

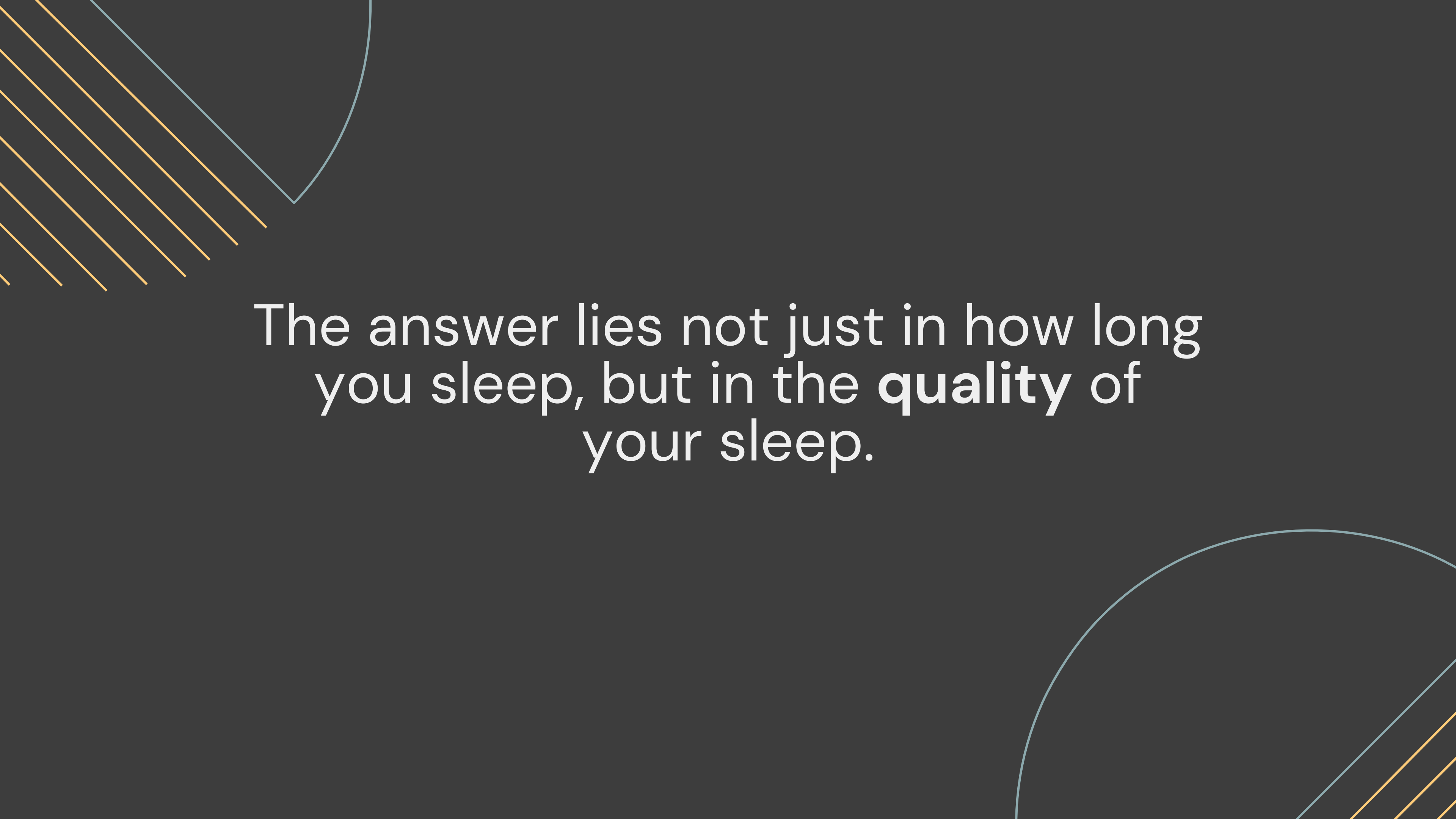


IMPACT OF INDOOR ENVIRONMENT ON SLEEP QUALITY


Malhaar Arora, Suhani Shrivastava

The image features a dark grey background with decorative elements in the corners. The top-left corner contains several parallel orange lines and a light blue curved line. The bottom-right corner contains a light blue curved line and several parallel orange lines. The text is centered in the middle of the page.

Ever wondered why you sometimes
wake up feeling tired, even after
sleeping for a full 8 hours?

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The answer lies not just in how long
you sleep, but in the **quality** of
your sleep.

