# Lumi Alarm – A Physical Probe for Sleep Satisfaction

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## Abstract
This study applied a Data-enabled Design approach to explore users' sleep context through probe deployment. The resulting Lumi Alarm, a light-based inform probe, aims to reduce non-sleep activities in bed and enhance the sleep experience by encouraging regular bedtime routines through responsive ambient light cues. A pilot test showed that reminders by light reduced non-sleep activities in bed, improved sleep efficiency, and increased user satisfaction with overall sleep activity.

## Author Keywords
Data-driven design, data physicalisation, sleep experience

## Introduction
Sleep is a fundamental component of human health and well-being, playing a crucial role in physical restoration, cognitive function, and emotional regulation.

In recent years, due to the combined effects of physiological, psychological, and environmental factors, sleep-related issues have become—and continue to be—a global public health concern [12]. A U.S.-based study on sleep reports that approximately 69.3% of adults experienced insufficient sleep during the 30 days prior to the survey [13]. In the Netherlands, 43.2% of respondents reported insufficient sleep, with adolescent

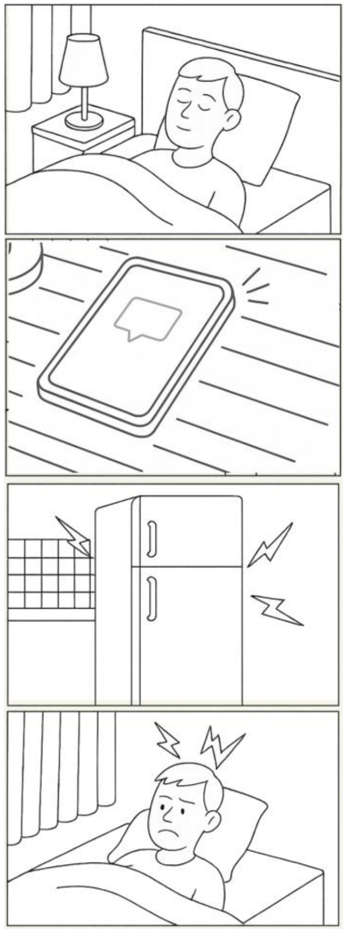

Figure 1: Scenario

females exhibiting particularly high rates of general sleep disturbances [9]. Many studies have identified low quality sleep as a causative factor in a range of physiological disorders such as cardiovascular disease, depression, anxiety, heart disease, etc [12, 1, 3]. According to Nelson et al., (2022), five core attributes have been identified as indicators of sleep quality: <u>sleep efficiency, sleep disturbances, sleep latency (SL), total sleep time, and wake after sleep onset (WASO)</u>. However, there remains a lack of clear, actionable strategies for how to <u>effectively improve sleep quality</u> based on these attributes.

In contrast, the findings of [11] offer a novel perspective: Rather than improving sleep efficiency, enhancing users' subjective well-being (SWB) regarding sleep can more effectively boost their positive mood and life satisfaction. Furthermore, sleep satisfaction has a more significant and sustained impact on future sleep, as well as physical and mental health. This view has also been validated in patients with sleep disorders or physical pain, for whom subjective feedback on sleep satisfaction effectively predicts and influences their fatigue or pain the next day [14, 15]**.** Therefore, while objectively poor sleep efficiency caused by environmental conditions, psychological stress, or physiological factors cannot be overlooked, <u>improving the subjective experience of sleep may represent a key pathway</u> toward enhancing both sleep quality and overall well-being.

In this context, we conducted an exploratory study using design interventions to better understand the factors that affect users' perceived sleep satisfaction and to explore opportunities for supporting more intentional and satisfying sleep behaviours.

## Method and challenges

We adopt the Research through Design (RtD) methodology as the overall methodological framework for this project [17]. RtD promotes knowledge generation through design practices and is particularly suitable for complex, subjective, and real-world contexts. Within this framework, we introduce the Data-Driven Design (DED) methodology [10] as the guiding approach. DED is a context-based design method that emphasises continuous interaction with users' living environments and treats data as creative material in the design process.

Additionally, we used a non-linear process to guide the development of research tools and design interventions [16]. This flexible structure enabled us to empathise with users, define challenges, generate ideas, prototype solutions, and evaluate outcomes in real-world contexts. During the contextual exploration and information exploration phases, we employed design probes [5, 8] to facilitate user reflection and collect qualitative and quantitative data. These probes helped us uncover potential behavioural and environmental factors influencing sleep satisfaction and supported the exploration of contextual user insights through physical data visualisation.

This study aimed to address two primary research questions: (1) What are the potential factors that may influence users' sleep satisfaction in everyday contexts? (2) Can the Physicalisation of users' sleep efficiency help them align their actual sleep performance with their expectations, thereby improving their subjective sleep satisfaction?

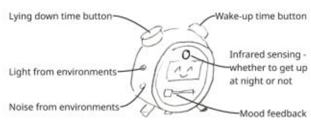


Figure 2: Ideation of the clock - shaped probe

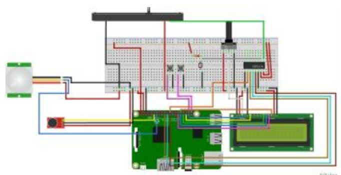

Figure 3: Module circuit design 1

Figure 4: Renderings of the development of probe 1

## Prototyping 1 - contextual exploration

## Empathy to ideation

Our design process began with a shared understanding that poor sleep environments are negatively affecting people's daily rest and long-term health. Prior studies have emphasized the detrimental impact of environmental factors such as noise and light on sleep. These elements can disrupt sleep continuity and reduce deep sleep, leading to fatigue, reduced concentration, and chronic health issues such as cardiovascular and metabolic disorders [2, 6, 7].

In our team brainstorming, we identified several potential sources of noise and light disturbance. These included: (1) personal electronic devices such as smartphones, TVs, and computers, which emit notifications, vibrations, and bright screens; (2) household appliances like air conditioners, refrigerators, and washing machines, which may produce continuous or intermittent sounds, as well as harsh indoor lighting; (3) natural environmental sounds such as wind, rain, or animal activity, especially noticeable at night; and (4) community-related noise, including neighbours' activities, night construction, car alarms, and waste collection services.

To better understand how these factors affect real users in their living environments, we developed an alarm clock - shaped probe concept (Figure 4). This probe embeds sensors into an everyday sleep-related object to minimize interference with users' routines while collecting more natural and authentic environmental data.

