow

Embedding energy consumption metrics inside of the electricity flow visual aid was perceived well by some participants and confusing to others. Many participants could see the different in flow speed when observing the appliances. Participants assumed that when the flow increased that was a direct correlation in energy consumption usage. Some participants experienced trouble when determining the direction that the flow was moving because at certain speed the flow looked like

it was going in reverse direction. This is known as the wagon-wheel effect. Which create a negative perspective on energy awareness because residents might start to believe that energy is flowing from the appliance to the energy grid. To counter the wagon-wheel effect participants worked around the problem by counting the number of times the flow stopped and used that statistic as a reference point to determine the energy consumption difference of the appliances.

Participant #3: *The current one ...both are moving almost at the same speed. I just decided on the basis of how still, how like, which appliance is taking more time to be still.*

Participant #20: *I think I felt it difficult to analyze which one is, you know, like going more at a faster rate, because it kind of like seemed the same, I think I could only tell when it stops. So I could tell, it stops for more time, for the air fryer.*

Participant #23: *I could easily tell when the electricity was stopped, like for the air fryer, when it was stopped and then it was flowing. But for the stove, I could not differentiate between if it was flowing more or it was flowing less.*

To remove the wagon-wheel effect the researchers suggest reducing the speed interval scale for the appliance. For example, the current maximum speed for the cooking appliances was 3020, reducing it by a factor of 10 to 302, would remove the wagon-wheel affect and residents would be able to see the direction clearly. Another problem was that the flow characteristics when working with, analyzing, and arguing the energy data was not sufficient. With there being no quantitative metric participants could not actually compute answers to the questions. Participants were only able to give qualitative responses not quantitative.

Participant #11: *The velocity of electricity through the wire, And the reason is that you can actually feel that consumable energy is through those wires.*

Participant #26: *Yeah, because people can easily understand how much flow is going into the valve. So the more speed, the more energy is consuming.*

Participants mentioned that if there was a reference point or a speed legend they would be able to compare the energy consumption better. Multiple participants suggested combining both the color coding and electricity flowing visual aid together. For example, using certain colors to represent flow speeds, informing residents of the participants flow speed instead of guessing, once the color is shown residents will automatically be available to identify the energy consumption range. Lastly the power meter which uses boxes and color to display energy consumption data insights, which has a combination of functionality elements of color, speed, and orientation.

6.3 Power Meter

Embedding energy data within the power meter was perceived well by participants because they could gather qualitative and quantitative insight from the visual aid. With there being 5 boxes participants could read, work with, analyze, and argue using the boxes to support their answers. Participant appreciated the clear and easy representations when observing the boxes displaying the energy consumption amount for the appliances. Participants were able to pick up on the energy consumption patterns when utilizing the boxes, recognizing the pattern allows participants the ability determine the average easily. In addition to using interacting with the boxes, the red color on the boxes caught residents' attention enabling them to see the quick changes.

Participant #2: *the block so much easier because they had a bright color code so and also, like they were taking a bit of time fluctuating, so it was easier to tell what they are depicting,*

Participant #5: *The boxes have a prominent red color...so it was very pretty easy to see that...it's was pretty clear.*

The power meter even resembled objects participants interacted with daily. For example, one participant even compares the power meter to the power bar from their electric bike. This

participant interacts with the power bar on bike to determine the energy status on the battery when riding and when charging to identify when the battery will be full.

Participant #29: *they watch at the bars, and they see that how much charge is left in there. Everyone is familiar with the charging of the batteries and their phones.....And if you plug in your phone, so it's going to show it's charging how much 60 65% so it's in the bar from your battery is in ... they have the color option the lower one is the red, and the upper one is kind of the green.*

The only suggestions received for the power meter included adding metrics to represent the energy consumption amount or the monetary value of energy consumption usage.

Participant #4: *One thing that could be done is we could give a monetary value to the boxes. You know, energy consumption could be translated into cash.*

7.Conclusion

7.1 Exploring Visual Aids for Effectiveness

There are alternative virtual reality data visualization aids that can be used to display energy data. Visual aids displaying energy data in the virtual environment can be utilized by individuals to construct knowledge of how energy is consumption throughout household appliances with the need of human interaction. This study aimed to reveal just how effective visual aids were are revealing energy data insights. This is one of the first pioneer studies using the visual aids (color coding, electricity flow, and power meter) to read, work with, analyze and argue energy consumption data. There was a need to first examine how participants perceived each visual aid individually. The authors expected results to vary due to constructivist, distributed cognition, and activity theories which informs the way individuals interact and construct new knowledge from the visual aids.

7.2 Color Coding

If the participants associated the colors green, yellow, and red with energy consumption level increasing, respectfully or related the color back to the traffic signal light they were able to justify the energy consumption of the appliance qualitatively. However, if the participants did not have a per determined relations with the three colors, the color served no purpose in relation to energy consumption usage. Meaning that the colors could be replaced by any colors. In addition participants had difficulties differentiating the colors to provide quantitative answers. Multiple participants suggested adding labels or creating a color legend. For participants mentioned instead of using different color to use one color but utilize different intensities. For example, use one color and chosen a light to dark color gradient that increases energy usage, instead of utilizing multiple color. In addition, add a metric or legend so the participants identify the current energy consumption usage level if needed.