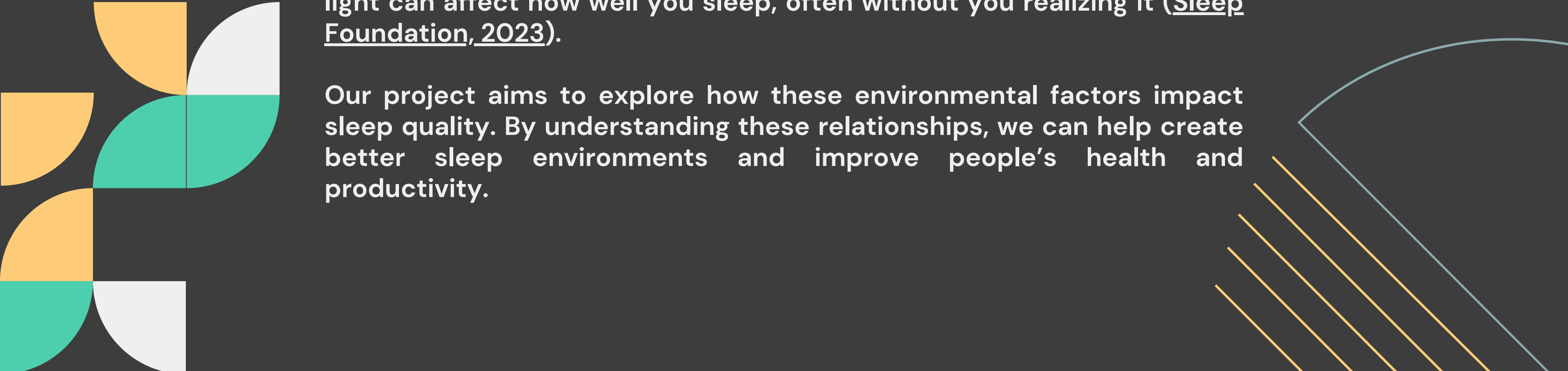


PROBLEM STATEMENT

Poor-quality sleep has been linked to health problems like a higher risk of heart disease and poor mental health, including mood issues and trouble concentrating ([CDC, 2021](#); [NIH, 2022](#)).

Studies suggest that factors like room temperature, noise, humidity, and light can affect how well you sleep, often without you realizing it ([Sleep Foundation, 2023](#)).

Our project aims to explore how these environmental factors impact sleep quality. By understanding these relationships, we can help create better sleep environments and improve people's health and productivity.



APPLICATIONS & IMPACT

01 – personalised sleep
recommendations

02 – Smart Sleep Solutions

03 – healthcare integration

ENHANCED SLEEP QUALITY

BETTER HEALTH OUTCOMES

INFORMED SMART TECHNOLOGY

LITERATURE REVIEW

Deep Learning for Sleep Quality Prediction

- **Focus:** Predicting sleep quality, specifically sleep efficiency, using wearable actigraphy data.
- Compares deep learning models (CNNs, RNNs) with traditional logistic regression.
- **Key Findings:** Deep learning models outperformed logistic regression, indicating their potential. However, they lack interpretability ("black box" nature).

Sathyanarayana, A., Joty, S., Fernandez-Luque, L., Ofli, F., Srivastava, J., Elmagarmid, A., Arora, T., & Taheri, S. (2016). Sleep Quality Prediction From Wearable Data Using Deep Learning. *JMIR mHealth and uHealth*, 4(4), e125. <https://doi.org/10.2196/mhealth.6562>

$$\text{Sleep Efficiency} = \frac{\text{TotalSleepTime}}{\text{TotalMinutesinBed}}$$

Impact of Indoor Environmental Quality (IEQ) on Sleep

- **Focus:** Investigates the relationship between IEQ (temperature, CO2, pollutants) and sleep quality using wearable devices and self-reported data.
- **Key Findings:** Pollutants like NO2, CO, and PM2.5 negatively affect sleep efficiency; however, some findings contradict previous research (e.g., CO2's impact).

Fritz, H., Kinney, K., Nagy, Z., Schnyer, D., & ASHRAE. (2020). Indoor Environmental Quality and its Effects on Human Sleep Quality. In *IAQ 2020: Indoor Environmental Quality Performance Approaches*. https://www.aivc.org/sites/default/files/2_C44.pdf

LITERATURE REVIEW

01 – multiple sleep stages
(light, deep, rem)

02 – Indoor env factors
(Temp, humidity, light)