## Probe development

The probe came to realization through careful module selection and circuit design. The controller used was a Raspberry Pi 3. This allowed us to open a web server through the Flask framework. Some modules had to be converted from analogy to digital through an MCP3008 module. The modules included: (1) PIR motion sensor (HC-SR501) - Detects movement during the night; (2) Microphone (KY-037) - Records sound levels during the night; (3) LDR sensor - Records light intensity levels during the night; (4) LCD display (HD44780) - Displays sleep rating questions; (5) Slide potentiometer - Indicates sleep satisfaction; (6) Buttons - Activates measuring vs idle mode

All modules were carefully mapped out in advance through the circuit design seen in Figure 2. The corresponding GPIO pins were used in the code to get all required values. To complement the environmental data collected by the sensor-based probe, we designed a Sleeping Diary to document participants' subjective experiences during each sleep session. The diary was intended to capture contextual and behavioural information related to sleep, such as the type of sleep (nap or main sleep), pre-sleep activities including phone use, caffeine intake, or exercise, experiences of falling asleep and returning to sleep, and any disruptions caused by noise or other factors. Participants were asked not only to report what happened, but also to reflect on how they felt, for example, whether they were able to relax into sleep immediately or whether they remembered what had disturbed their sleep. These subjective inputs provided by the diary played a crucial role in capturing information that could not be accessed through sensor data alone. The details are in Appendix A.

Figure 5: Probe 1 for test


Figure 6: UI design for web dashboard

Figure 7: Test 1 picture

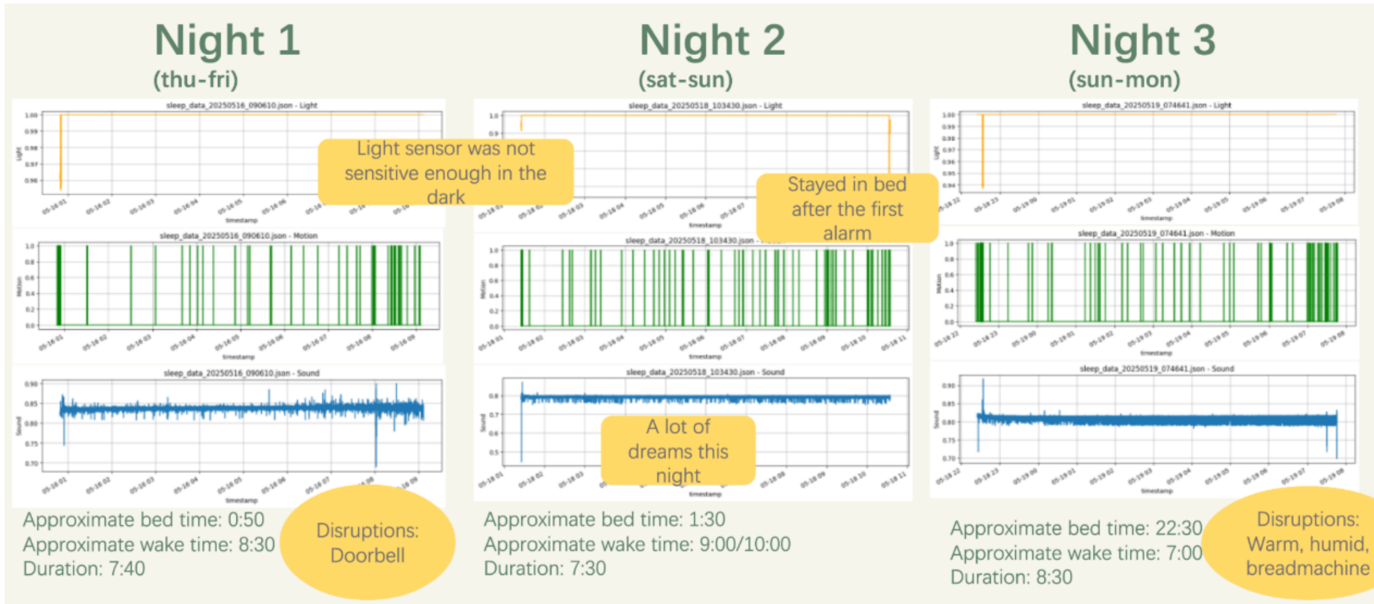


Figure 8: Data Collected

## Probe with diary for the test

Figure 5 shows the final version of our final tool used for testing, which included a physical probe and a sleeping diary. We conducted a three-day test with one of the members from the design team, during which we collected data on environmental noise and light levels in her living space, as well as sleep-related metrics such as movement, sleep cycles, and subjective sleep satisfaction.

## Test and Results

We set up the Probe at the home of one of the group members. Participants followed the following procedure for testing and provided the necessary data. The probe was tested for three nights by one of our group members. An overview of the results can be found in Figure 8. An interesting observation is the lack of accuracy in the light intensity sensor. Once the curtains were closed, the sensor was not accurate enough to distinguish any variations in light intensity. After each night, the sleeping diary (Appendix B) was filled in by the user. These diary entries gave us insights (Appendix C) into the disruptions happening during the night.

## Data as Conversation Starter

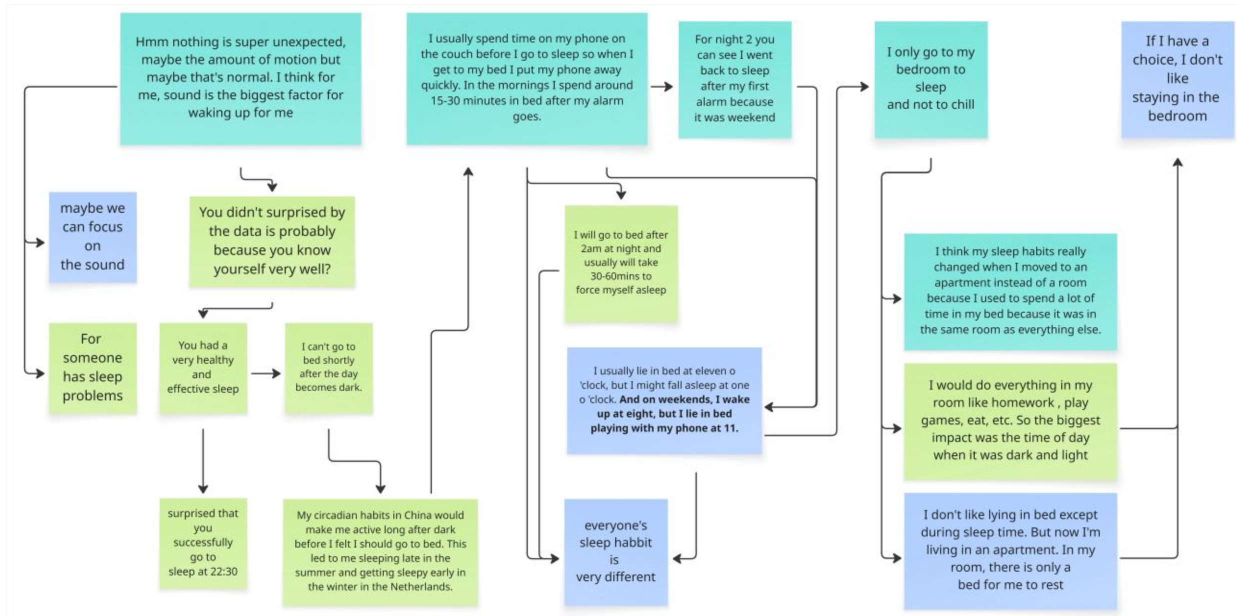


Figure 9: Insight collected

Figure 9 illustrates the reflections and discussions that emerged during our first design iteration, where team members engaged in data-driven conversations with participants. In this session, we used personal sleep data as a conversational starter to prompt participants to reflect on their own sleep habits and routines. The following is a summary description of the views of the three participants in the discussion.

