# Human-Computer Interaction for Sustainable Energy: A Multimodal and Gamified Learning System

A Coursework Report for
Advanced Human Computer Interaction (F21AD)

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# 1 Introduction

This is a project report that explores the design of a Human-Computer Interaction (HCI) system that gamifies energy conservation through multimodal interaction within an (Internet of Things) IoT-integrated household. The project focuses on a family of four (two parents and two children, aged 13 and 5) who seek to estimate their energy consumption and learn about energy savings through an interactive and engaging experience.

The goal of this project is to develop an interactive, multimodal system that educates and motivates families, particularly children, on sustainable energy usage through gamification. By using User-Centred Design (UCD) principles, the system fosters engagement and behaviour change through a game-based approach.

The proposed solution integrates a well-structured interface and interaction model, incorporating touch, gesture, and voice-based modalities to enhance usability and engagement across different age groups. Accessibility and usability are prioritized by using WCAG 2.1 guidelines, ensuring inclusivity of users with colour blindness and other accessibility needs.

Beyond education, the system actively encourages habit formation and behaviour change through visual cues, digital nudges, and interactive challenges. The multimodal gaming experience in the app is designed to accommodate different cognitive and developmental levels, incorporating tailored feedback, interactivity, and progressive challenges that reinforce energy-saving behaviours.

Key game-based learning elements—such as rewards (Zaps), leaderboards, and daily challenges—further enhance motivation and encourage long-term engagement. This research-driven approach aims to provide an intuitive, engaging, and inclusive user experience, promoting environmental awareness and sustainable energy habits within households.

Insights from background research and requirements analysis have informed the design process, leading to the development of low-fidelity storyboards and a high-fidelity interactive prototype in Figma.

# 2 Background Research & Requirements Analysis

The design of effective Human-Computer Interaction (HCI) systems requires a User-Centred Design (UCD) approach, ensuring that systems align with users' cognitive abilities, behaviours, and preferences **(Norman, 1986)**. In the context of energy conservation, engagement and motivation are critical for sustained behaviour change (Froehlich et al., 2009).

This project focuses on the development of a gamified energy-saving system for a family of four (two parents and two children, aged 5 and 13). The system employs multimodal interaction (gesture, touch, and voice) and gamification techniques (leaderboards, rewards, eco-feedback) to educate and motivate household members toward sustainable energy usage.

To inform the design, this section presents a literature review on:

- Usability & UI design for energy conservation systems
- Multimodal interaction techniques (voice, gesture, touch) and their usability
- Gamification and behavioural psychology for habit formation
- Accessibility standards (WCAG 2.1) and inclusive design considerations

## 2.1 LITERATURE REVIEW

### 2.1.1 Usability & User Interface Design for Energy Conservation Systems

Effective UI design plays a key role in promoting energy-efficient behaviours. Studies show that real-time energy feedback, clear data visualization, and minimal cognitive load significantly affect engagement and decision-making.

**Murugesan et al. (2015, IEEE)** found that real-time energy usage feedback through visual dashboards increases user awareness and reduces energy consumption by up to 20%. Our design adopts a dashboard-based UI that presents real-time household energy data using clear graphical representations.

**Still et al. (2020, AIS Transactions on HCI)** emphasize that saliency in mobile interfaces improves user engagement by ensuring that essential information (e.g., energy usage alerts) is distinctly displayed. Our UI applies visual saliency principles, highlighting urgent notifications in high-contrast colours.

**Rosa & Valentim (2020, ACM)** investigated the usability challenges faced by visually impaired users in mobile apps, finding that colour contrast, font scalability, and voice interaction are critical for inclusivity. Our system adheres to WCAG 2.1 accessibility guidelines, offering adjustable font sizes, high-contrast modes, and voice command options.

**Our Conclusion :** These findings justify a UI/UX decision that enables a data-driven, visually engaging, and accessibility-compliant interface to effectively support energy conservation behaviours.

### 2.1.2 Multimodal Interaction: Touch, Gesture, And Voice Inputs

Multimodal interfaces enhance usability by accommodating diverse user preferences and cognitive abilities. Different users—particularly children and individuals with accessibility needs—benefit from voice commands, gesture-based controls, and interactive touch elements. **Chen et al. (2020, IEEE)** explored child-computer interaction, concluding that children of ages 5-13 prefer voice and gesture interactions over text-based inputs. This insight supports our integration of gesture-controlled lighting and voice-activated tasks to engage younger users effectively.

**Froehlich et al. (2009, ACM)** highlighted the impact that tangible feedback mechanisms (e.g., buttons, interactive objects) had to enhance learning and retention. Inspired by this, our design includes a physical confirmation button for children to verify completed energy-saving actions.

**Zhuang et al. (2019, ScienceDirect)** demonstrated how interactive feedback mechanisms influence behaviour change in energy-related tasks**.** While their study focused on air-conditioning settings in workplaces**,** the principles of instant feedback and behaviour reinforcement apply to our gamified approach to household energy conservation**.**

**Our Conclusion :** These studies confirm a design decision to use voice-driven commands, gesture-based appliance control, and tangible interactions for improving usability and engagement.

### 2.1.3 Gamification & Behavioural Change for Energy Conservation

Gamification is a proven behavioural psychology tool for habit formation and motivation. Studies in energy conservation and environmental education suggest that game elements such as rewards, leaderboards, and eco-feedback improve user engagement and long-term behaviour change.

**Jinsong et al. (2024, Springer)** demonstrated that serious games significantly improve environmental awareness and decision-making skills. Our system leverages a gamified leaderboard and reward system (‘Zaps’) to encourage household members—especially children—to actively participate in energy-saving challenges.

**Sanguinetti et al. (2018, Elsevier)** found that eco-feedback mechanisms (real-time updates on energy usage) significantly reduce electricity consumption by making energy-saving efforts visible and rewarding. Our app integrates a gamified eco-feedback loop, where users receive instant performance-based rewards for reducing energy waste.

**Patricia et al. (2013, Springer)** explored the role of persuasion in energy consumption behaviour, emphasizing that interactive information displays influence decision-making. This supports our design of daily energy-saving tips and real-time nudges, helping users develop sustainable habits.

**Our Conclusion :** These studies support our use of game mechanics and eco-feedback to encourage long-term energy-saving habits.

### 2.1.4 Accessibility & Inclusive Design Considerations

A key challenge in mobile UI design is ensuring accessibility for users with disabilities. Many energy-saving applications fail to accommodate visually impaired, colour-blind, or neurodiverse users, limiting inclusivity.

**WCAG 2.1 (W3C)** outlines accessibility principles such as sharp contrast, text size adjustability, and multimodal interaction. Our system follows these principles by allowing customizable fonts, high-contrast themes, and voice aid.

**Cordell (2015, Springer)** discusses cognitive accessibility, highlighting that clear navigation and visual cues improve usability for children. Our dual-mode interface (simplified for kids, detailed for parents) aligns with these insights.

**Bosserez (2018, DRS)** emphasizes the need for designing for dynamic user behaviour rather than static environments when encouraging energy-saving habits. This insight supports our adaptive UI elements, ensuring real-time adjustments based on user engagement and learning progression.

**Our Conclusion :** These sources informed us of the methods to include a accessibility-first design approach, ensuring easy and fair access for all users.

## 2.2 DESIGN REQUIREMENTS IDENTIFIED

**From our literature review, we define key usability, accessibility, and interaction goals:**

| Requirement | Justification (Research Backing) | Implementation in App |
|---|---|---|
| **Gamification & Rewards** | ***(Jinsong et al., 2024)*** Leaderboards & incentives sustain engagement. | Leaderboard, Zaps reward system, progress tracking. |
| **Multimodal Interaction** | ***(Chen et al., 2020)*** Kids prefer gesture & voice commands. | Voice-controlled tasks, gesture-based actions, touch UI. |
| **Real-Time Feedback** | ***(Sanguinetti et al., 2018)*** Immediate feedback improves habits. | Energy usage dashboard, daily insights, notifications. |
| **Accessibility Compliance** | ***(WCAG 2.1)*** High contrast, font scaling & voice interaction. | Colour-blind friendly colour palette, voice assistant, scalable UI. |
| **Persuasive UI Design** | ***(Patricia et al., 2013)*** Information display influences behaviour. | Interactive dashboards, energy-saving tips, real-time nudges. |

# 3 Low Fidelity design using Personae, Storyboards & Use Cases

Designing an effective multimodal, gamified energy-saving system requires a clear understanding of end-user characteristics, behaviours, and needs. User personas, storyboards, and use cases are essential user-centred design (UCD) tools that help shape interaction flows, accessibility considerations, and engagement strategies **(Norman, 1986).**

This section presents:

- Personae that define the primary users and their goals.
- Storyboards illustrating real-world usage scenarios.
- Use cases outlining key interactions between users and the system.