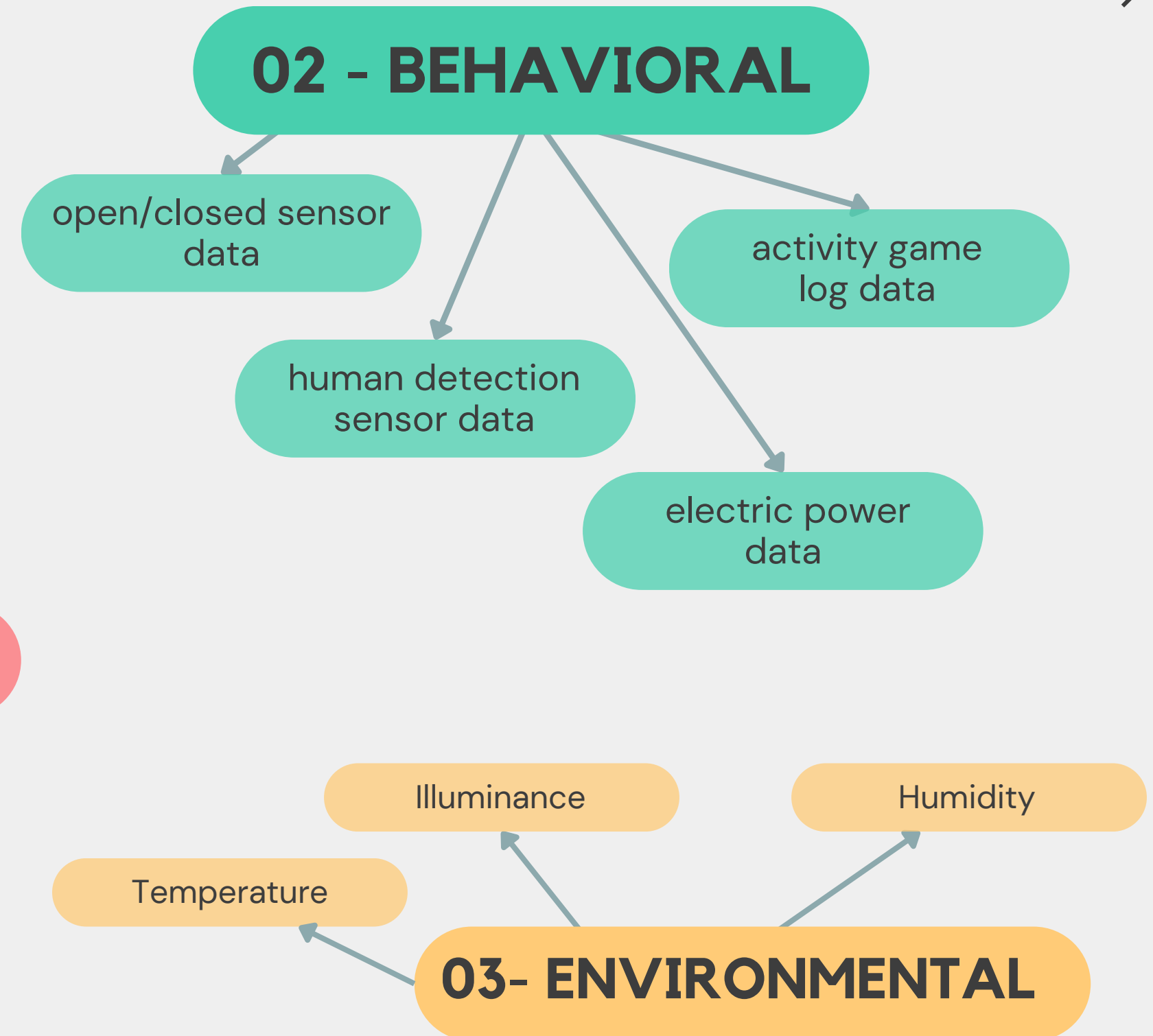
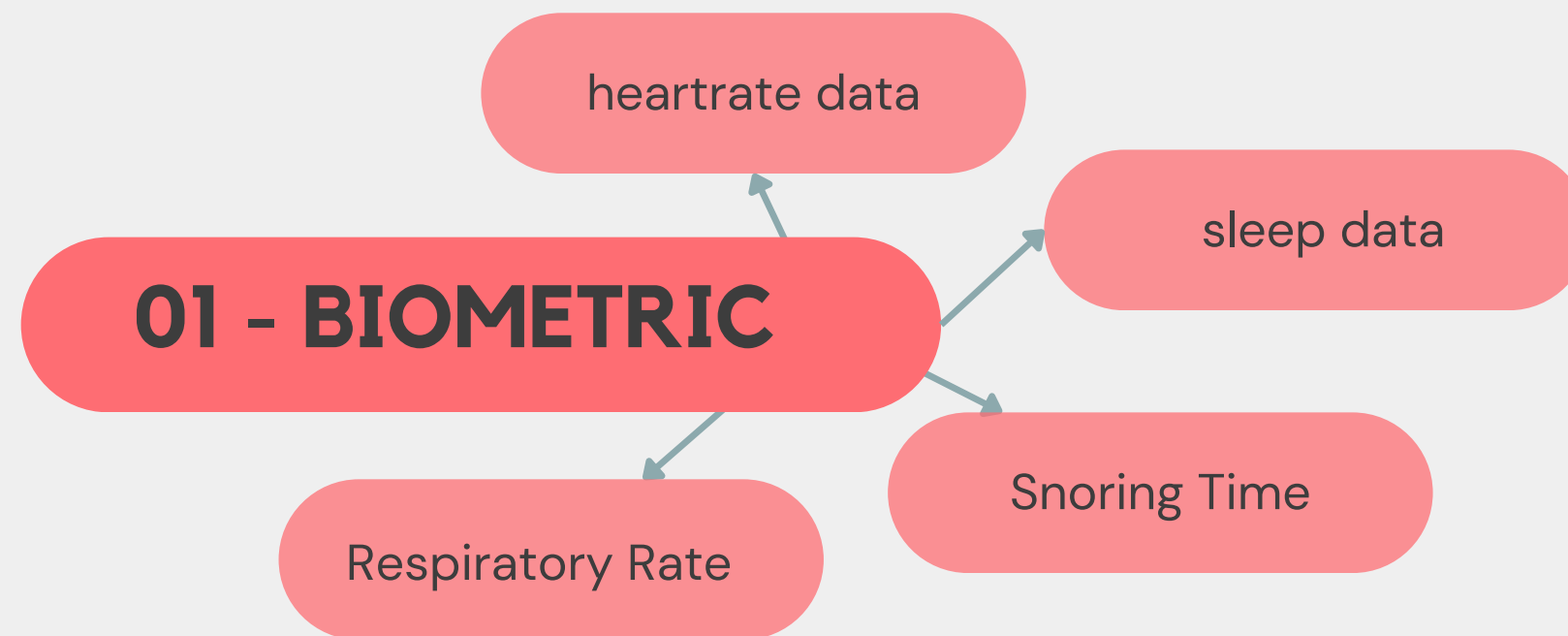
DIFFERENCES FROM EXISTING RESEARCH