One participant shared, *"I do everything in one space — sleep, work, chill — so it' s tough to shut down. I' m up past 2:00 AM and it takes hours to fall asleep. And my sleep is greatly affected by the change in the length of the day and night." Another described how, despite reserving their bedroom for sleep, prolonged phone use in bed still delayed sleep onset:" My room' s only for sleep, but I still fall asleep late—like two hours after getting in bed. I' m usually on my phone." A third participant reflected on the contrast between living in a single room and a larger apartment:" I used to live in a single room and spent a lot of time in bed, which messed with my sleep. Now, I keep my bedroom just for sleep—I chill on the couch, so when I go to bed, I fall asleep quickly."*

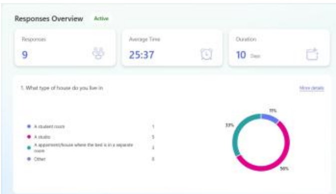

Figure 10: Further research across the class

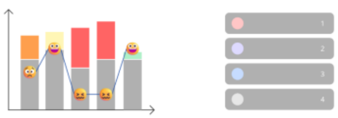
Figure 11: Draft of ranking in app

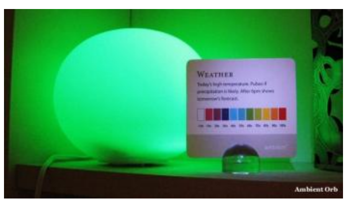

Figure 12: Example of the data physicalisation

## Discussion and insights

These design and research observations led us to move beyond environmental factors such as noise and lighting. Although the impact of these elements on sleep quality has been well established in prior studies and was also acknowledged by our participants, we found it difficult to influence participants' living environments directly through the use of probes.

We also observed that the more non-sleep-related activities participants engaged in while in bed, such as eating, working, or using their phones, the lower their reported sleep satisfaction tended to be. This trend was especially evident among participants living in studio apartments or single-room settings, where the boundaries between functional areas are often unclear.

Therefore, rather than directly attempting to modify the physical environment, we consider that encouraging behavioural change may provide an alternative method to promote users to redefine their interaction with their living space, especially with their beds, to improve their sleep experience satisfaction.

## Prototyping 2 – Informed exploration Development

Subsequently, we conducted a questionnaire (Figure 10) on the impact of the sleep environment on sleep habits, such as the percentage of time spent in bed during sleep, other activities performed in bed before sleeping, and factors affecting sleep quality. It was found that, after excluding sleep environment and health issues, sleep satisfaction is closely related to sleep habits. For example, another noteworthy finding is that using a mobile phone before sleeping is the most common behaviour, but this behaviour does indeed affect sleep satisfaction. Generally speaking, when users spend the expected amount of time in bed, their sleep satisfaction is higher. The details of the questionnaire are in Appendix D.

Based on the findings from the first iteration, the design focus of the second prototype shifted to how to provide an encouraging approach to promote users' willingness to change their living environment. Using bed as a starting point to improve people's sleep experience. Therefore, the design is divided into two parts: how to provide an encouraging approach and how to improve people's sleep experience through changing their use of beds. In the former part, effective positive reminders could be a possibility, such as using rankings within the app (Figure 11) to motivate users to maintain good data. In the latter part, bedtime information will be collected and communicated to users in order to encourage behavioural changes and habit optimisation. Two types of bedtime information will be collected: estimated in-bed time and actual in-bed time, which will be used to calculate efficiency. Users will be informed of this information in two ways: first, through reports displayed directly in the app, although this is not very intuitive; second, through data visualisation and physicalisation, most likely in the form of indicator lights. Inspired by Ambient Orb, physicalisation involves using changes in light colour to clearly illustrate the situation [4]. For example (Figure 12), the colour range changes from cool to warm to indicate the temperature.

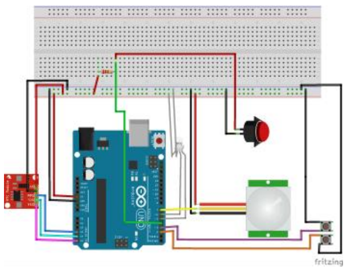

Figure 13: Module circuit design 2

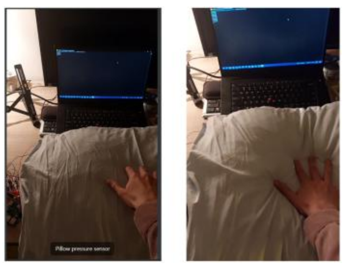

Figure 14: Probe 2 design

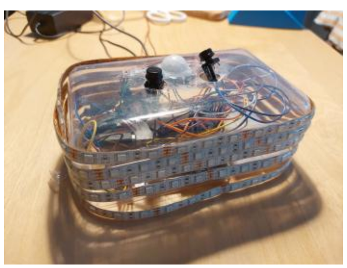

Figure 15: Probe 2 for test

## Data collection structure

In the second phase of the design, we built a new data collection structure (Figure 17) based on the last prototype. The time when the user gets out of bed and lies down on the bed will be recorded and combined to form the user's actual in-bed time. This data can be input via the pressure sensor in the pillow or the prototype button. Additionally, the user's prepared in-bed time will be recorded, which can be input via the prototype slider or the app and combined to form the user's estimated bedtime. By comparing these two different in-bed times, efficiency can be analysed, and conclusions or reports can be generated.