7.3 Electricity Flowing

The electricity flow visual aid was not perceived well by all individuals because of the flow's inability to produce quantitative reason, participants main justification was qualitative results. The flow speed which was linked to the electricity usage created a wagon-wheel effect at the higher energy consumption level for the cooking and heating appliances. As a result participants could not differentiate between what direction the electricity was flowing or which appliance was consuming more energy. To counter act this effect the researchers are suggesting that they will decrease the scale interval to slow down the overall speed of the electricity flow. In addition, the participants mentioned using a legend reference point or color-coding approach to categorize the

speed, to construct more quantitative responses. Without legend or color-coding approach participants were subjectively drawing a conclusion.

7.4 Power Meter

The power meter was the most accepted visual aid because of its power to provide both qualitative and quantitative reasoning for participants to gather energy consumption insights. The defined boxes and prominent red color enable participants to gather quick calculations and observe patterns. The power meter also resembled objects in the real world like the battery status bar on electricity bicycles and modern-day cell phones. To improve the functionality of the power meter participants suggest adding energy and monetary metrics to each of the boxes. Adding metrics to the boxes would enable residents to make easy comparison and began to associate a shape with an energy consumption meaning.

7.5 Takeaways

The findings suggest that utilizing visual aids with embedded energy data to construct knowledge is possible. However visual aids should be tailored to residents' ability to read, work with, analyze, and argue the energy data embedded within. As shown in the results of the study, each visual aid has pros and cons depending on the participants. One visual aid might be perceived well, and that same visual aid might not be perceived well by another participant. Embedding energy metrics within the visual aids provides another perspective for residents to understand how energy is consumed throughout household appliances without the need to interpret raw energy data. Utilizing a visual aid embeds all the confusing energy calculations that deter residents for wanting to understand the implications of energy consumption, into an easy and readable format.

7.6 Future Studies

Future studies will involve testing the color coding, electricity flow, power meter, and other visual aids with affordable housing residents. Affordable housing residents are the primary individuals who will benefit from this advancement use of alternative data visualizations. Residents are spending too much money on utility bills, which causes them to foreshadow other essential expenses needed to survive in life. However, residents want to reduce their bill but are not aware on how energy should be consumed through these homes and what actionable steps are needed to reduce energy consumption. Using visual aids in the virtual environment tailored to resident energy, graphical, and data literacy provides a way for residents to (1) become a aware and (2) make informed decisions to alter their energy behaviors to reduce their energy consumption usage reducing their utility bills.

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CHAPTER 6: CONCLUSIONS, IMPLICATIONS, AND CONTRIBUTIONS

Research Question for Manuscript 1

The first manuscript research question asked, “How do residents read, work with, analyze, and argue with 2-dimensional data visualization formats containing energy consumption data of household appliances? “Based on the findings from the first manuscript, when reading a 2D data visualization its essential to have legends and marker colors to compare variables. When working with the 2D data visualizations participants were confused with the energy metrics presented on the axis title which derailed their process for computing the average, therefore energy metrics within the data visualization should adhere to a persons data literacy level. When analyzing the the 2D data visualizations participants successfully determined the energy total or different over a given period, its important to ensure the axis title aligns with participants understanding. And finally, when participants were arguing they utilized different visualization components: peaks and valleys, on and off periods, and the changes in color as evidence to support their claim.

Research Question for Manuscript 2

The second manuscript research question asked, “How can displaying energy data using alternative visual aids in the virtual environment impact a resident's ability to read, work with, analyze, and argue about energy consumption data?”. Based on the findings from the second manuscript, when reading the energy data embedded within the visual aids participants were able to identify the colors and the number of blocks shown in the power meter. However participants were also able to determine which direction the energy was flowing throughout the wire, due to the wagon-wheel effect created from the excessive speed. When participants were working with the visual aid to determine the average, participants were only able to provide quantitative reasoning for the color coding and the electricity flow because there were not quantitative metris

present. However, participants were able to produce quantitative averages when interacting with the power meter because the boxes were defined themselves. When participants were asked to analyze the visual aids relationship to energy consumption amounts. Participants were able to determine that the speed of the electricity flow and number of blocks used in the power meter was proportionate to amount of energy usage. But participants did not always associate green, yellow, and red with different levels of energy consumption due to their life experiences involving color. And finally, for arguing using the visual aids participants had difficult time arguing utilizing the color coding and electricity flow because it was subjective to the residentia percevtions. The power meter provided the best evidence because participants could quantify their response by comparing or averaging the number of blocks used.

Research Question for Manuscript 3

The third manuscript research question asked, “(1)How can constructivist learning theory be implemented to impact a residents ability understand three visual aids in the virtual environment?(2) How effective were the visual aids sufficient at revealing energy data insights? And (3) How could the visual aids be altered to improve the align with participants perceptions or ways of learning?” Based on the funding from the third manuscript, first starting with the color coding if participants had a preconceived notion to green, yellow, and red in relation to energy that understand that mean low to high energy consumption. If they did not have a preconceived notion, the color did not serve a purpose and were not related to energy consumption insights at all. Next moving on to the electricity flow was not perceived well by individual because participants had trouble (1) understanding the direction of the electricity flow and (2) they didn’t have a reference point or legend to determine exact energy consumption usage. And finally the power meter was

the most accepted and understood visual aid due to participants ability to gather for qualitative and quantitative energy insights.