## 3.1 PERSONAE

### 3.1.1 Persona of Jay Thompson ( Father)

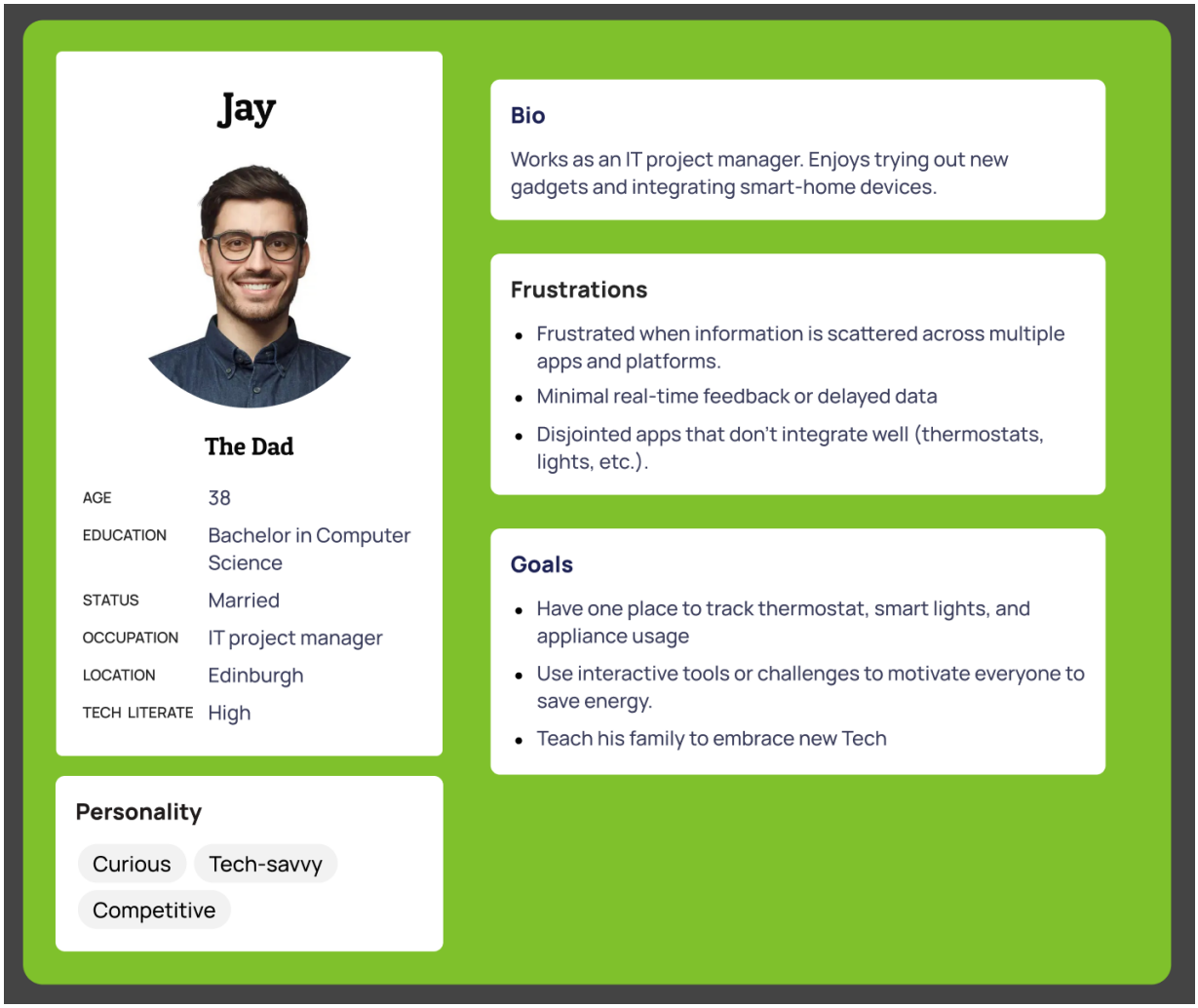



**Fig 1. Persona of the Father (Jay Thompson)**

### 3.1.2 Persona of the Ann Thompson (Mother)

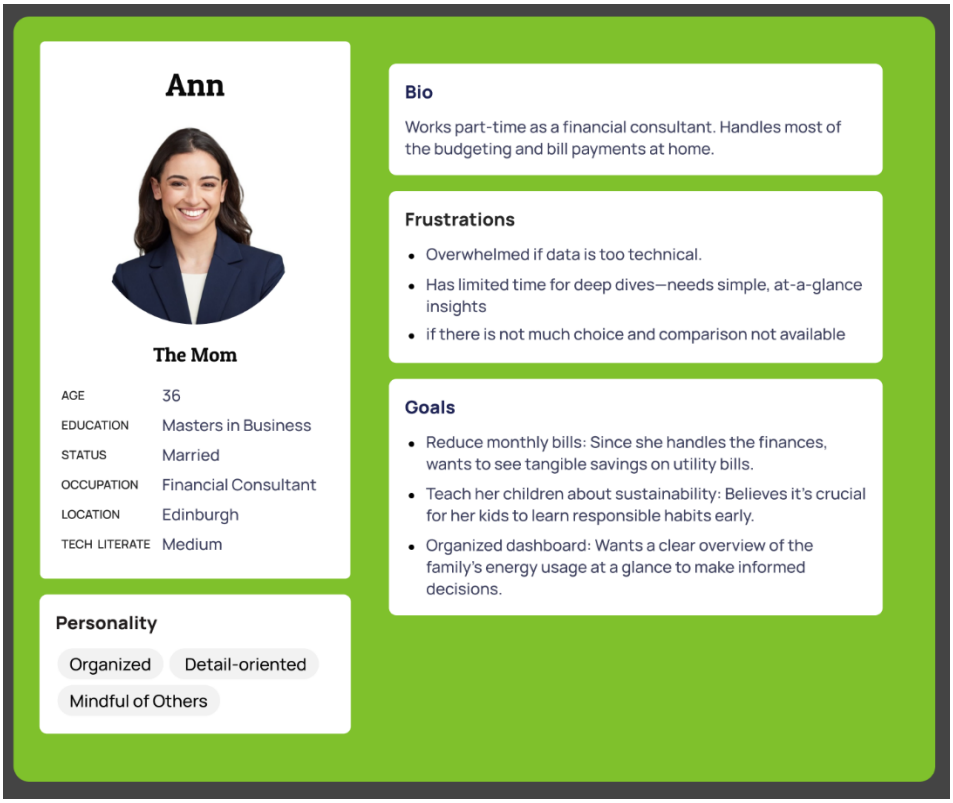



**Fig 2. Persona of the Mother (Ann Thompson)**

### 3.1.3 Persona of Tabitha Thompson (13y old child)

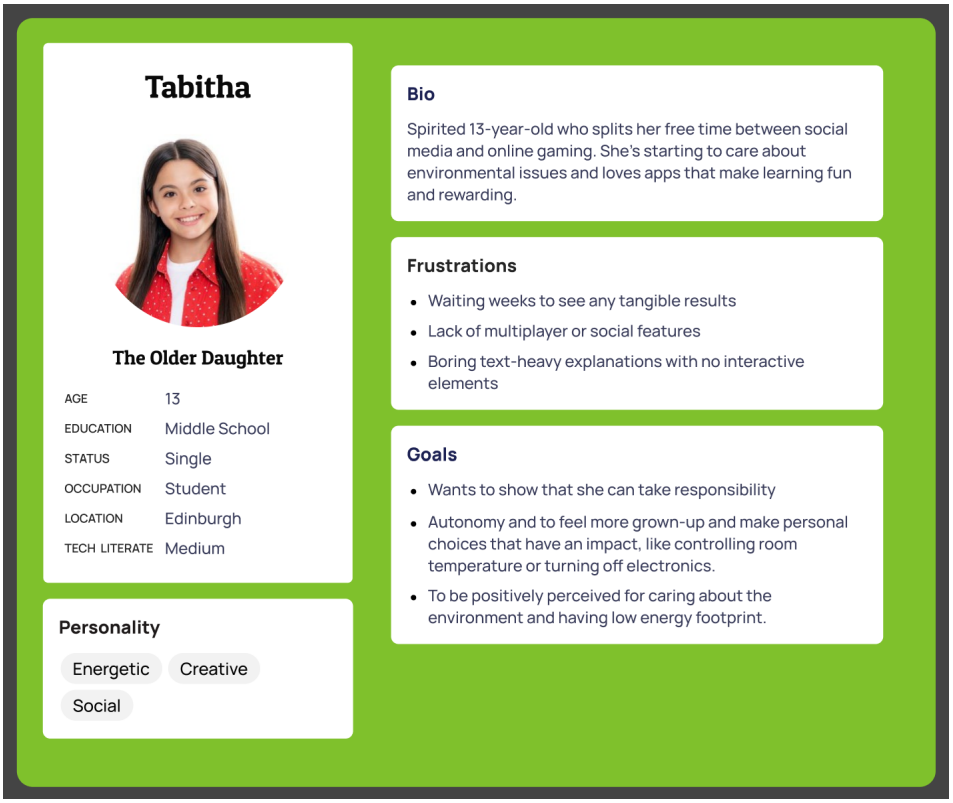



**Fig 3. Persona of the 13y old Child (Tabitha Thompson)**

### 3.1.4 Persona of Zoe Thompson (5y old child)

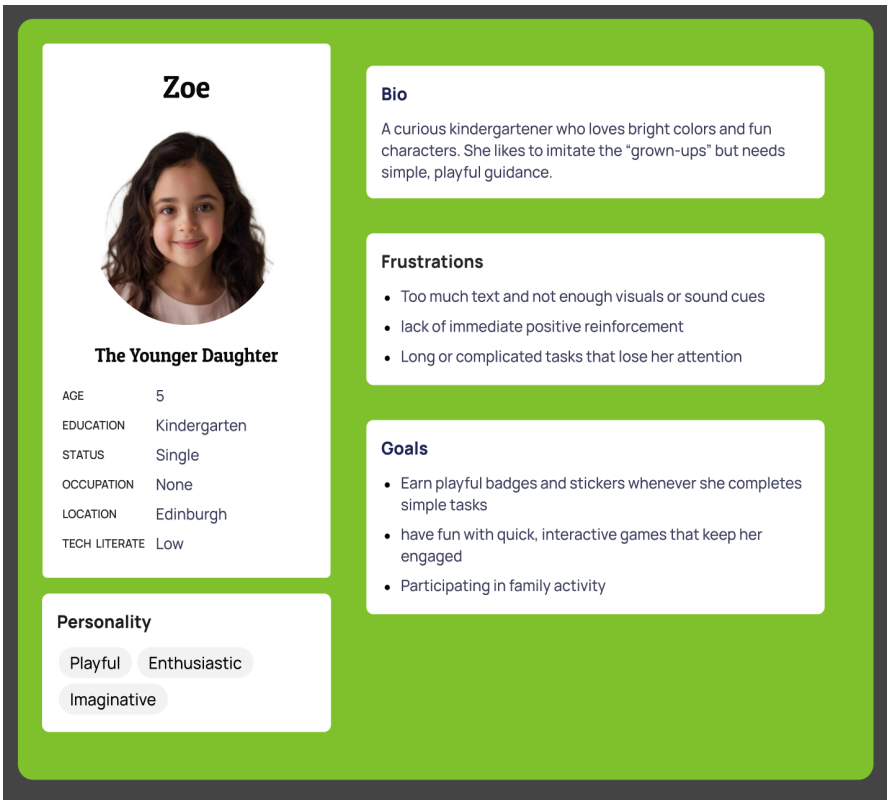



**Fig 4. Persona of the 5y old Child (Zoe Thompson)**

## 3.2 STORYBOARDS AND USE CASES

Storyboards visually illustrate how users interact with the system in real-world scenarios. The following scenarios cover multimodal interactions (touch, voice, gesture), accessibility, and gamification elements.

### 3.2.1 Storyboard 1: Parent remotely monitoring Energy Usage and Turns off the Air Conditioner (A/C).

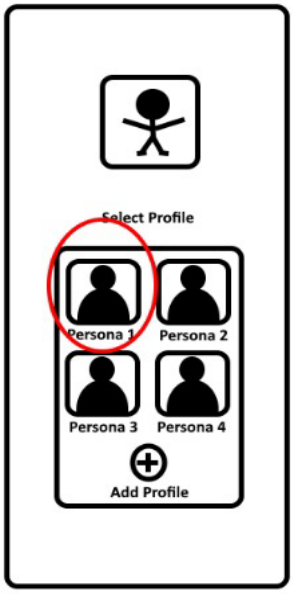
Scenario:

Jay logs into the parent dashboard to check household energy usage. He notices that the A/C is left on and uses the remote-control feature from the device's menu to turn it off.

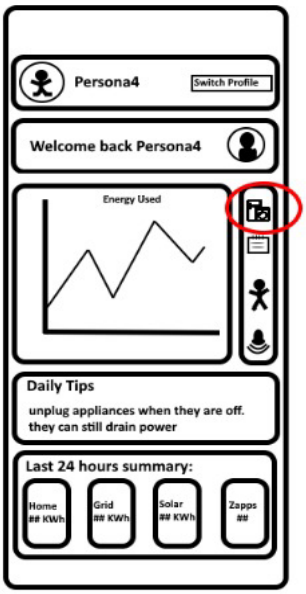
Flow:

1. Jay opens the app → Completes Login to select profile → App Shows "Energy Dashboard".
2. Views total household energy consumption.
3. Notices A/C is left on and is consuming energy.
4. Goes to devices homepage to turn off the A/C remotely.

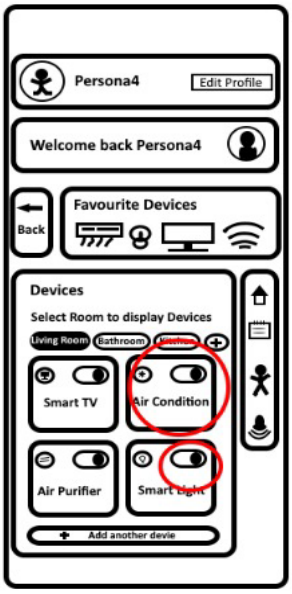

User Logs in



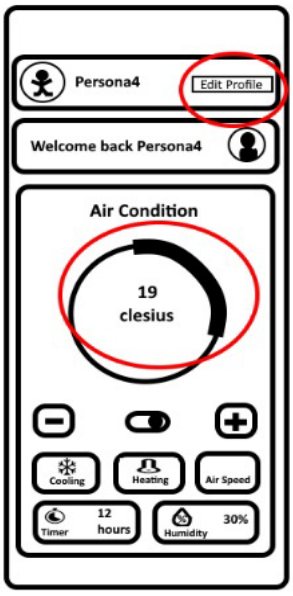

They select their profile



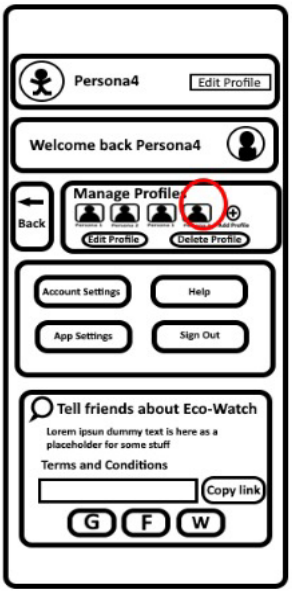

They view daily usage summary then they click on device icon




They see which devices are on then they turn off the lights by switching the toggle. Then they click on the air condition to view




They change the temperature then they decide to edit their profile




They can edit their profile or the children's profiles

**Fig 5. Storyboard of the Parent Use Case**

### 3.2.2 Storyboard 2: Child Engaging in Gamified Task.

Scenario:

Zoe waves at Mr. Zappy to turn off the light and earns a Zap reward.