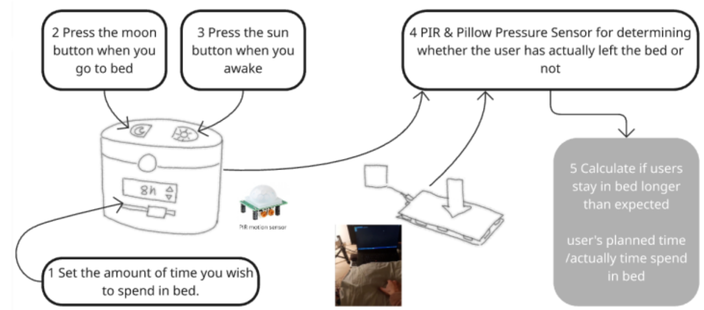


Figure 16: Data collection draft

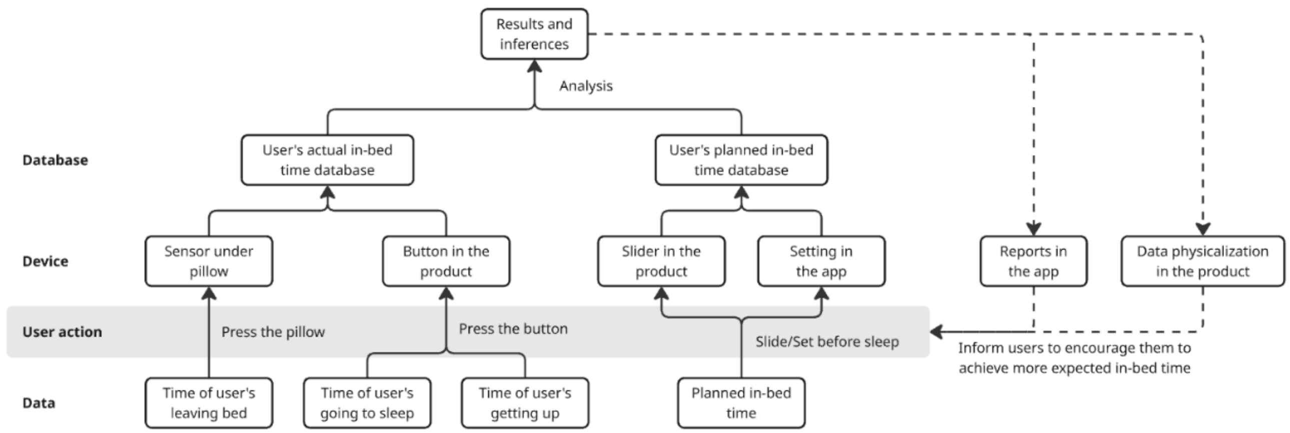


Figure 17: Data collection structure

## Probe design

Probe (Figure 14) is determined based on pressure sensors. Place the pressure sensor under the pillow, and when pressure is detected, the sensor will continuously record data. By comparing the difference between the data received by the sensor and the data not received, the user's actual time spent in-bed can be determined. Additionally, his method may not be accurate, so button on the actual prototype is also needed to assist in recording time points. Codes are in Appendix E.

Figure 18: Rendering of probe 2

## Prototype and data physicalisation

The main product component of the second prototype (Figure 18) is divided into two distinct functional areas: input by buttons and sliders, and output by data physisalisation. The input buttons and sliders are integrated into the product, allowing users to adjust their bedtime by pressing the buttons. The data physicalisation on the output end uses changes in light colour to indicate the user's in-bed time status, with cool tones indicating the user is not in bed and warm tones indicating the user is in bed. The lights are controlled in tandem with pressing the input buttons, and the lights will turn off after a certain period of time. In the initial concept (Figure 19), it was also proposed to use light colour to indicate the time difference from the prepared in-bed time, but this was abandoned because keeping the lights on for an extended period could disrupt sleep.

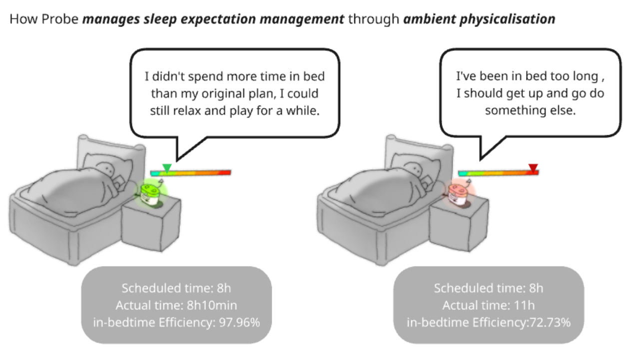


Figure 19: Data visualization concept

## Support app

The application (Figure 20) serves as the supporting component of the second prototype, primarily featuring two functions: input and output section, and a ranking page designed to incentivise users. On Main Page 1, the duration of data collection will be displayed, along with a congratulatory message for the top-ranked user. On Main Page 2, the input side will include the user's prepared in-bed time, while the output side will provide a report on the entire prototype or design product. On Main Page 3, a ranking with friends will be included to encourage user engagement.


Figure 20: Support App

## User Test

To evaluate the impact of the Lumi Alarm on users' awareness of their sleep behaviour and overall sleep satisfaction, we conducted a short-term user test on a participant in their real living environment (Figure 21). A participant from the elective course who had previously reported low sleep satisfaction through verbal feedback was selected for testing. This study defines two types of sleep satisfaction: sleep quality satisfaction, referring to the participant's subjective

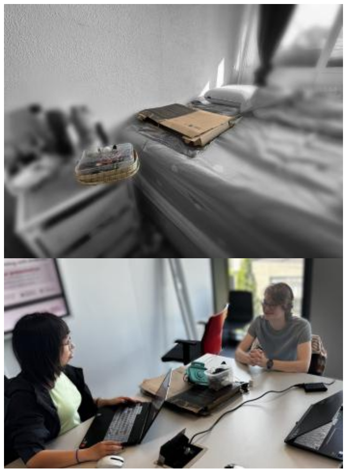

Figure 21: Test 2 pictures

Figure 22: Final probe

evaluation of sleep upon waking, and sleep activity satisfaction, reflecting overall satisfaction with the entire process from getting into bed to getting out, including related behaviours and emotions.

It is worth mentioning that due to time and technical constraints, it was not possible to fully realise the original Lumi Alarm design, which involved using lighting fixtures and gradient colours. Instead, a simplified test probe consisting of a transparent box with built-in light strips, button modules, pressure sensors, passive infrared (PIR) motion sensors and LEDs was used. The planned three-day user testing period was shortened to one night, and the probe's limitations in terms of size, ease of use and lighting range may have affected the results of the test.

The test procedure follows:

Before using the probe, the participant completed a pre-test baseline form to record typical sleep patterns, in-bed activities, and levels of satisfaction with both sleep quality and sleep activity over the past week. This served as a reference for analysing changes after the intervention.

During the test night, the participant followed a set routine. When the pressure sensor detected that the participant had laid down, the light turned on. Pressing the "sleep" button turned the light off. Upon waking, the participant pressed the "awake" button, which turned the light back on. The light remained on until the participant left the bed, at which point the pressure sensor triggered the light to turn off.