Implications

Research Question 1

The finding of the first manuscript enables researchers, utility companies, and policy makers to move away from standardized data visualization and create charts that align with individual literacy levels. Implementing personalized data visualization in utility companies will promote energy awareness in hopes of reducing electric bills. In addition, the results from this study contributes to the residential energy data visualization framework. The goal of the Residential Energy Chart Framework (RECF) is to create a data visualization framework, where charts can be developed to match a person's current energy-graphical-data literacy level, revealing how energy is being consumed throughout the home, resulting in complete understanding.

Research Question 2

The findings of the second manuscript allow researchers and utility companies to know that there are alternative data visualizations that can display residential energy data. Instead of using confusing and complicated energy data which residents have problem understanding that data can be embedded within visual aids. The study's finding gives new insights into the domain of energy data visualization capabilities by utilizing different visual aids (color coding, electricity flow, and power meter) in the virtual world. Virtual reality creates a new perspective for residents to see electricity usage which is invisible to the human eye. For example, imagine receiving your monthly utility bills in the form of a simulation or virtual reality message. And the message displays how energy was consumed throughout the home using a visual aid that align with the residents literacy levels.

Research Question 3

The findings of the third manuscript allow researchers to learn from how participants interacted with the visual aid and adjust accordingly. The goal of using visual aids is to reduce the complexity there is with energy data and put it in a simple forms for residents to understand. Implementing visual aids is an alternative data visualization that could be used but they must be tested before it can actually be implemented by utility companies or enforced to be used by policy makers. Revamping the visual aids for displaying energy usage in the virtual environment, enables more functionality possibilities to be implemented to increase residents understanding of the energy awareness.

Contributions to Research

The study results in several distinct research contributions including:

- 1) A operationalization of reading, working with, analyzing, and arguing residential energy consumption data.
- 2) Creating a conceptual framework for defining how an individual is able to read, work with, analyze, and argue energy consumption data.
- 3) A relative comparison of three 2D chart types displaying energy consumption data of household appliances.
- 4) A relative comparison of three visual aids displaying energy consumption data of household appliances in the virtual environment.

These research contributions help with the creation and the design of data visualizations to display residential energy data. There is little to no literature that investigates how residents are reading, working with, analyzing, or arguing energy data visualizations. This research contribution kicks starts the literature growth on evaluating different data visualizations including 2D chart

types and visual aids used in the virtual environment to see which one aligns with residents energy, graphical, and data literacy level instead of using standardized visualizations.

Limitations and Research Recommendations

The limited use of chart types, appliance types, and visual aids introduced bias within the research study. This dissertation only utilized three 2D chart types (the area, bar, and circular column chart), because these are the main chart types used throughout utility bills. Other chart types could have been chosen that better align with participants literacy levels. In the same matter, only three visual aids (color coding, electricity flowing, and power meter), were utilized due to visualize features the brain immediately process being color, size, and orientation. And lastly only utilizing three appliance types of pairs limited a persons ability to recall energy consumption usage especially if they had no knowledge of the energy consumption insights of the given appliances.

The qualitative response from participants was limited due to the format of the questionnaire. The questions asked from the questionnaire did not allow participants to go in-depth with their responses to fully understand what components on the chart types they utilized to compute the answer for the questions. For example, some participants answered in one-word responses while others gave elaborate explanations of the process they performed. The future questionnaire will present questions to participants in a manner that extracts full depth explanation from participants when they are reading, working with, analyzing, and arguing the energy data embedded within the data visualization.

Participant engagement of affordable housing members is needed to broaden implications of using alternative data visualizations to showcase energy data. The recruitment of residents was not successful due to communication issues and time constraints. The researchers are in the process of building partnerships with affordable housing communities such as CHP (Community Housing Partners) and True Ground Housing Partnership), to conduct community engagement in the future with residents. These partnerships are essential for testing and evaluating the effectiveness of current and alternative data visualizations, helping to identify improvements needed to enhance residents' energy awareness.

Future plans also include developing partnerships with utility companies to pilot data visualization to gather qualitative and quantitative data from a wider range of residents, not just affordable housing community members. Since utility companies have standardized the data visualization of utility bills for the longest time, research and evidence still needed to be gathered on why the change would be necessary. This opportunity will also showcase the power of personalizing data visualization to utility companies from the customers perspective.

Conducting participatory design workshops with residents in the future will allow utility companies to see the level of engagement and appreciation residents experience using alternative data visualizations. Tailoring data visualizations to individuals' literacy levels, rather than creating general schematics, empowers residents by putting knowledge directly in their hands.

APPENDIX A – Chapter 3 Manuscript #1

A.1 - 2D Questionnaire for Reading, working with, analyzing, and arguing

A.1.1 Questionnaire for Lighting Appliance Pair

2D Data Visualization - Area Chart

Read (What data is represented?):

Determine what two appliances are being compared.

Work with (Acquiring):

Determine the average hourly energy consumption of the LED bulb.

Analyze (Aggregating):

Determine how much total energy was consumed from 8:00 am- 8:30 am by Incandescent bulb.

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the LED bulb consumes more energy than the Incandescent bulb.

2D Data Visualization - Bar Chart

Read (What data is represented?):

Determine the units on the Y-axis.

Work with (Acquiring):

Determine the average hourly energy consumption of the incandescent bulb.

Analyze (Aggregating):

Determine how much total energy was consumed from 8:15 am- 8:30 am by LED bulb.

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the LED bulb consumes more energy than the Incandescent bulb.

2D Data Visualization - Circular Column Chart

Read (What data is represented?):

Determine the units on the X-axis

Work with (Acquiring):

Determine the average hourly energy consumption of the LED bulb.