- **OUR PROJECT AIMS TO ASSESS MULTIPLE SLEEP STAGES (DEEP, REM, LIGHT) IN RELATION TO ENVIRONMENTAL FACTORS.**
- **OUR PROJECT EXAMINES ONLY INDOOR ENVIRONMENTAL FACTORS LIKE TEMPERATURE, HUMIDITY, LIGHT AND THEIR COMBINED EFFECTS ON SLEEP QUALITY.**

EXPERIMENT PROTOCOL & DATASET INFO

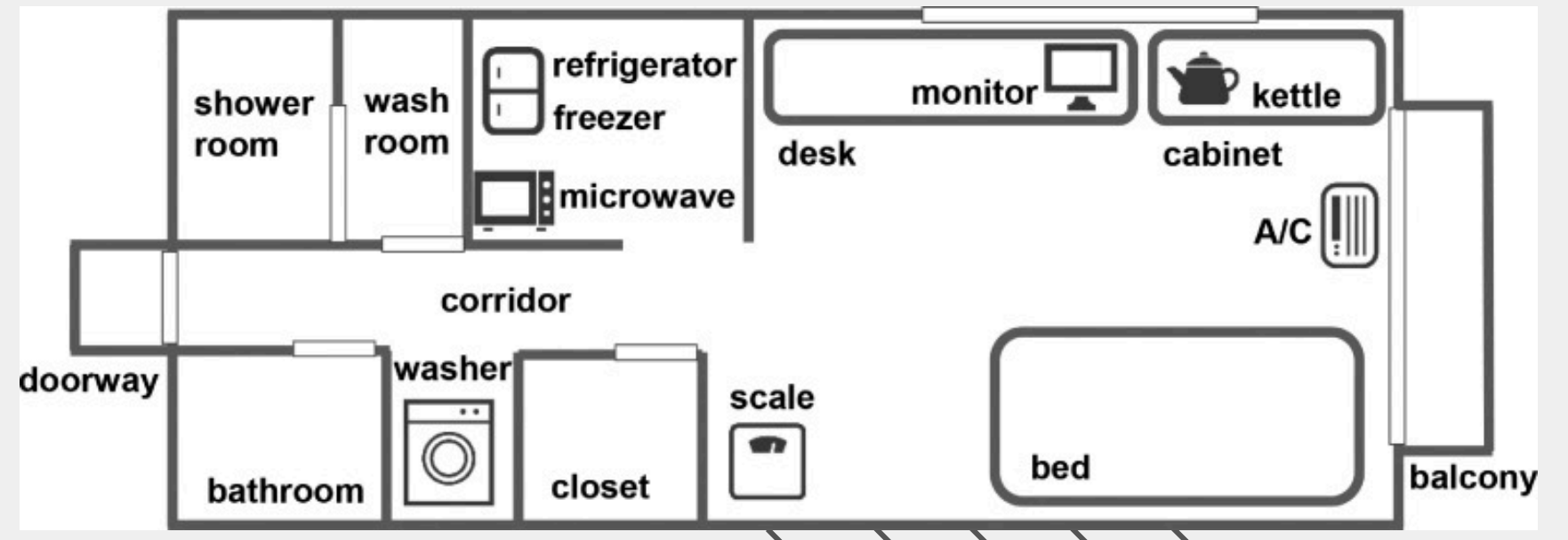
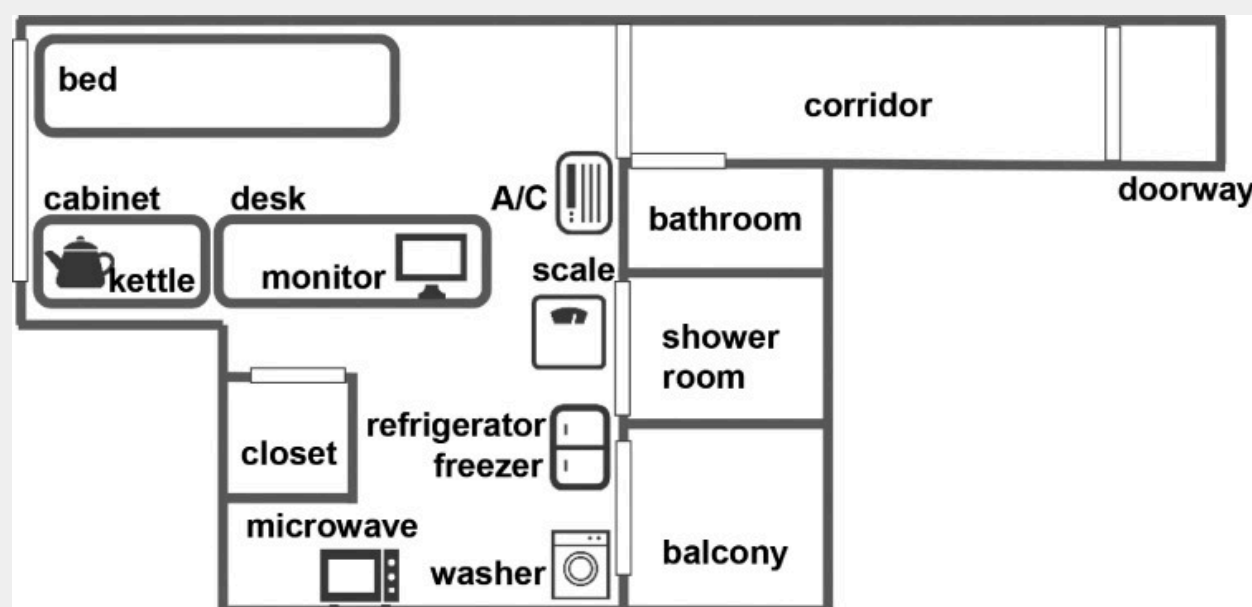
NATURE OF DATASET