After the night of testing, the participant completed a sleep diary, rating their sleep activities and satisfaction on a scale from 1 to 5. To address the limitations of the simplified probe, a co-constructed storyboarding method was used during the post-test interview (Figure 23). This helped the participant imagine the intended system, in which the light gradually shifts from green to red based on time spent awake in bed. Based on this imagined scenario, the participant also completed a hypothetical Day 2 diary to reflect on the desired user experience.

## Result

The test results show that the participant experienced noticeable changes in both behaviour and subjective sleep evaluation. Although the intervention lasted only one night and was supplemented by a co-constructed storyboard for a hypothetical second day, the data revealed clear shifts in bedtime habits and satisfaction levels (Figure 24).

**Reduction in non-sleep activity.** Before the test, the participant reported that they typically spending 30 to 60 minutes using their phone in bed before falling asleep. After using Lumi Alarm, this was reduced to about 15 minutes. The same reduction was maintained in the imagined scenario, suggesting that the light prompt helped discourage extended phone use before sleep.

**Improved sleep efficiency.** With less non-sleep activity, time in bed was shortened by around 15 minutes, totalling 7 hours and 45 minutes. Sleep duration remained similar, while efficiency increased from a baseline of 87.5% – 93.75% to 96.77% on the

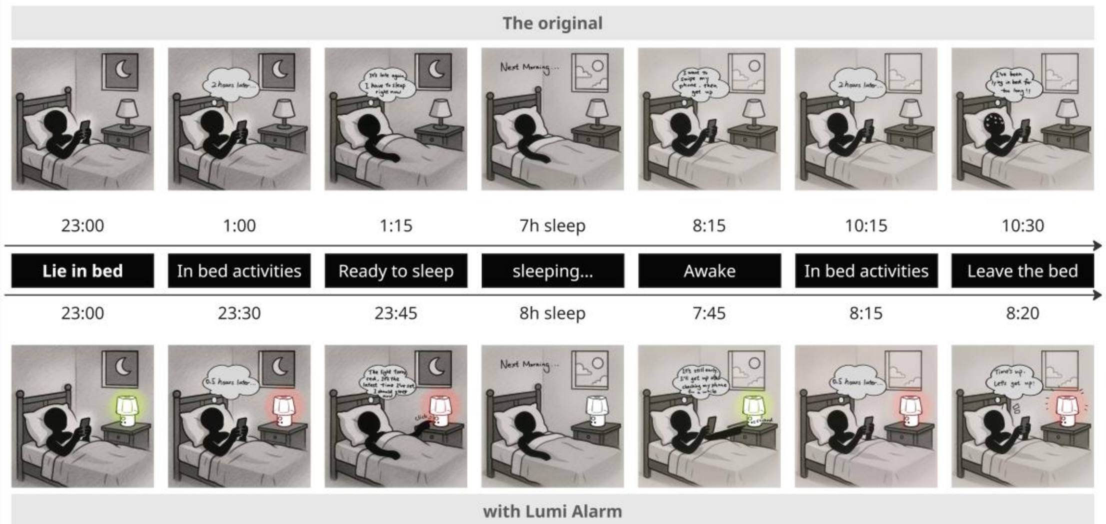


Figure 23: Co-constructing Story Board

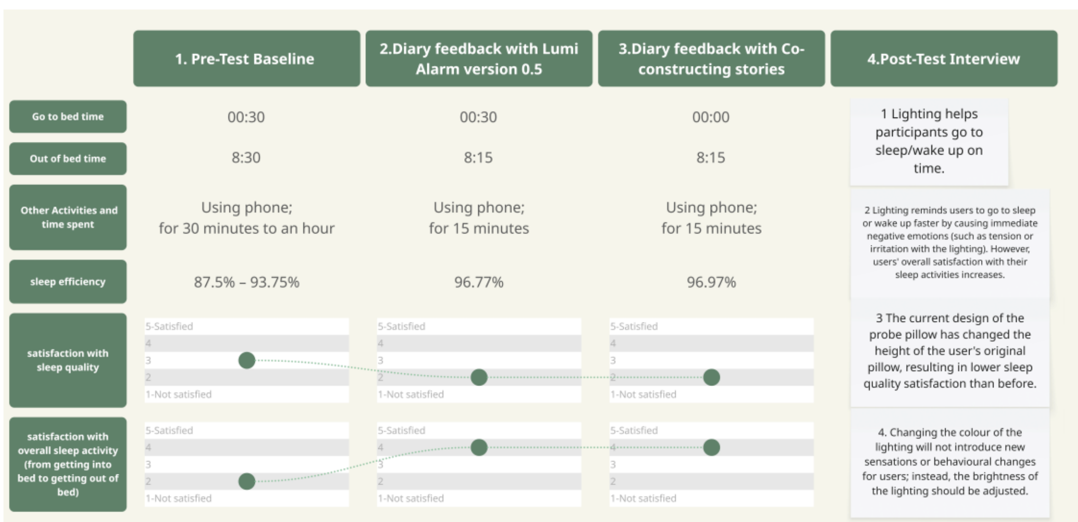


Figure 24: Test results summary

test night. In the imagined scenario, the participant expected this to remain stable at about 96.97%.

**Sleep satisfaction.** Sleep quality satisfaction stayed relatively low (3/5 at baseline, 2/5 on test days) due to discomfort caused by the pressure sensor raising the pillow height. In contrast, sleep activity satisfaction improved from 2/5 to 4/5 and remained at that level in the imagined version. The structured routine and reduced distractions contributed to a more positive overall experience.

Besides, feedback from post-test interviews provided further insights. Although the current design lacks colour-changing features, light prompts still proved effective. Participants noted that brightness adjustments might be more influential than colour shifts in guiding sleep-related behaviour, as reflected in the co-constructed storyboard. In addition, the green light, due to its fixed brightness and tone, caused brief tension or irritation, which prompted users to turn off the light quickly and reduce non-sleep activities. These negative emotions were described as temporary and no longer noticeable by the next morning.

These results suggest that even without improvements in sleep quality, users may feel more satisfied with their sleep experience when bedtime behaviour is more structured and intentional. The Lumi Alarm demonstrated effectiveness in guiding such behaviour through light prompts that induce brief discomfort during non-sleep activities. To enhance comfort and accommodate individual preferences, adjustable brightness and colour should also be considered in future design.

**Future Work**

Limitations include short test duration and a small participant pool. Future research should:

(1) Expand participant samples and testing periods.
(2) Improve sensor ergonomics (e.g., under-mattress or wearable designs).
(3) Provide more adaptive physical feedback (e.g., dimming lights, sound cues).
(4) Integrate mobile apps for personalized goal setting, tracking, and transparency.