Flow:

1. Zoe opens the app → Completes Login to select profile → App Shows "Task Available".
2. Presses begin button to start the task.
3. Zoe waves at Mr. Zappy to turn off the light and earns a Zap reward.
4. Goes to Race Leaderboard to spend the earned Zaps .

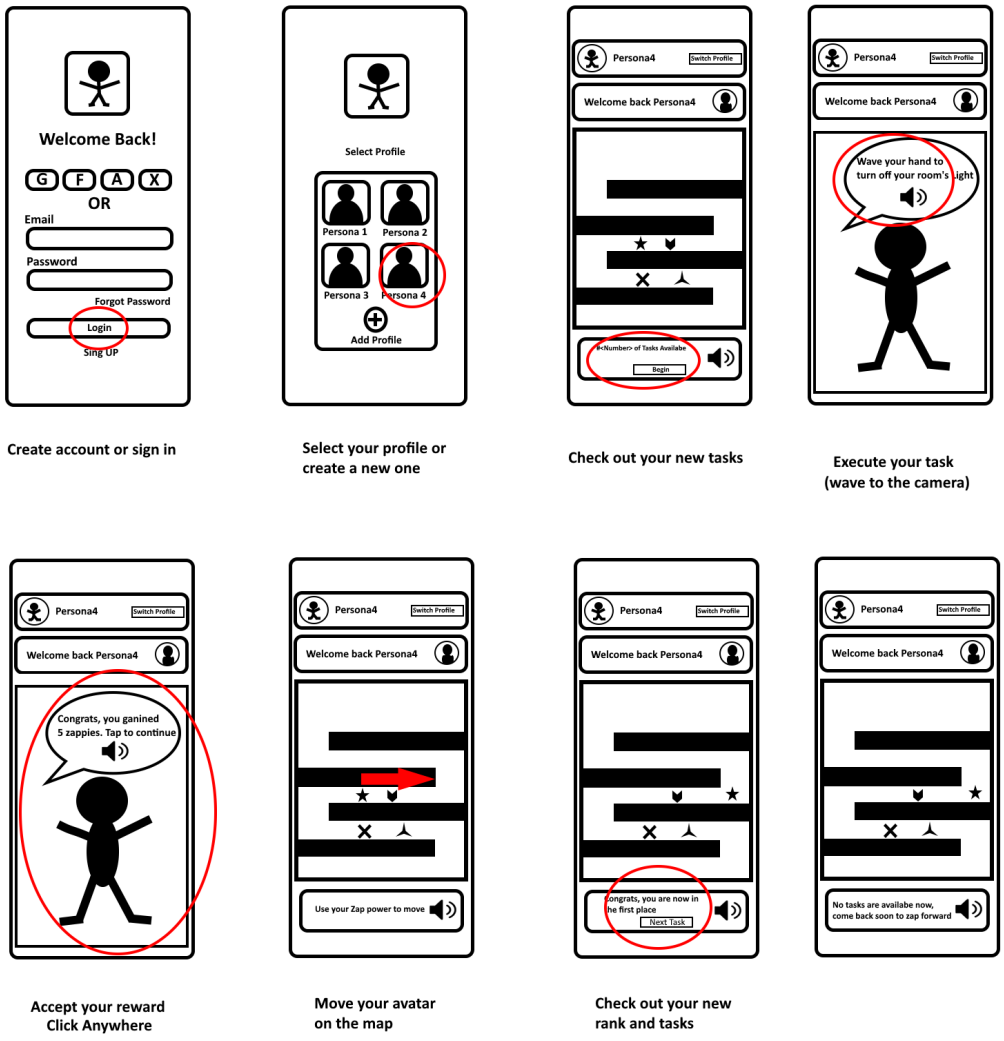



**Fig 6. Storyboard of the Child Use Case**

## 3.3 Feedback Received for Low Fidelity Design

3 details advised to us by our mentor for the transition from the low fidelity design phase to high fidelity design phase were :

- To ensure adequate accessibility features are added.
- To ensure consistency in UI/UX features.
- To ensure strict compliance with WCAG 2.1 (W3C) Guidelines.

# 4 High-Fidelity Prototype Implementation

## 4.1 Overview Of the Figma Prototype

The Eco-Watch application is a high-fidelity interactive prototype developed using Figma. It features multimodal interactions, gamification mechanics, and accessibility enhancements designed to help a family of four (two parents, two children aged 13 and 5) understand and reduce their energy usage.

The prototype includes an interactive user interface where users can monitor energy consumption, participate in gamified energy-saving tasks, and track their progress through leaderboards and rewards (Zaps). The design adheres to Advanced Human-Computer Interaction (HCI) principles and follows the User-Centred Design (UCD) methodology, ensuring an engaging, inclusive, and educational experience.

### 4.1.1 Key Features and Interaction Design

1. User Profiles & Personalized Dashboards

- Parent Dashboard: Provides real-time energy usage monitoring, cost tracking, and device control.
- Child Dashboard: Features an interactive, gamified interface that rewards sustainable actions.
- Profile Switching: Users can switch between profiles to access different interfaces tailored to their roles.

2. Multimodal Interaction & Gamification

- Touch Interface: Allows users to interact with dashboards, set preferences, and track progress.
- Gesture-Based Controls: Designed for children to turn off appliances by waving at the screen.
- Voice Commands: Supports hands-free interaction, particularly beneficial for younger children and accessibility needs.
- Gamified Rewards (Zaps): Users earn Zaps for completing energy-saving challenges, which can be used in the in-app leaderboard system.

3. Real-Time Feedback & Eco-Nudging

- Daily Tips & Insights: Users receive personalized energy-saving suggestions based on their consumption habits.
- Dynamic Energy Visualization: Real-time graphical representation of household energy consumption trends.
- Adaptive Challenges: Tasks vary based on real-time energy usage patterns to encourage behaviour change.

### 4.1.2 Accessibility and Inclusive Design

The prototype integrates Web Content Accessibility Guidelines (WCAG 2.1) to ensure usability for all users, including those with disabilities.

- Colour-Blind Friendly UI: High-contrast themes and a colour palette meeting AAA and AA compliance standards.
- Adjustable Text Size: Users can modify font sizes to enhance readability.
- Voice Assistive Features: Enables hands-free interaction, particularly useful for children and visually impaired users.
- Simple & Intuitive Navigation: Designed to accommodate all age groups, including young children.