- Dataset Title: **Biomedical Data and Sensing Information in Smart Rooms**
- Source: [DOI: 10.17632/ygy9zmhts5.1](https://doi.org/10.17632/ygy9zmhts5.1)
- Type of Data: Multimodal
- Total Participants: 23
- Why this dataset? focuses on human behavior in smart environments (HTI)



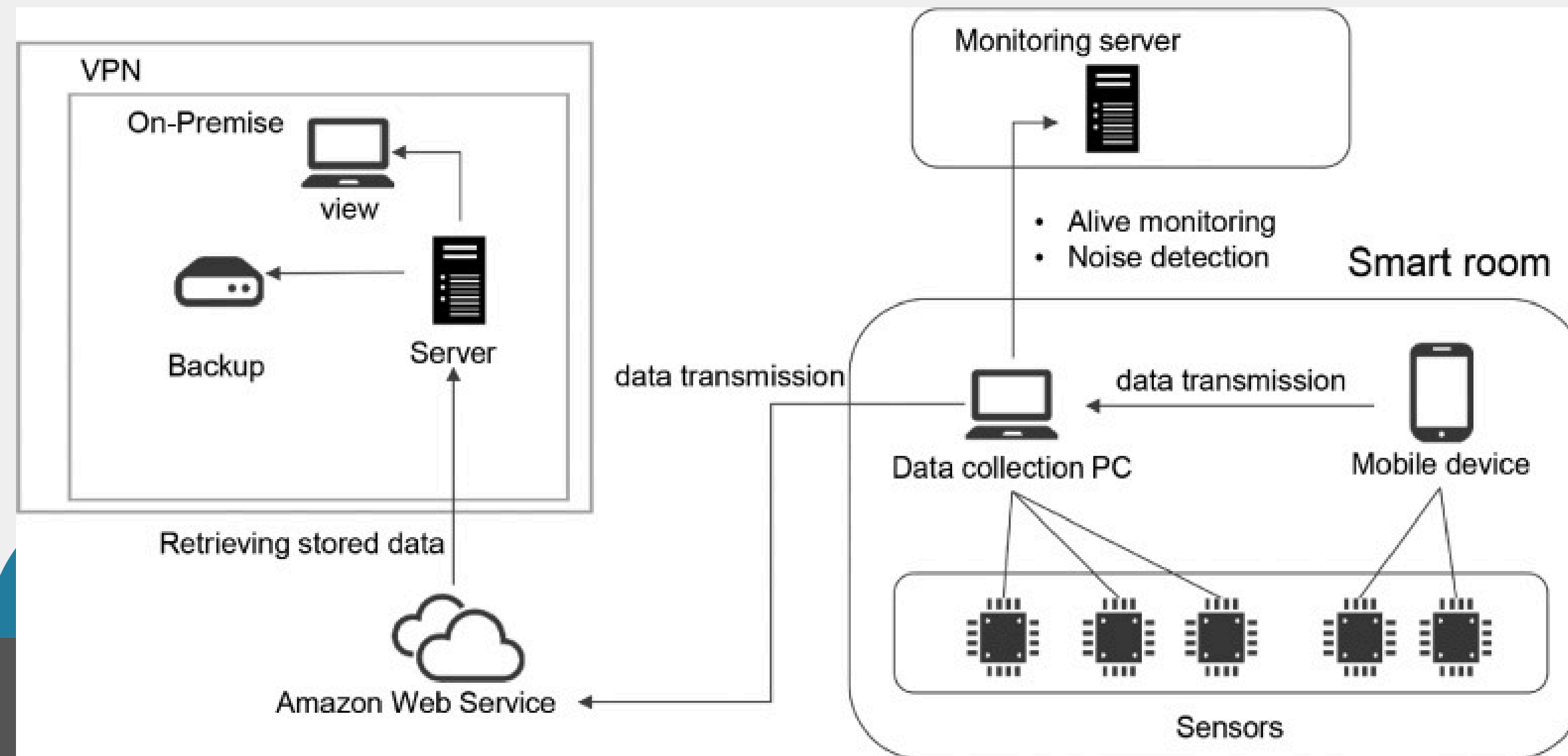
DATA COLLECTION

- 23 SUBJECTS (16 MALE AND 7 FEMALE).
- BETWEEN THE AGES OF 20 AND 38.
- EACH SPENDING 1 WEEK TO 2 MONTHS IN SMART ROOMS
- DURATION OF THE EXPERIMENT IS 2 YEARS
- ASKED TO WEAR A SMARTWATCH AND LIVE A NORMAL LIFE IN THE SMART ROOM.
- VIDEO CAMERA WAS INSTALLED IN THE ROOM TO ENSURE THE SENSORS WERE WORKING PROPERLY,
- TWO SMART ROOMS WERE PREPARED IN TOKYO, JAPAN.