**Acknowledgements**

We would like to thank ChatGPT-4o for assistance in generating the Figure 1, co-constructed storyboard and helping to reduce the amount of text. Prompt words are in Appendix F.

## Discussion

This study explores how design interventions can improve users' sleep satisfaction by identifying perceived influencing factors. Findings suggest that even short-term, simplified interventions can positively affect users' sleep awareness and behaviors. Despite limited scope and duration, valuable insights emerged on the relationship between physical feedback, behavioral habits, and perceived sleep satisfaction.

**Changes in Sleep Behaviour:** A key observation was the reduction of non-sleep-related activities, particularly phone use in bed. Before the intervention, participants typically spent 30–60 minutes on their phones before sleep. After using the Lumi Alarm detector, this dropped to around 15 minutes. This change occurred without explicit instructions, indicating that the real-time light prompt subtly influenced behavior. Participants described the light as slightly stressful, prompting them to press the sleep button earlier. Although discomfort wasn't the original intent, this mild tension became an effective behavioral driver. Participants noted that brightness adjustment (rather than tone) would be a more comfortable method, suggesting future interventions should prioritize personalization and comfort.

**Improved Sleep Efficiency and Perception:** Sleep efficiency improved from a baseline of 87.5–93.75% to 96.77% during probe usage, even though total sleep duration remained stable. Reduced pre-sleep waking time led to increased actual sleep time. Although one participant experienced discomfort from the pressure sensor, they still reported increased satisfaction with their sleep behavior. This suggests that behavioral control or regularity can improve perceived satisfaction, even if objective quality remains unchanged.
The findings highlight a distinction between satisfaction with sleep quality and satisfaction with sleep-related activities. This supports previous research showing that subjective satisfaction is influenced by both physiological factors and users' perceptions of their habits and choices.

**Design Principles and Reflections:** Several key design principles shaped this work. We used narrative and personal experience to uncover design needs and maintain close environmental integration, deploying the detector in real home settings. This enabled us to shift focus from purely environmental optimization to supporting conscious behavior change. Our approach balanced qualitative and quantitative data. Sensor data was interpreted alongside diary entries, interviews, and a collaborative storyboard session. This helped validate speculative ideas and enriched empirical understanding. We also critically reflected on technological transparency. While the detector provided useful feedback, limitations such as fixed lighting, physical discomfort, and lack of fine control highlight areas for improvement (e.g., customizable brightness and better ergonomic integration).

## Conclusion

This study shows that low-threshold design interventions like Lumi Alarm can enhance sleep behaviors and perceived satisfaction. Combining sensor data with real-life insights helped shift design focus toward conscious habit-building, highlighting the need for personalization and comfort in future sleep technologies.

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**Appendix A**

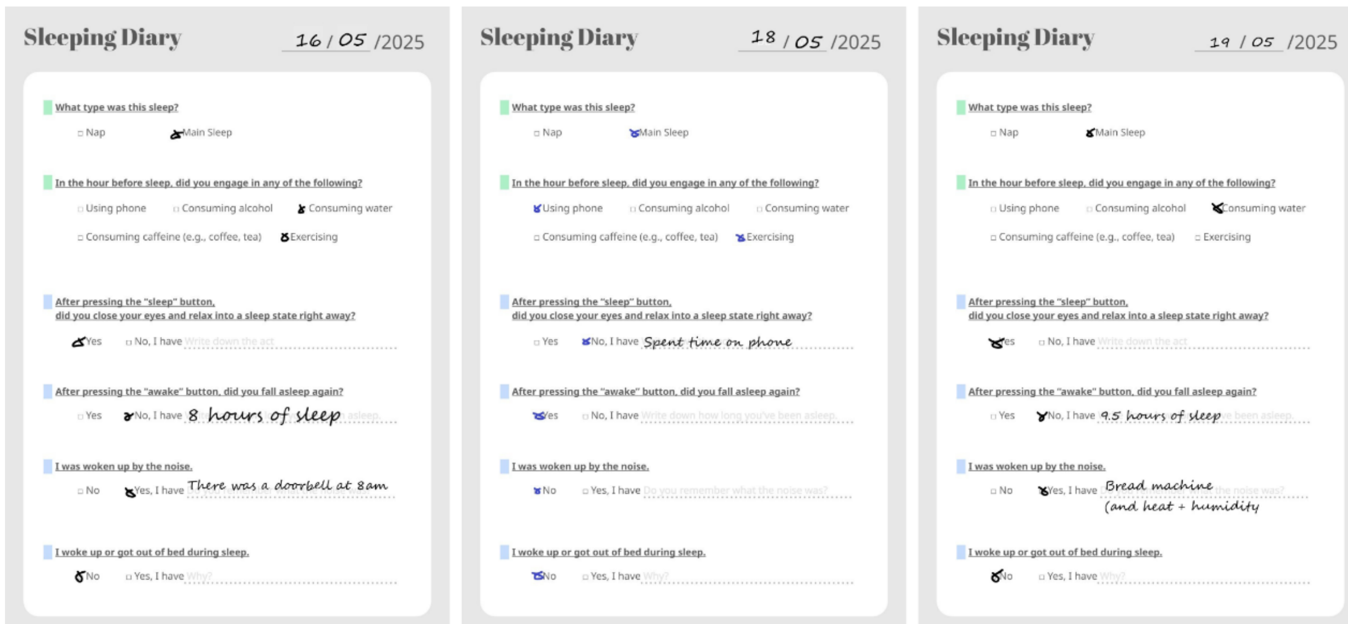
Details of probe 1

Acting as a reflective tool, the diary encouraged participants to pay closer attention to the details of their sleep behaviours and to record their experiences promptly after each night. It also enabled us to develop a deeper understanding of their nightly routines and their perceived sleep quality.

Initially, the design included a web-based monitoring dashboard that allowed the user to carefully monitor their sleep statistics based on the sensor values. Ultimately, while the UI design was created and support for the web page was supported, the dashboard was never used in testing.

**Appendix B**

Sleep diary questionnaire



Sleeping Diary 16 / 05 /2025

What type was this sleep?
Nap | Main Sleep

In the hour before sleep, did you engage in any of the following?
Using phone | Consuming alcohol | Consuming water
Consuming caffeine (e.g., coffee, tea) | Exercising

After pressing the "sleep" button, did you close your eyes and relax into a sleep state right away?
Yes | No, I have Write down the act

After pressing the "awake" button, did you fall asleep again?
Yes | No, I have 8 hours of sleep

I was woken up by the noise.
No | Yes, I have There was a doorbell at 8am

I woke up or got out of bed during sleep.
No | Yes, I have Why?