## 4.2 User Interface (Annotated)

### 4.2.1 Start Screen


**Fig 7. User Onboarding - App Starting Screen**

### 4.2.2 Signup Screen

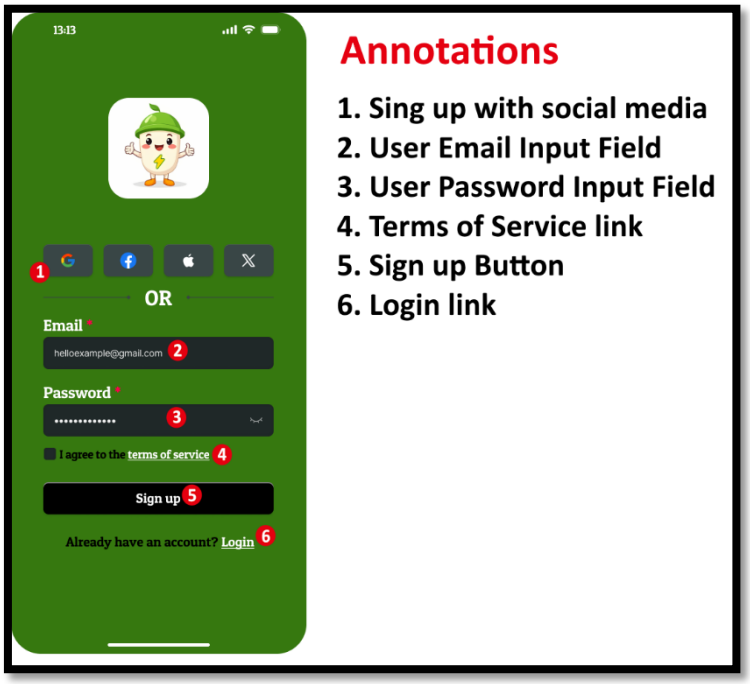



Fig 8. User Onboarding - Signup Screen

### 4.2.3 Login Screen


Fig 9. User Onboarding - Login Screen

### 4.2.4 Profile Creation Screen for New User

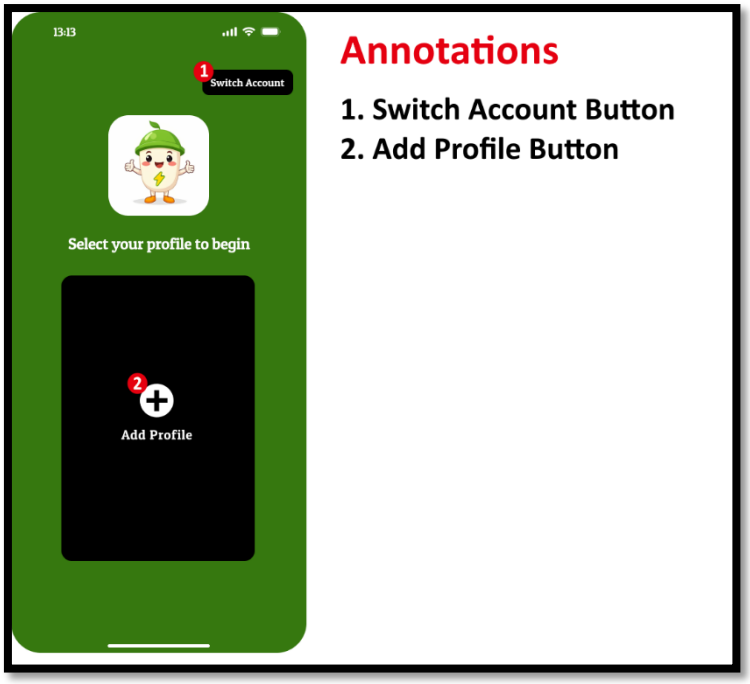



Fig 10. User Onboarding - Profile Creation Screen

### 4.2.5 Profile Selection Screen for New User


Fig 11. User Profile Selection Screen

### 4.2.6 Parent Dashboard Home Screen

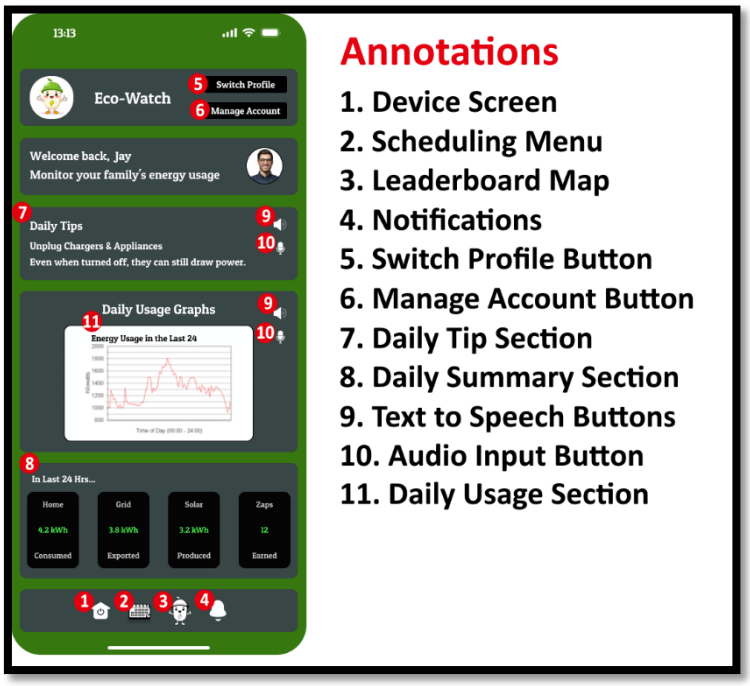



**Fig12. Parent Dashboard - Home Screen**

### 4.2.7 Parent Dashboard Devices Screen

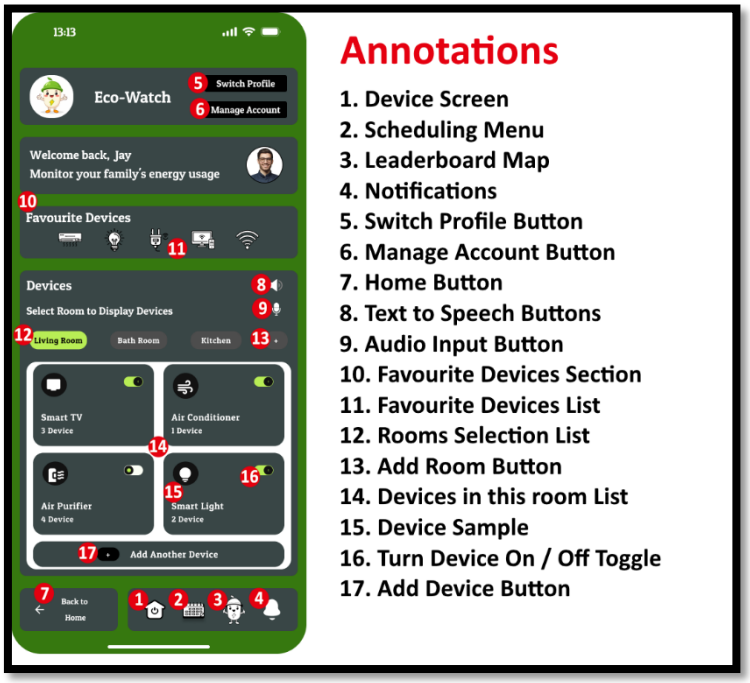



**Fig 13. Parent Dashboard - Devices Screen**

### 4.2.8 Parent Dashboard Device Control Screen

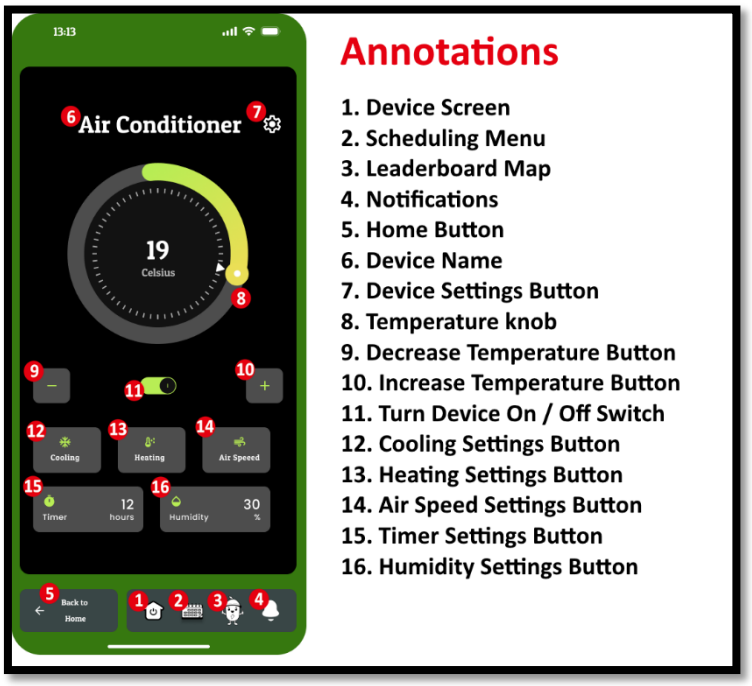