DATA COLLECTION

A DATA COLLECTION SYSTEM WAS SET WHICH CONTROLLED ALL SENSING SYSTEMS AND STORED THE COLLECTED DATA IN AMAZON SIMPLE STORAGE SERVICE (AMAZON S3)



23 SUBJECTS

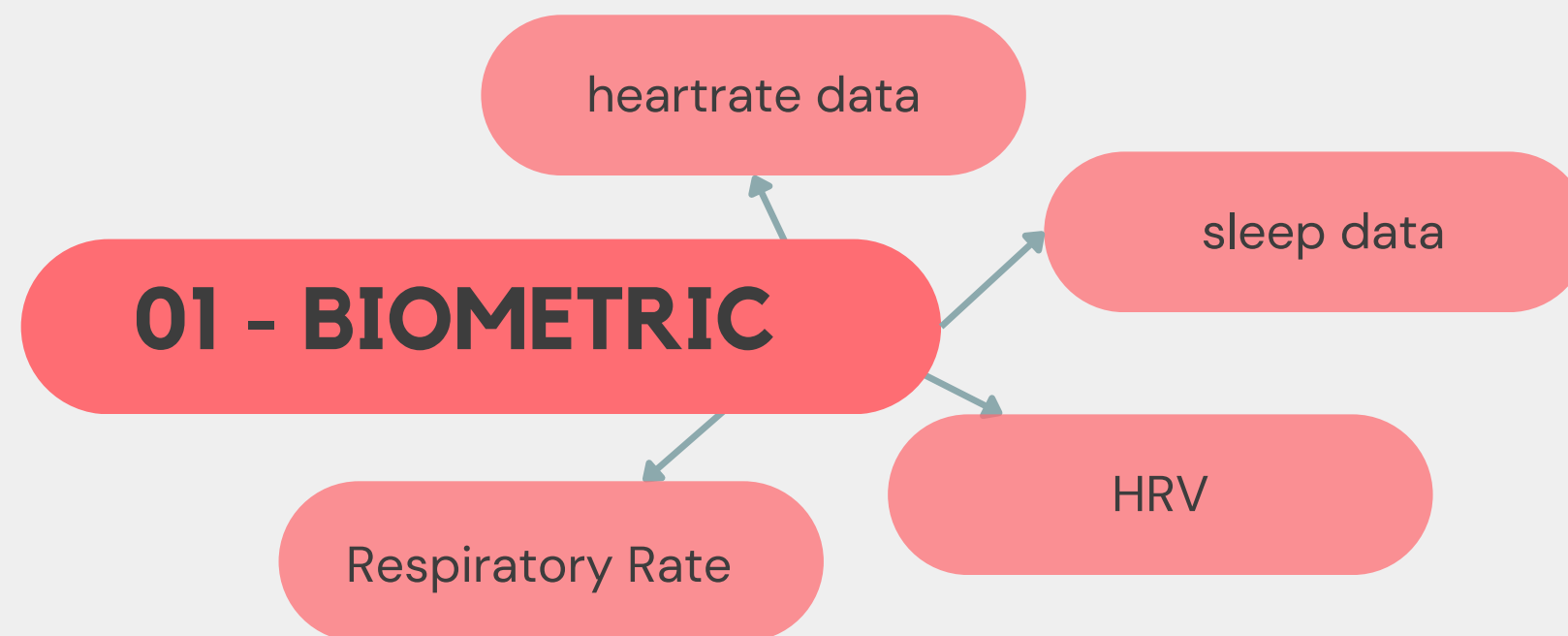
30 SENSOR TYPES

18,418,359 DATAPOINTS

- Smartwatch Data:
 - **COLLECTED USING FITBIT CHARGE3 AND WITHINGS SLEEP.**
 - **MEASURES: HEART RATE, SLEEP STAGES (REM, LIGHT, DEEP), SNORING TIME, RESPIRATION RATE**
- Environmental Data:
 - **COLLECTED USING NATURE REMO AND WS-USB01-THP.**
 - **MEASURES: HUMIDITY, TEMPERATURE, & ILLUMINANCE**

NATURE OF DATASET

- Type of Data: Unimodal
- Total Participants: 12
- Number of trials per person: 3–5
- Data collection Source: Apple Watch
- Datapoints: 401