Analyze (Aggregating):

Determine the energy consumption difference between the 8:15pm and 8:45 pm minute mark by the incandescent bulb.

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the incandescent bulb consumes more energy than the LED bulb.

A.1.2 Questionnaire for Cooking Appliance Pair

2D Data Visualization - Area Chart

Read (What data is represented?):

Determine what two appliances are being compared.

Work with (Acquiring):

Determine the average hourly energy consumption of the Air fryer.

Analyze (Aggregating):

Determine how much total energy was consumed from 8:00 pm- 8:30 pm by Stove.

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the Air fryer consumes more energy than the Stove.

2D Data Visualization - Bar Chart

Read (What data is represented?):

Determine the units on the Y-axis.

Work with (Acquiring):

Determine the average hourly energy consumption of the stove.

Analyze (Aggregating):

Determine how much total energy was consumed from 8:15 pm- 8:30 pm by Air fryer.

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the Air fryer consumes more energy than the Stove.

2D Data Visualization - Circular Column Chart

Read (What data is represented?):

Determine the units on the X-axis

Work with (Acquiring):

Determine the average hourly energy consumption of the Air fryer.

Analyze (Aggregating):

Determine the energy consumption difference between the 8:15am and 8:45 am minute mark by the stove.

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the stove consumes more energy than the Air fryer.

A.1.3 Questionnaire for Heating Appliance Pair

2D Data Visualization - Area Chart

Read (What data is represented?):

Determine what two appliances are being compared.

Work with (Acquiring):

Determine the average hourly energy consumption of the space heater.

Analyze (Aggregating):

Determine how much total energy was consumed from 8:00 pm- 8:30 pm by Heat Pump.

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the Space heater consumes more energy than the Heat Pump.

2D Data Visualization - Bar Chart

Read (What data is represented?):

Determine the units on the Y-axis.

Work with (Acquiring):

Determine the average hourly energy consumption of the heat pump.

Analyze (Aggregating):

Determine how much total energy was consumed from 8:15 pm- 8:30 pm by space heater.

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the Space Heater consumes more energy than the Heat pump.

2D Data Visualization - Circular Column Chart

Read (What data is represented?):

Determine the units on the X-axis

Work with (Acquiring):

Determine the average hourly energy consumption of the space heater.

Analyze (Aggregating):

Determine the energy consumption difference between the 8:15pm and 8:45 pm minute mark by the heat pump.

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the heat pump consumes more energy than the space heater.

A.2 9 different chart types displaying the residential energy data of the household appliances.

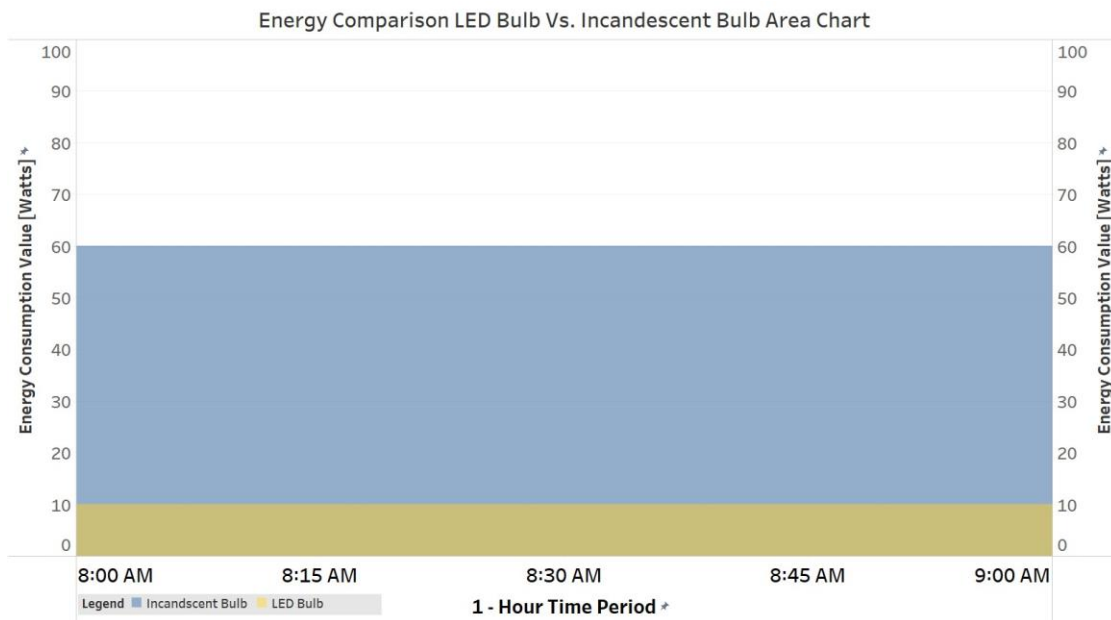


Figure 24: Area chart comparing the LED Bulb Vs. the Incandescent Bulb.