**Fig 14. Parent Dashboard - Device Control Screen**

### 4.2.9 Parent Dashboard Manage Account Screen


**Fig 15. Parent Dashboard - Manage Account Screen**

### 4.2.10 Parent Dashboard App Settings Screen

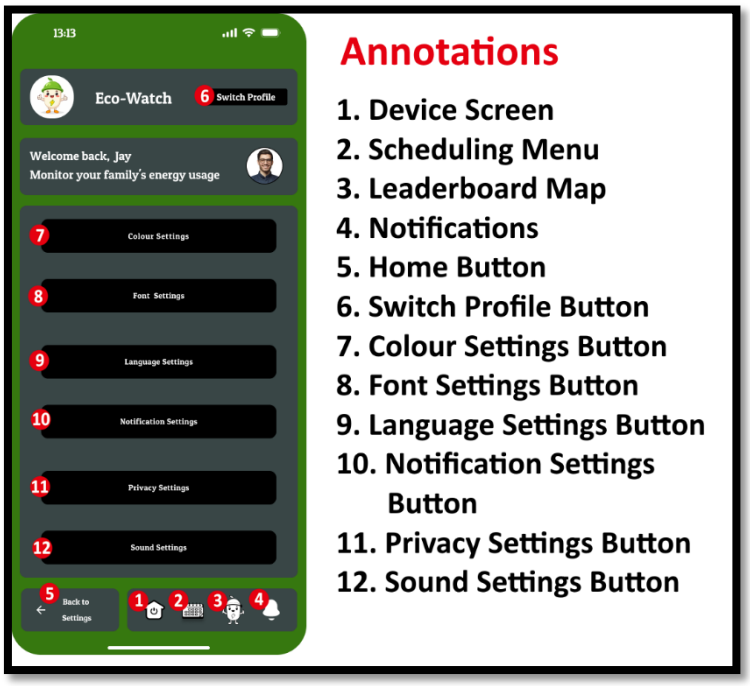



Fig 16. Parent Dashboard – App Settings Screen

### 4.2.11 Child Dashboard Home Screen

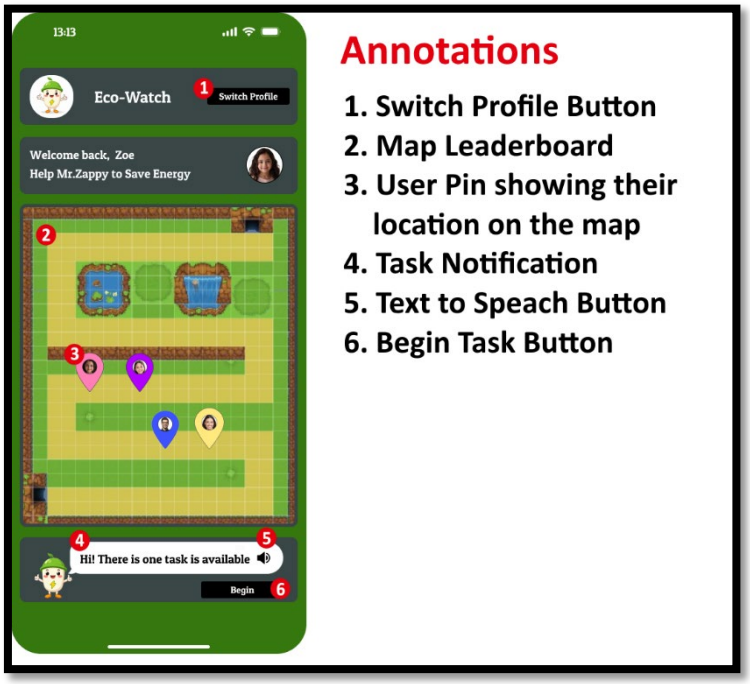



Fig 17. Child Dashboard - Home Screen

### 4.2.12 Child Dashboard Task Screen

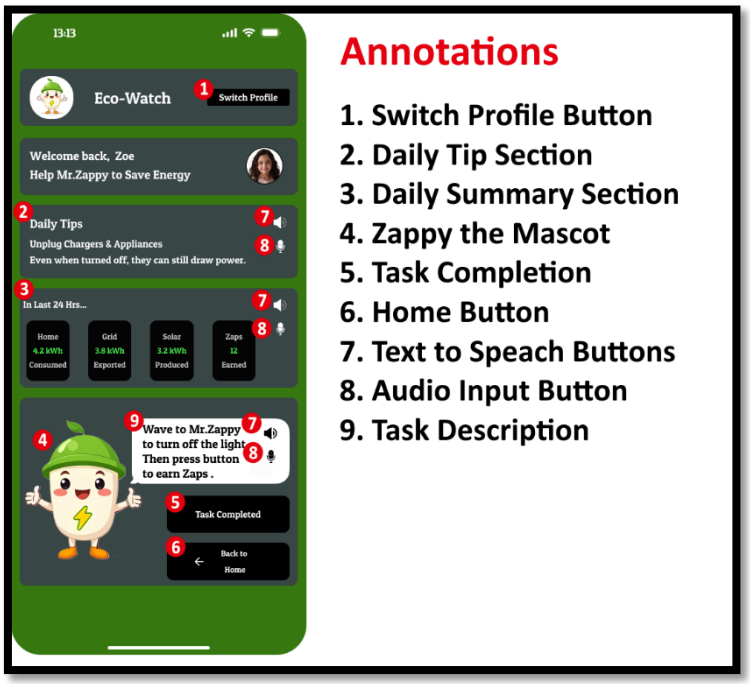



Fig 18. Child Dashboard – Task Screen

### 4.2.13 Child Dashboard Task Completion Screen

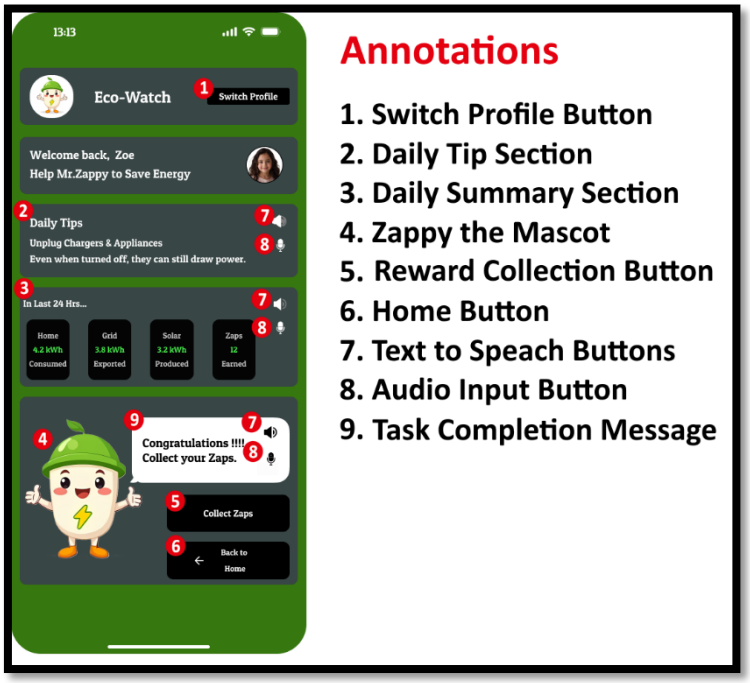



Fig 19. Child Dashboard – Task Completion Screen

### 4.2.14 Child Dashboard Leaderboard Screen

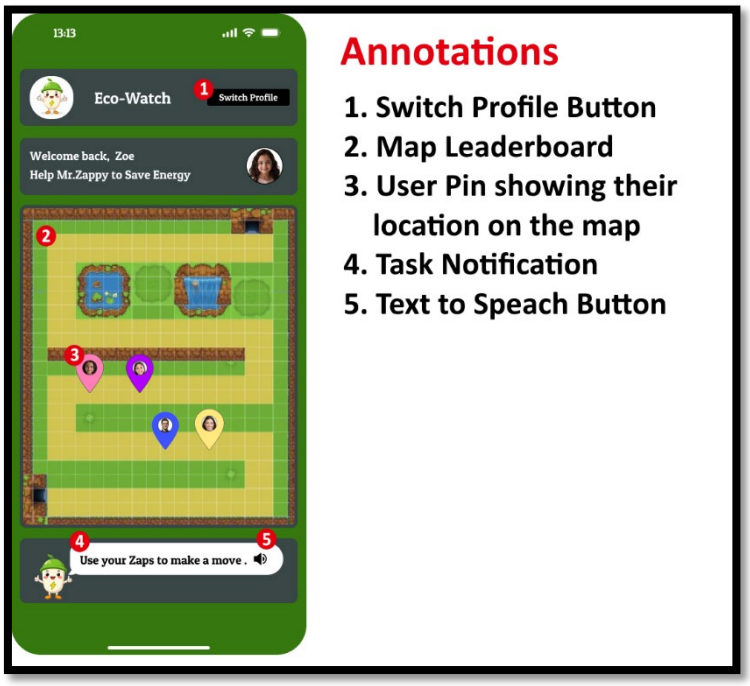



**Fig 20. Child Dashboard – Leaderboard Reward Screen**

### 4.2.15 Child Dashboard Leaderboard Progression Screen

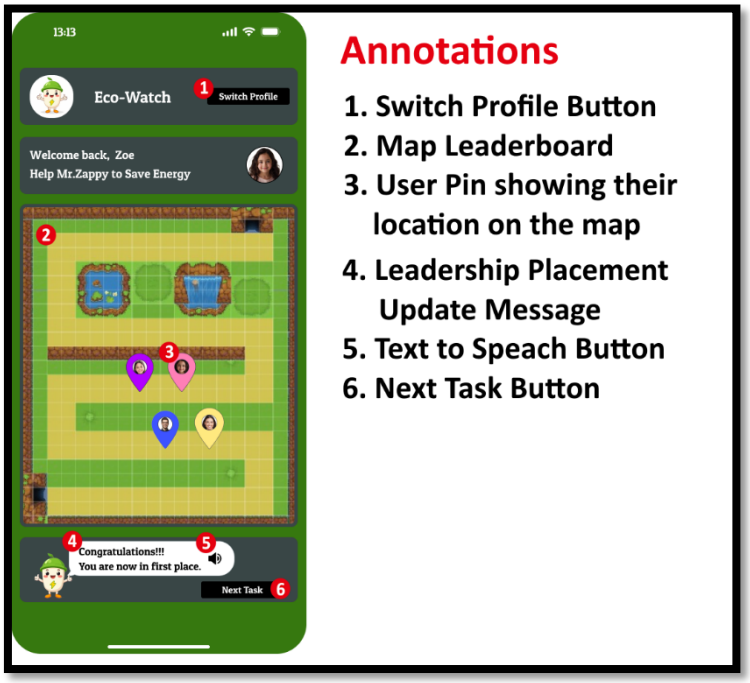



**Fig 21. Child Dashboard – Leaderboard Progression Screen**

### 4.2.16 Child Dashboard Return to Home Screen

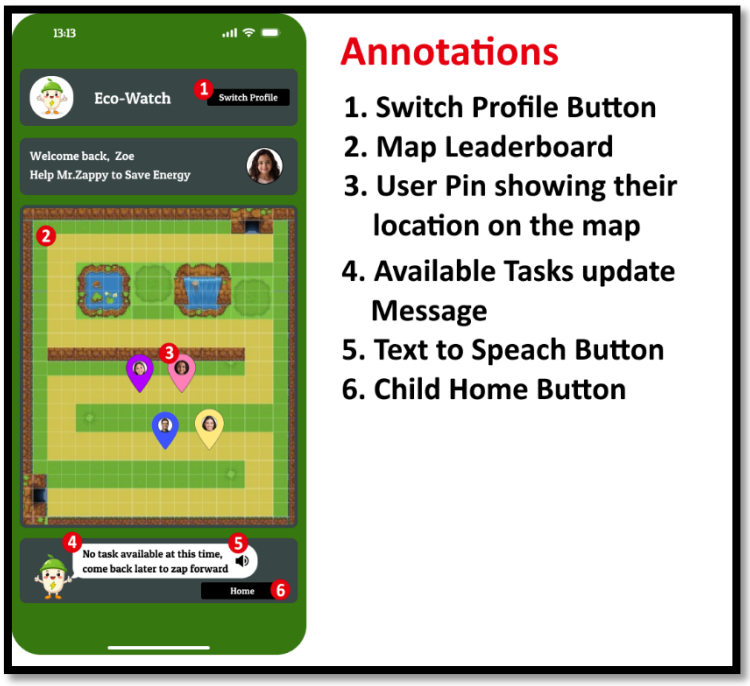