02- ENVIRONMENTAL

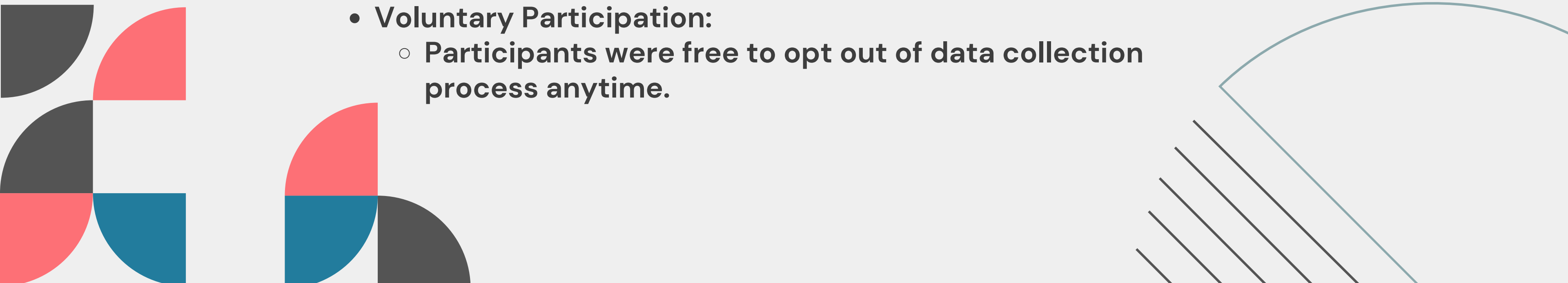
Environmental Audio

```
graph TD; A[02- ENVIRONMENTAL] --> B[Environmental Audio]
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A yellow rounded rectangle labeled "02- ENVIRONMENTAL" has a single arrow pointing down to a smaller yellow rounded rectangle labeled "Environmental Audio".

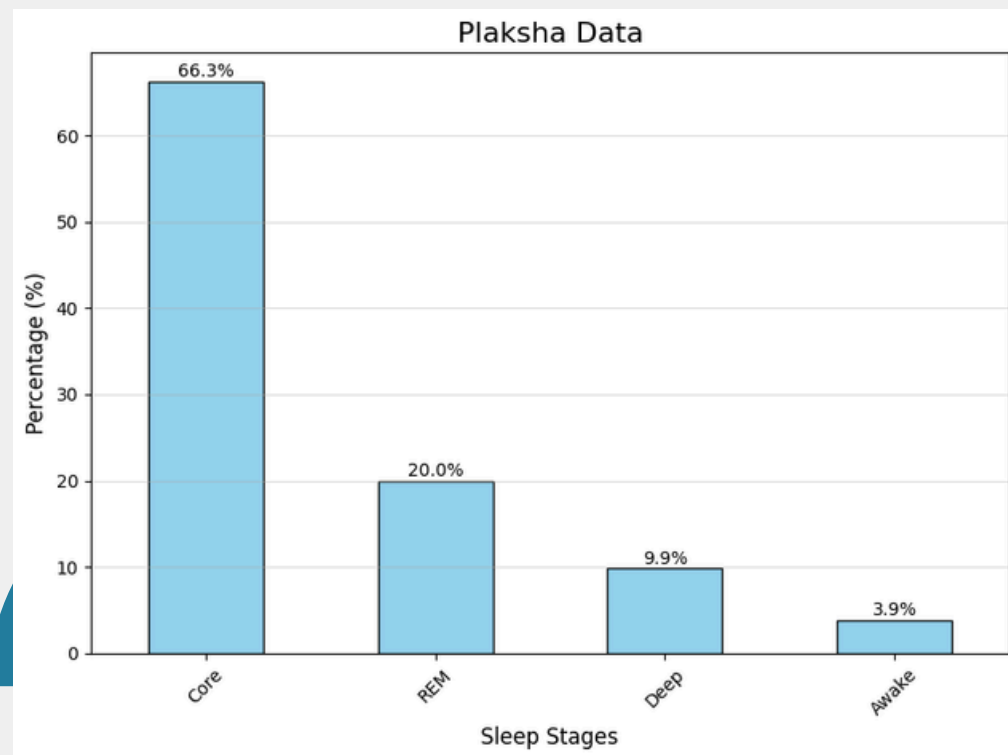
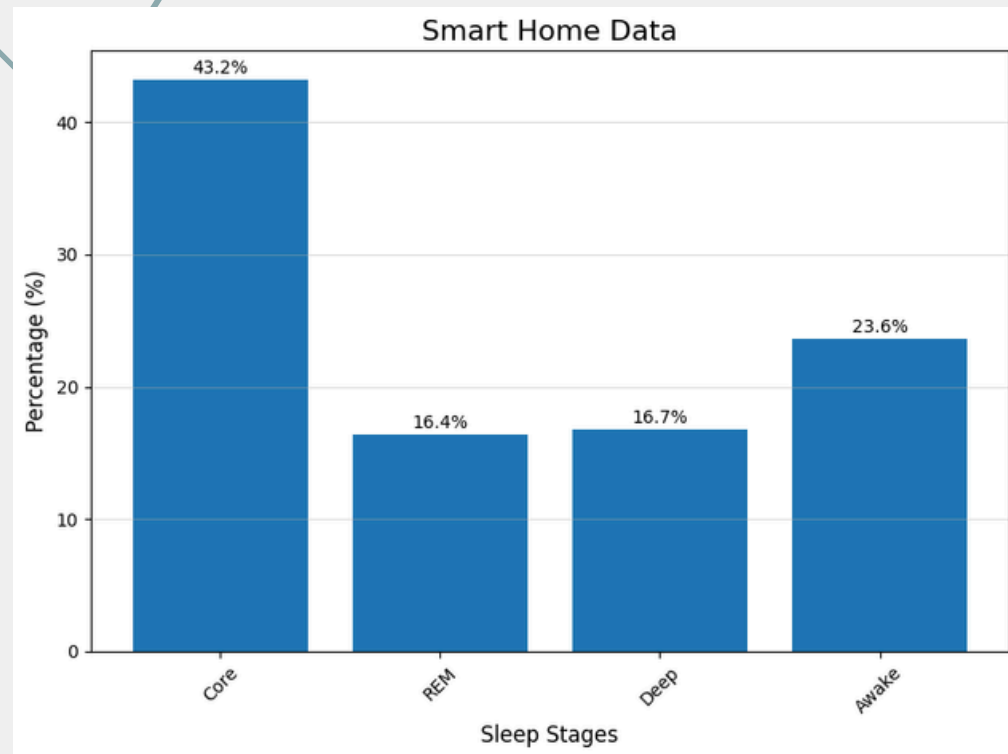


ETHICAL CONCERNS

- **Consent and Privacy:**
 - Written consent obtained from all participants.
 - **Data Anonymization:**
 - Data from subjects at high risk of re-identification were excluded.