Sleeping Diary 18 / 05 /2025

What type was this sleep?
Nap | Main Sleep

In the hour before sleep, did you engage in any of the following?
Using phone | Consuming alcohol | Consuming water
Consuming caffeine (e.g., coffee, tea) | Exercising

After pressing the "sleep" button, did you close your eyes and relax into a sleep state right away?
Yes | No, I have Spent time on phone

After pressing the "awake" button, did you fall asleep again?
Yes | No, I have Write down how long you've been asleep.

I was woken up by the noise.
No | Yes, I have Do you remember what the noise was?

I woke up or got out of bed during sleep.
No | Yes, I have Why?

Sleeping Diary 19 / 05 /2025

What type was this sleep?
Nap | Main Sleep

In the hour before sleep, did you engage in any of the following?
Using phone | Consuming alcohol | Consuming water
Consuming caffeine (e.g., coffee, tea) | Exercising

After pressing the "sleep" button, did you close your eyes and relax into a sleep state right away?
Yes | No, I have Write down the act

After pressing the "awake" button, did you fall asleep again?
Yes | No, I have 9.5 hours of sleep

I was woken up by the noise.
No | Yes, I have Bread machine (and heat + humidity

I woke up or got out of bed during sleep.
No | Yes, I have Why?

## Appendix C

Details of test 1

*Night 1*

During night 1 of the user test, the only disruption mentioned was an unexpected doorbell ringing at 8AM. This disruption can be directly seen in our data, as there is an increase in both sound and motion during this period. Another observation we make is that there is relatively less motion when compared with the two other nights. One possible speculation we have for this observation is the possible lack of intense dreams. The approximate bedtime for this night is 00:50 and the wake time is 8:30, meaning the total sleep duration is 7 hours and 40 minutes.

*Night 2*

During night two the user reported no significant disruptions in the diary, though in later discussion this night was said to be filled with more dreams than regular. The approximate bedtime was 1:30. From the data we see two groups of intense motion in the morning, as was our suspicion, this was confirmed to be due to ignoring the first alarm. The first wake time was at 9:00, followed by the second wake time at 10:00.

*Night 3*

Multiple disruptions occurred during night 3, likely resulting in the frequent motion. The user reported that their bread machine was running throughout the night in another room, occasionally resulting in sound disruptions. The sound sensor was not sensitive enough to pick up this sound.  Another logged disturbance was heat and humidity due to the unfortunate combination of forgetting to open the window before sleeping and having laundry drying in the room. The approximate bedtime for this night is 22:30 and the wake time is 7:00, meaning the total sleep duration is 8 hours and 30 minutes.

1. What type of house do you live in

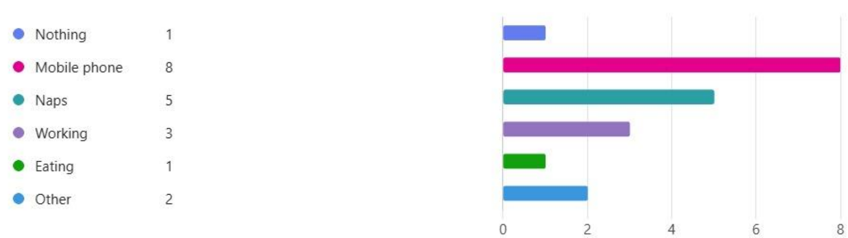
More details


2. What percentage of your time in bed do you actually spend sleeping?

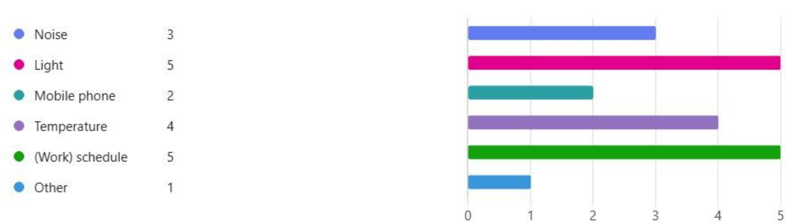
More details


3. What other things do you do in bed besides sleep?

More details




5. What factors effect your sleep quality the most?




4. If you selected anything in the previous question, why do you do this in your bed?

8 Responses

| | | |
|---|---|---|
| 1 | anonymous | Scrolling on phone becomes a habit before the sleep |
| 2 | anonymous | Before and after sleep, doing social media to woke myself up. |
| 3 | anonymous | Staying next to my bed makes me feel safe |
| 4 | anonymous | For convenience, it's more comfortable than the couch, but I only do it wearing clean clothes |
| 5 | anonymous | I have the bad habit of checking my phone before sleeping. So that comes naturally. I sometimes take my laptop to bed with me when I have to work on something for short time (30 min max, cause the posture gets uncomfortable after that) I do it when I'm lazy to sit behind my desk or I don't need to be fully focused. |
| 6 | anonymous | Nappig is sleeping so correct location, phone to relax and what films (which exactly limits sleep) and reading to really relax |
| 7 | anonymous | Because I can lie in bed and it's labour-saving to play phone. |
| 8 | anonymous | i like to lay in my bed to do things sometimes, especially when i want to relax a bit |

## Appendix D

Details of the questionnaire

The survey collected data from students living in student rooms, studios, apartments, and houses. On average, the highest percentage of users spend 80%-100% of their time in bed sleeping, followed by 60%-80%. During non-sleeping hours on the bed, users typically engage in activities such as using their phones, taking naps, working, or eating, with phone usage being the most common. The reasons for this are diverse, including using the phone to stay awake, finding it more convenient to use the phone in bed, or simply out of habit.

Users believe that the most important factors affecting sleep quality are lighting and work schedules, followed by temperature and noise.

6. Are you satisfied with your sleep quality in the last two weeks?

More details


7. Are you satisfied with your sleeping habits in the last two weeks?

More details


9. Any other comments?

5 Responses

| ID ↑ | Name | Responses |
|---|---|---|
| 1 | anonymous | No |
| 2 | anonymous | Not yet |
| 3 | anonymous | no. |
| 4 | anonymous | nope! good luck |
| 5 | anonymous | My sleep quality is lower this weeks despite my sleep habits due to the factor of a broken leg with a cast that limits my moving ability in bed (which I do often, so I wake up when my body thinks of moving) |