Fig 22. Child Dashboard – All Task Completed Screen

## 4.3 User Flow and Clickable Task Pathways

A general flow of the app is shown below using the high-fidelity prototype.

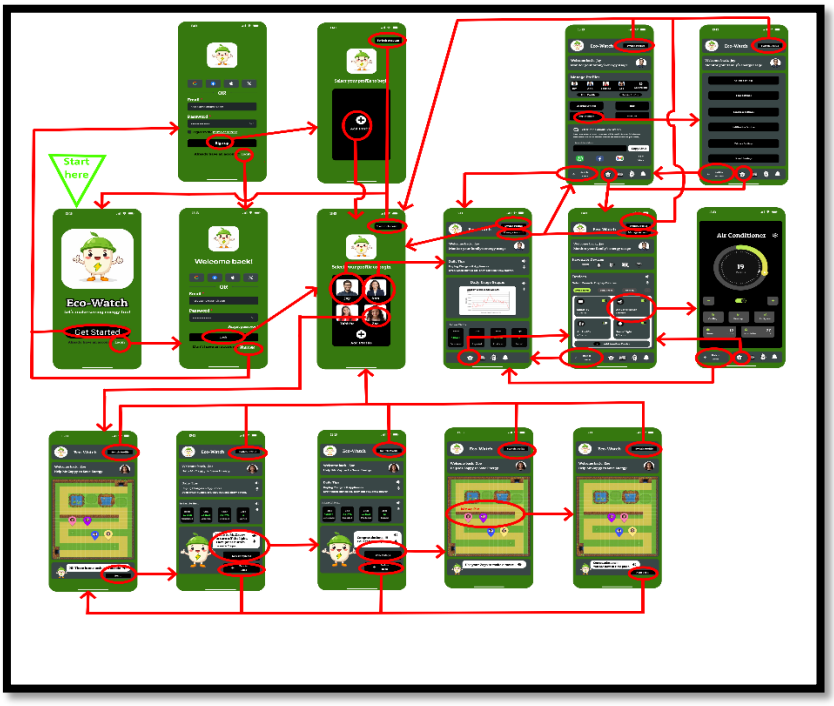



Fig 23. User Flow for the entire App

Two main task pathways were implemented in the Figma prototype to demonstrate core interactions. These are clearly described in the next two sections.

### 4.3.1 Task Pathway 1: Parent Remotely Managing Energy Usage

The flow of the app use case in the parent's scenario goes as follows :-

- Parent logs into the Eco-Watch app.
- Views real-time household energy consumption on the Dashboard.
- Notices that an appliance (e.g., Air Conditioner) is consuming excess energy.
- Navigates to the Device Management section.
- Turns off the appliance remotely using the app.
- Notices  updated energy statistics on the Parent Home Screen.