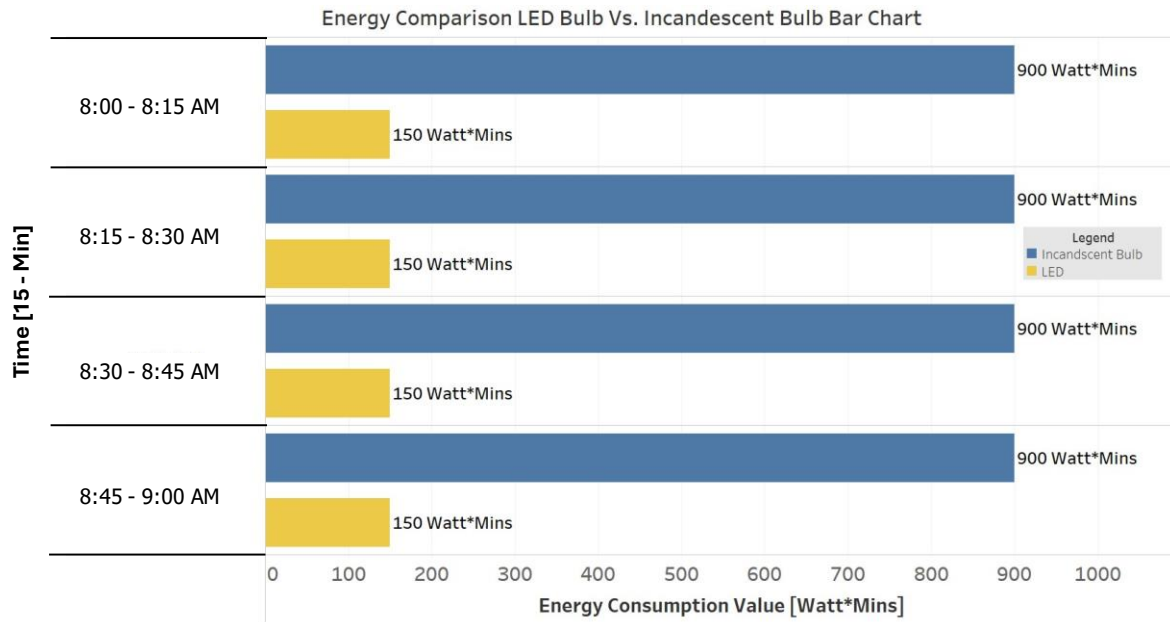


Figure 25: Bar chart comparing the LED Bulb Vs. the Incandescent Bulb.

Energy Comparison LED Vs. Incandescent Bulb

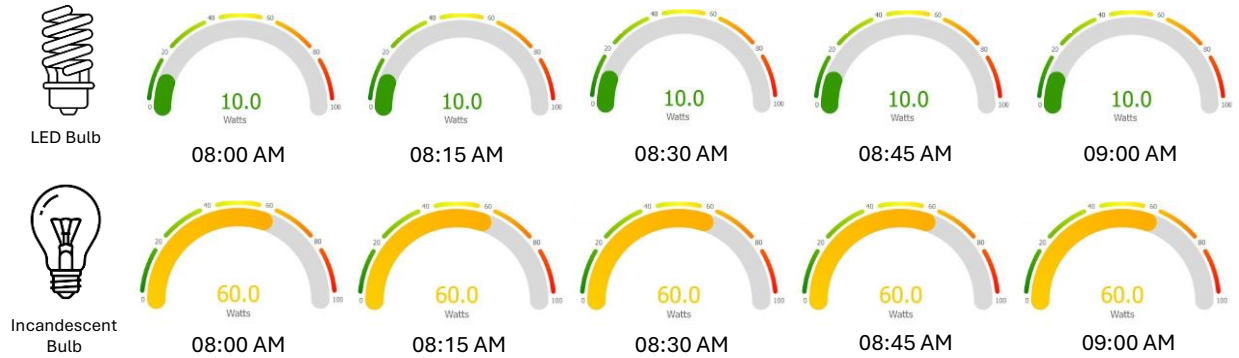


Figure 26: Circular column chart comparing the LED Bulb Vs. the Incandescent Bulb.

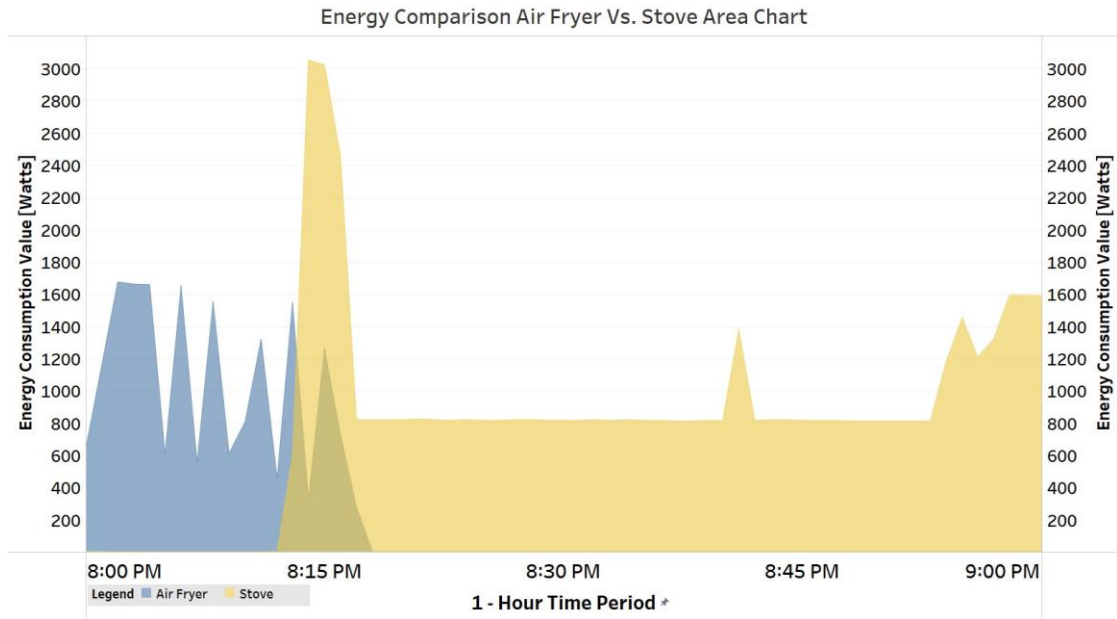


Figure 27: Area chart comparing the Air Fryer Vs. the Stove.