8. How does your sleep environment effect your sleep habits?

9 Responses

| ID ↑ | Name | Responses |
|---|---|---|
| 1 | anonymous | Bad sleep environment and bad habits severely affected my sleep quality |
| 2 | anonymous | I used to sleep in dormitory with my three roommates. Now it's just me. I think I will be more influenced by people. |
| 3 | anonymous | It's peaceful and quiet, so that helps with falling asleep. |
| 4 | anonymous | Since I do everything in my studio, sometimes I feel like I'm losing my sense of time. |
| 5 | anonymous | In general having distractions and bright light disturbs me. Living in a studio I have a room divider instead of a seperate room for my bed. It is too easy to switch doing things, or to get up and eat something when your fridge is 2 meters away |
| 6 | anonymous | Now that days are longer, I wake up before my desired time, even when the curtains are closed. I'm sensitive to noise, and falling asleep with loud noise in the background is hard for me, but I don't usually wake up from regular noise (unless it's a very loud, sudden noise) My pillow has a huge effect on my sleep quality, so staying over at friends' is usually a challenge. |
| 7 | anonymous | It is more important that the bed is good enough and I am relaxed (or tired) enough than what the exact environment is. For temperature is the blanket adjustable, for light is a sleep mask accessible, for noice when I sleep I sleep. |
| 8 | anonymous | If the environment is too hot or too noisy, then I will feel hard to fall in asleep. Light only have impact when I'm following a regular sleep habit, which means that when I'm too tired, light won't influence my sleep. |
| 9 | anonymous | i always put my phone beside me, so i suggest it's a big factor, cause im always swiping my phone before i sleep |

Users believe that the most significant factors affecting sleep quality are lighting and work schedules, followed by temperature and noise. Most users are satisfied with their sleep quality over the past two weeks, while their assessment of sleep habits is mostly average.

There are also differing conclusions regarding the impact of sleep environments on sleep habits, such as the number of people living together, quietness, disturbances, bright light, length of daylight hours, bed comfort, user relaxation levels, temperature, and other pre-sleep behaviours. Additionally, physical discomfort or restricted mobility due to illness also act as negative factors.

## Appendix E

Codes of probe 2

```cpp
#include "RGBdriver.h"
#include "rtc.h"

// Button and sensor pins
const int button1Pin = 2; // Sleep button
const int button2Pin = 3; // Wake button
const int pressurePin = 4;
const int motionPin = 7;

// RGB LED driver (Catalex)
#define LED_CLK 6
#define LED_DIO 5
RGBdriver Driver(LED_CLK, LED_DIO);

int startHour = 23;
int endHour = 8;
bool inAlarmMode = true;
bool isSleeping = false;
unsigned long overrideUntil = 0;

int get_current_hour() {
  return rtc_get_hour();
}

int get_current_minute() {
  return rtc_get_minute();
}

bool user_in_bed() {
  bool pressure = digitalRead(pressurePin) == LOW;
  bool motion = digitalRead(motionPin) == HIGH;

  Serial.print("Pressure detected: ");
  Serial.print(pressure);
  Serial.print(" | Motion detected: ");
  Serial.println(motion);

  return pressure || motion;
}

bool button1Pressed() {
  return digitalRead(button1Pin) == LOW;
}

bool button2Pressed() {
  return digitalRead(button2Pin) == LOW;
}

void update_led_alert() {
  int hour = get_current_hour();
  Serial.print("Current hour: ");
  Serial.println(hour);

  if (startHour == -1 || endHour == -1) return;
  if (!inAlarmMode) return;

  if (millis() < overrideUntil) {
    Driver.begin();
    Driver.SetColor(0, 0, 0);
    Driver.end();
    Serial.println("LED off due to override.");
    return;
  }

  if (isSleeping) {
    Driver.begin();
    Driver.SetColor(0, 0, 0);
    Driver.end();
    Serial.println("User is sleeping. LED off.");
    return;
  }

  if (user_in_bed()) {
    Serial.println("User is in bed.");
    if ((startHour < endHour && (hour < startHour || hour > endHour)) ||
        (startHour > endHour && (hour > endHour && hour < startHour))) {
      int delta = abs(hour - startHour);
      int red = constrain(delta * 40, 0, 255);
      int green = constrain(255 - delta * 40, 0, 255);
      Driver.begin();
      Driver.SetColor(red, green, 0);
      Driver.end();
      Serial.print("Outside time. LED: R");
      Serial.print(red);
      Serial.print(" G");
      Serial.println(green);
    } else {
      Driver.begin();
      Driver.SetColor(0, 255, 0);
      Driver.end();
      Serial.println("Within time. LED: Green");
    }
  } else {
    Driver.begin();
    Driver.SetColor(0, 0, 0);
    Driver.end();
    Serial.println("User not in bed. LED off.");
  }
}

void setup() {
  Serial.begin(9600);
  Serial.println("Starting Sleep Tracker...");

  rtc_init();
  // Uncomment this line once to set the time, then comment again
  //rtc_set_time(16, 9, 0, 18, 6, 25); // 14:30:00, 16 June 2025

  pinMode(button1Pin, INPUT_PULLUP);
  pinMode(button2Pin, INPUT_PULLUP);
  pinMode(pressurePin, INPUT);
  pinMode(motionPin, INPUT);

  Driver.begin();
  Driver.SetColor(0, 0, 0);
  Driver.end();

  delay(2000);
}

void loop() {
  // Check if both buttons are pressed for override
  if (button1Pressed() && button2Pressed()) {
    overrideUntil = millis() + 15UL * 60 * 1000;
    Serial.println("Override activated for 15 minutes.");
    Driver.begin();
    Driver.SetColor(0, 0, 0);
    Driver.end();
    delay(1000);
    return;
  }

  // Button 1: Going to sleep
  if (button1Pressed()) {
    isSleeping = true;
    Serial.println("User is going to sleep.");
    Driver.begin();
    Driver.SetColor(0, 0, 0);
    Driver.end();
    delay(1000);
    return;
  }

  // Button 2: Waking up
  if (button2Pressed()) {
    isSleeping = false;
    Serial.println("User woke up.");
    delay(1000);
  }

  update_led_alert();
  delay(1000);
}
```

## Appendix F

AIGC

(1)

Co-constructing Story Board used the ChatGPT-4o model to generate four basic sketch scenes of bedrooms during the production process. The original image and prompt generated by AI are as follows:

| | | | |
|---|---|---|---|
|  |  |  |  |
| Please help me generate the following in a simple line drawing style:<br>A person lying in bed at night, preparing to go to sleep. | A person is playing with the mobile phone in bed, preparing to go to sleep. | Generate scene: The next morning, a person is lying in bed. | In the morning, a person lies in bed playing with their mobile phone. |

(2)

Original prompt of Figure 1: 帮我画一个完整的故事板 一共四个场景 第一个是主人公躺在床上准备睡觉 第二个是他听到了来自邻居的噪音 第三个是床头的手机屏幕因为消息通知亮了 第四个是家里的冰箱发出噪音

Translation: Help me draw a complete storyboard: there are four scenes in total. The first is the protagonist lying in bed getting ready to sleep, the second is him hearing noise from his neighbour, the third is the mobile phone screen on the bedside table lighting up due to a message notification, and the fourth is the refrigerator at home making noise.