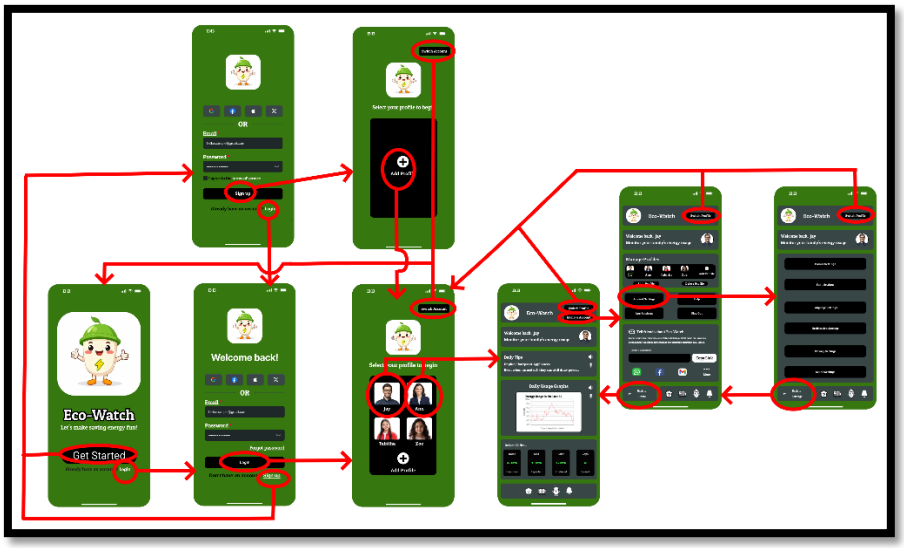



**Fig 23. User Flow for Parent through the App (New User)**


**Fig 23. User Flow for Parent through the App (Existing User)**

### 4.3.2 Task Pathway 2: Child Engaging in Gamified Task

The flow of the app use case in the child's scenario goes as follows :-

- Child logs into the Eco-Watch app.
- Receives an alert: "Task Available: Help Mr. Zappy Save Energy!"
- Presses "Begin Task".
- Waves at Mr. Zappy (gesture-based interaction) to turn off a virtual light.
- Earns Zaps (reward points) and moves up the leaderboard.
- Receives an energy-saving tip as a reward.

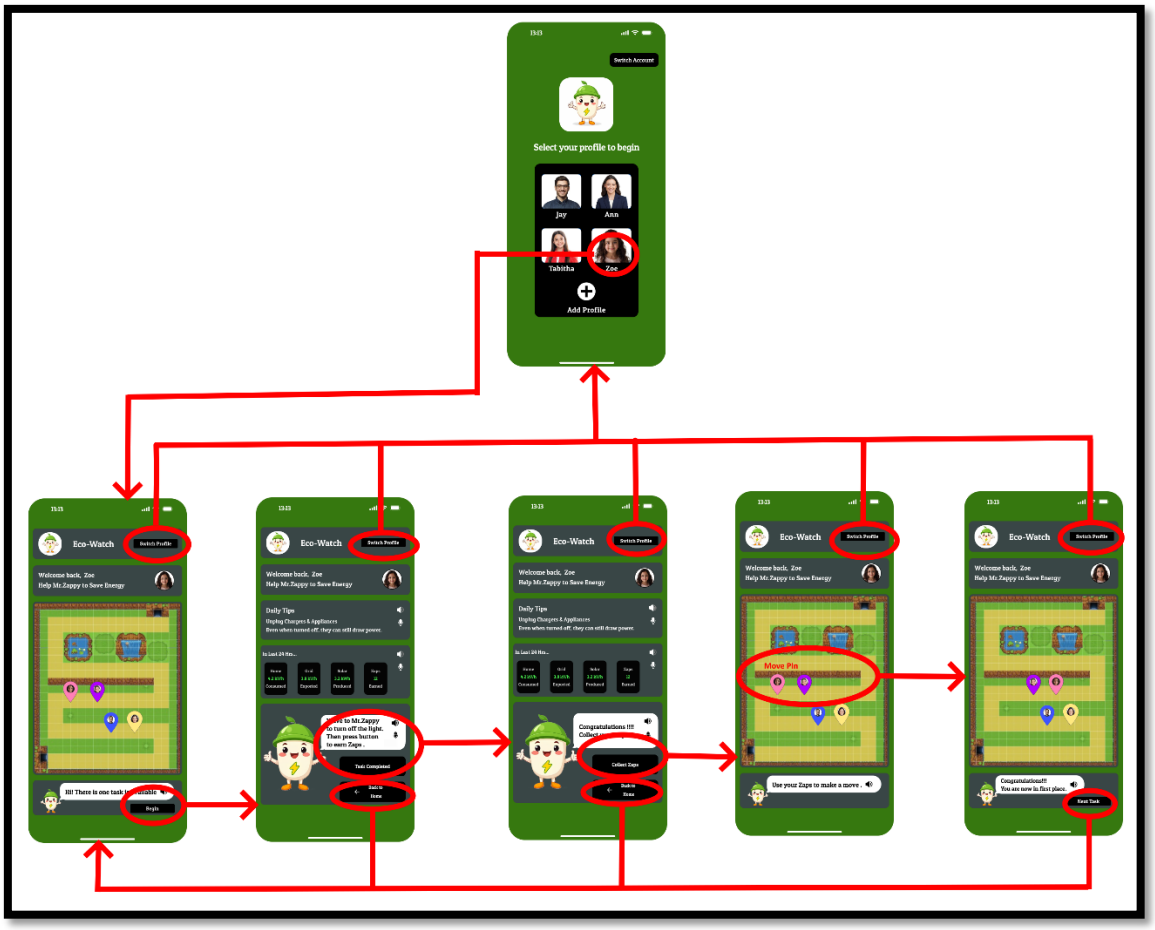



**Fig 23. User Flow for Child through the App**

# 5 Gantt Chart & Task Assignments

Syed Arif – SA

Ahsan Fazili – AF

Abdulla Allami -AA

| Tasks | Week 1 | Week 2 | Week 3 | Week 4 | Week 5 | Week 6 | Week 7 | Week 8 | Week 9 |
|---|---|---|---|---|---|---|---|---|---|
| **User Research** | | | SA AF AA | SA AF AA | | | | | |
| **Literature Review** | | | SA AF | AA | | | | | |
| **Storyboards** | | | | AA | | | | | |
| **Personae** | | | | SA | | | | | |
| **Use Cases** | | | | SA AF AA | | | | | |
| **Prototype Development** | | | | | SA AA | SA AF AA | | | |
| **Testing & Iteration** | | | | | | SA AF AA | SA AF AA | | |
| **Final Report** | | | | | | | AF | SA AF AA | |
| **Presentation & Demo** | | | | | | | SA AF AA (was sick) | | |

# 6 Figma Prototype Link

https://www.figma.com/proto/01jw3qDFwOrb9R7CNAfI20/Coursework---PG-DUbai---Group-3?page-id=0%3A1&node-id=3-14&p=f&viewport=36%2C38%2C0.16&t=DWsUO6v1FQH0nzAB-1&scaling=scale-down&content-scaling=fixed&starting-point-node-id=3%3A14

# 7 Conclusion

This report has detailed the design and development of Eco-Watch, an interactive, gamified, multimodal energy-saving system for a family of four. By leveraging User-Centered Design (UCD) principles and insights from advanced HCI research, our prototype fosters sustainable energy habits through engaging game mechanics and real-time feedback.

Our literature review highlighted the importance of usability, accessibility, multimodal interaction, and gamification in promoting behavioral change. Findings from reputable sources (Springer, Elsevier, ACM, IEEE) informed our design decisions, ensuring that the system is evidence-based and effective. The prototype integrates gesture-based interactions, voice commands, and touch-based controls to create an intuitive and inclusive experience for both young children and adults.

Through the low-fidelity storyboards and high-fidelity Figma prototype, we implemented key Advanced HCI concepts, including:

- Gamification mechanics (leaderboards, Zaps rewards, interactive challenges) to enhance engagement.
- Multimodal interaction (voice, gesture, touch) tailored to different user abilities.
- Accessibility features compliant with WCAG 2.1 guidelines, ensuring inclusiveness for all users.
- Real-time eco-feedback and nudges, encouraging continuous behavior change.

The evaluation of our design through expert feedback emphasized three key areas of improvement:

- Strengthening accessibility compliance with additional contrast options and text scalability.
- Ensuring consistency in UI/UX features for a seamless user experience.
- Refining gamification elements to maintain long-term engagement.

Future iterations of the system could explore adaptive AI-driven nudges for personalized energy-saving suggestions and sensor integration with IoT devices for automated energy monitoring.

By successfully addressing the coursework requirements, our project provides a research-driven, user-friendly, and engaging solution to household energy conservation.

The Eco-Watch system demonstrates how Human-Computer Interaction principles can drive sustainable behavior change while ensuring accessibility, usability, and engagement for all users.

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