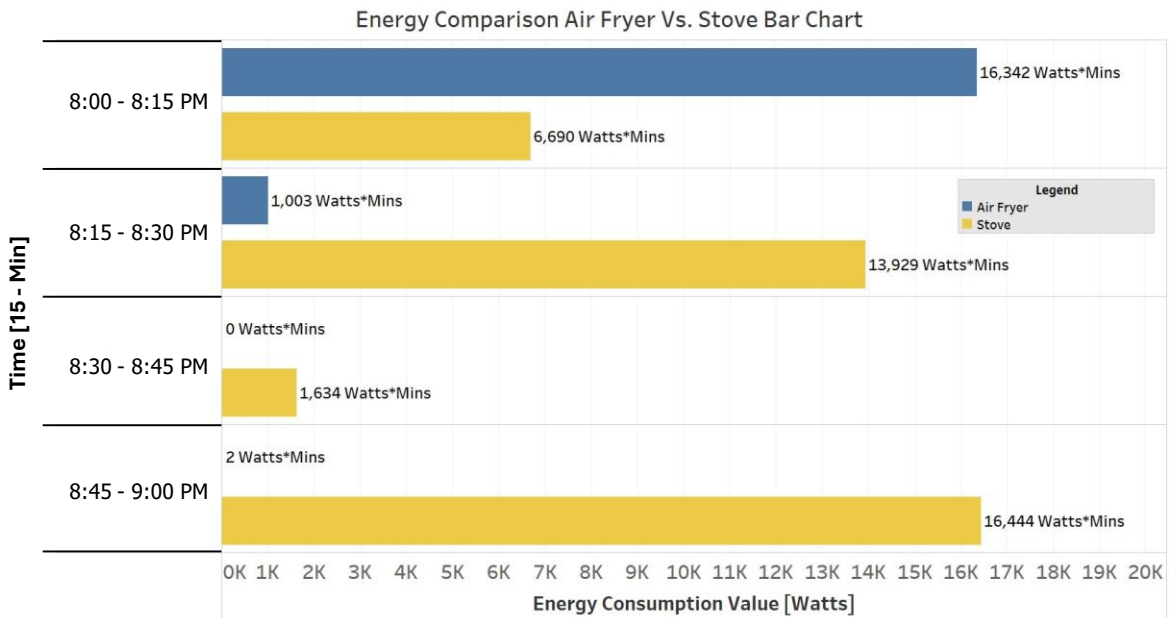


Figure 28: Bar chart comparing the Air Fryer Vs. the Stove.

Energy Comparison Stove Vs. Air Fryer

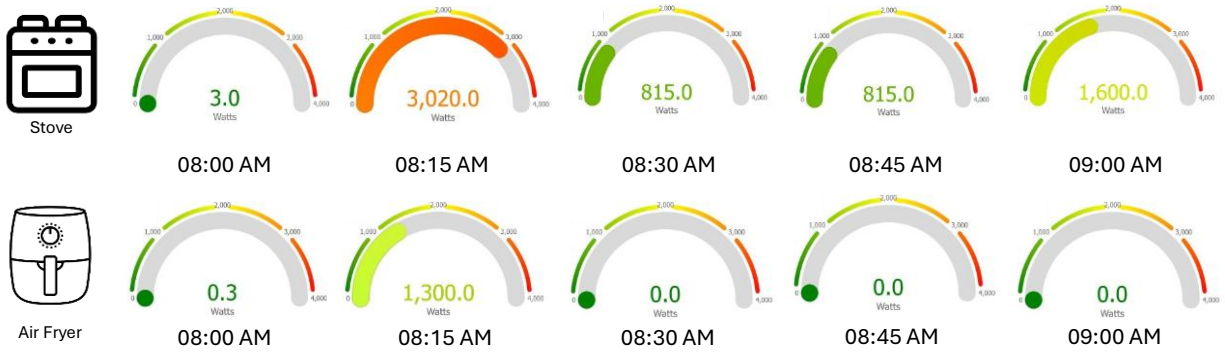


Figure 29: Circular column chart comparing the Air Fryer Vs. the Stove.

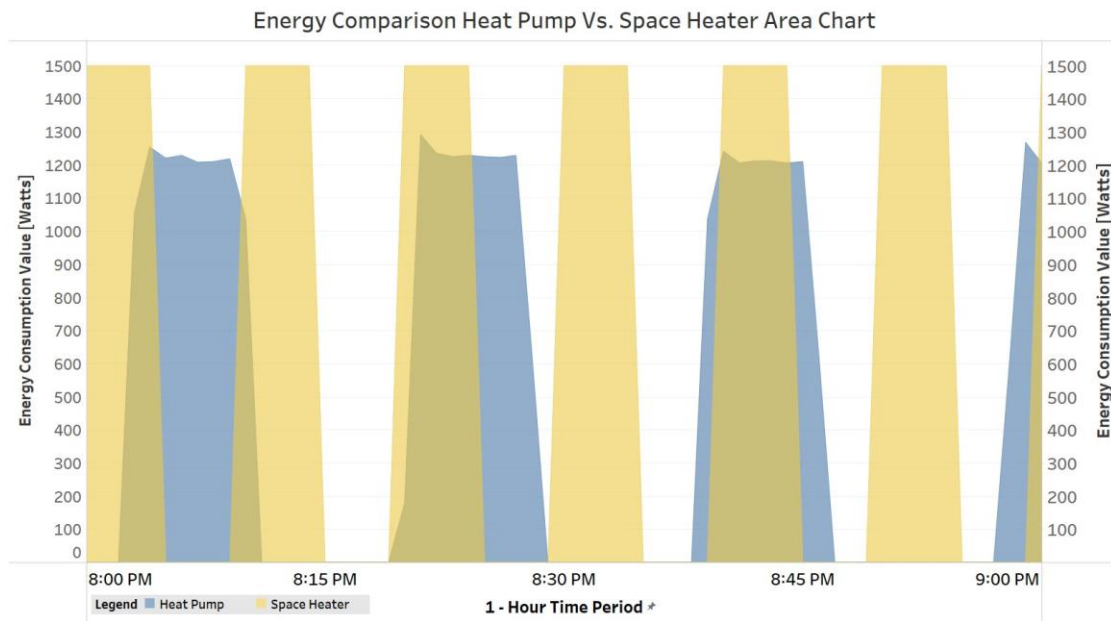


Figure 30: Area chart comparing the Heat Pump Vs. the Space Heater.

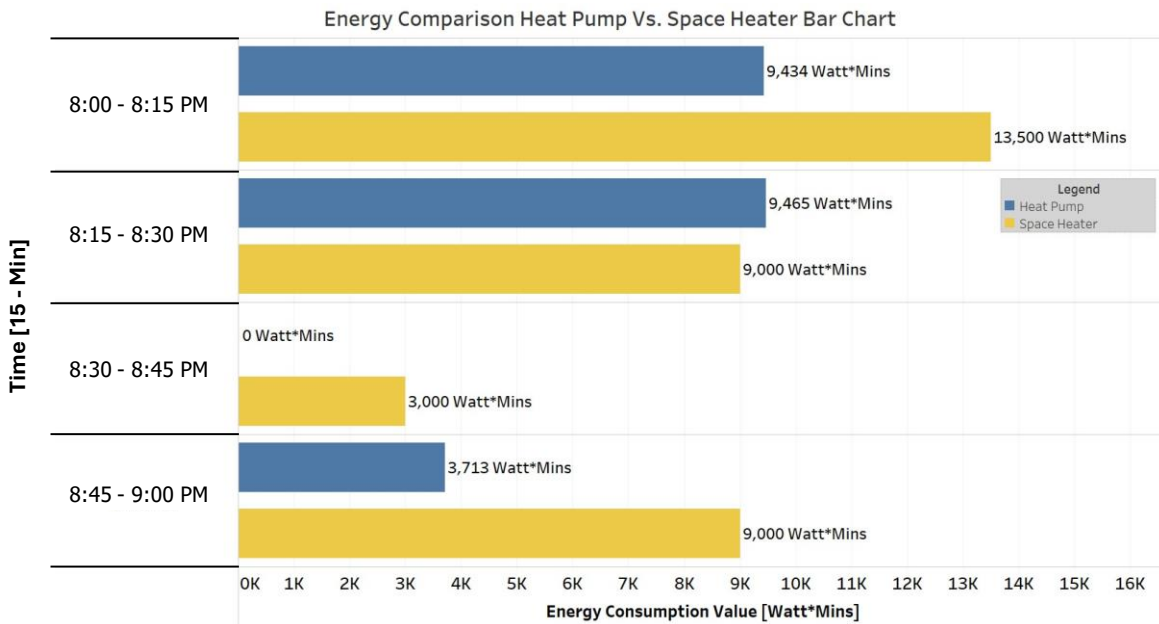


Figure 31: Bar chart comparing the Heat Pump Vs. the Space Heater.

Energy Comparison Heat Pump Vs. Space Heater

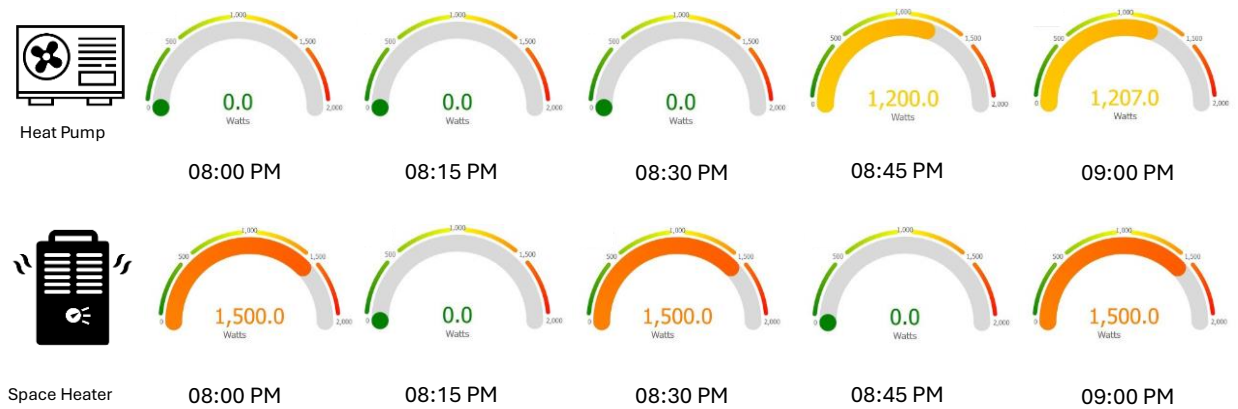


Figure 32: Circular column chart comparing the Heat Pump Vs. the Space Heater.

APPENDIX B – Chapter 4 Manuscript #2

B.1 - VR Questionnaire for Reading, working with, analyzing, and arguing

B.1.1 Questionnaire for Lighting Appliance Pair

VR Data Visualization – Color Coding

Read (What data is represented?):

What colors are shown on the LED bulb, then the incandescent bulb?

Work with (Acquiring):

Determine the average number of seconds each color is present on the LED and incandescent bulb, remember the energy data updates every data and is looped to repeat itself every 5 seconds.

*Remember the color resets every five seconds.

Is the color changing?

Determine the average number of seconds each color is shown.

How long is each other color shown (in seconds) on the LED and Incandescent bulb?*

Remember the color resets every five seconds

Analyze (Aggregating):

How are the colors linked/relation to the energy consumption amount?

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the LED bulb consumes more energy than the incandescent bulb.

VR Data Visualization – Electricity Flowing

Read (What data is represented?):

How is the electricity flowing through the wire to the LED bulb, then the incandescent bulb?

Work with (Acquiring):

Determine the average electricity flow speed of the LED and incandescent bulb.

**If you had to quantify it

Analyze (Aggregating):

How is the electricity flow linked/related to the energy consumption amount/level?

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the incandescent bulb consumes more energy than the LED bulb.

VR Data Visualization – Power Meter

Read (What data is represented?):

How many blocks are used in the power meter of the LED, then how many have used in the Incandescent bulb?

Work with (Acquiring):

Determine the average number of boxes used in the LED and incandescent bulb.

Analyze (Aggregating):

How are the boxes linked/related to the energy consumption amount?

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the LED bulb consumes more energy than the incandescent bulb.

B.1.2 Questionnaire for Cooking Appliance Pair

VR Data Visualization – Color Coding

Read (What data is represented?):

What colors are shown on the air fryer, then the stove?

Work with (Acquiring):

Determine the average number of seconds each color is shown on the stove, and air fryer
remember the energy data updates every second and is looped to repeat itself every 5 seconds.

***How long is each color shown (in seconds) on the stove and air fryer?

Remember the color resets every five seconds

Analyze (Aggregating):

How are the colors linked/related to the energy consumption amount?

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the stove consumes more energy than the air fryer.

VR Data Visualization – Electricity Flowing

Read (What data is represented?):

How is the electricity flowing through the wire to the air fryer, then the stove?

Work with (Acquiring):

***Determine the average electricity flow speed of the stove and the air fryer.

How would you quantify the electricity flow speed of the stove and air fryer?

Analyze (Aggregating):

How is the electricity flow linked/related to the energy consumption amount?

Argue (Provide evidence):

How would you use the electricity flow to provide evidence to argue or justify the following statement: Johnny believes that the air fryer consumes more energy than the stove.

VR Data Visualization – Power Meter

Read (What data is represented?):

How many blocks are used in the power meter for the air fryer, then how many have used in the stove?

Work with (Acquiring):

Determine the average number of boxes used in the air fryer and stove.

Analyze (Aggregating):

How are the boxes linked/related to the energy consumption amount?

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the stove consumes more energy than the air fryer.

B.1.3 Questionnaire for Heating Appliance Pair

VR Data Visualization – Color Coding

Read (What data is represented?):

What colors are shown on the heat pump, then the space heater?

Work with (Acquiring):

Determine the average number of seconds each color is present on the heat pump and space heater, remember the energy data updates every second and is looped to repeat itself every 5 seconds.

***How long is each other color shown (in seconds) on the heat pump and space heater?

Remember the color resets every five seconds

Analyze (Aggregating):

How are the colors linked/related to the energy consumption amount?

Argue (Provide evidence):

How would you virtual visual aid provide evidence to argue or justify the following statement:

Johnny believes that the heat pump consumes more energy than the space heater.

VR Data Visualization – Electricity Flowing

Read (What data is represented?):

How is the electricity flowing through the wire of the heat pump?, then the space heater?

Work with (Acquiring):

Determine the average electricity flow speed of the heat pump and space heater.

How would you quantify the speed of the flow to the heat pump? ... space heater?

Analyze (Aggregating):

How is the electricity flow linked/related to the energy consumption amount?

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes

that the space heater consumes more energy than the heat pump.

VR Data Visualization – Power Meter

Read (What data is represented?):

How many blocks are used in the power meter for the heat pump, then how many are used in the space heater?

Work with (Acquiring):

Determine the average number of boxes used for the heat pump and space heater.

Analyze (Aggregating):

How are the boxes linked/related to the energy consumption amount?

Argue (Provide evidence):

How would you provide evidence to argue or justify the following statement: Johnny believes that the heat pump consumes more energy than the space heater.