 - **Voluntary Participation:**
 - Participants were free to opt out of data collection process anytime.
- 

PRE-PROCESSING

PRE-PROCESSING



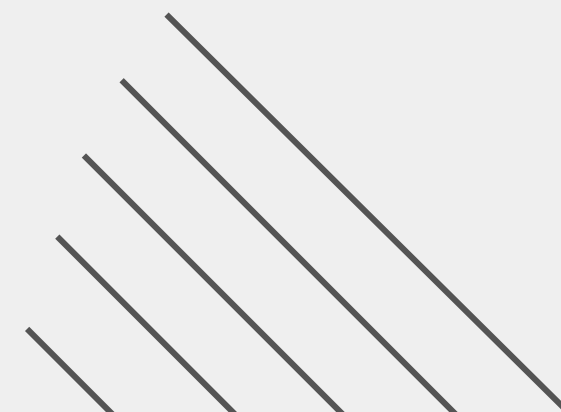
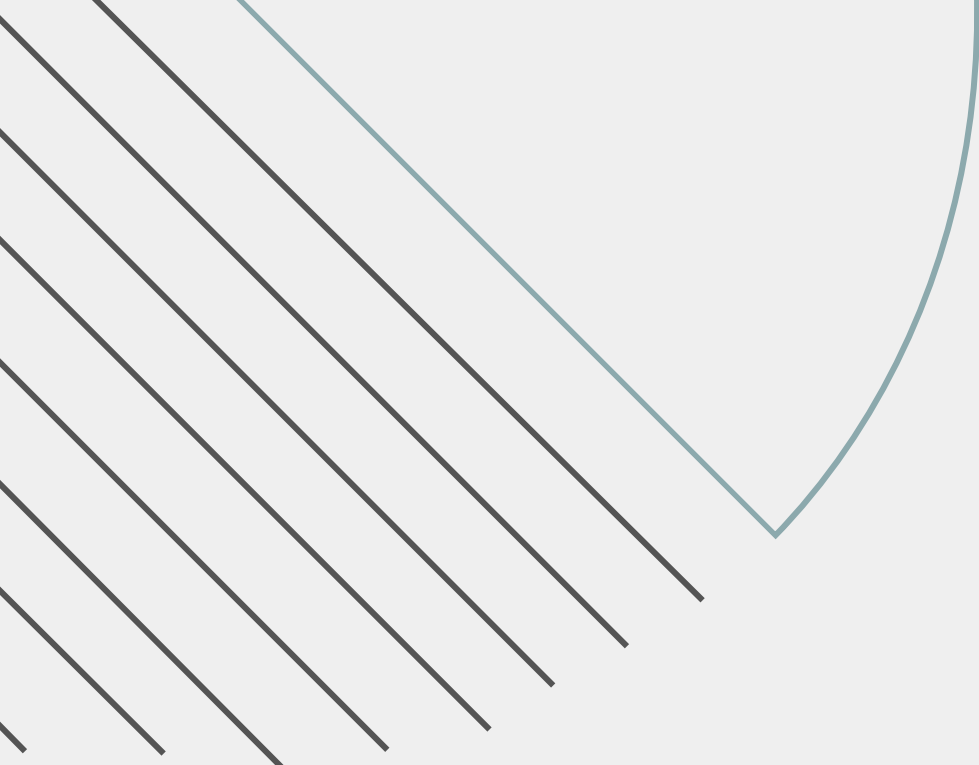
1. Merge environmental conditions data, HRV, Heart Rate, Respiration Rate & Snoring with sleep status data based on closest timestamp

2. Repeat the process for each participant and concatenate into final dataframe

3. Aggregated values to get day wise sleep and environmental data.

4. Filled NA/NaN values by propagating last valid observation to next valid to ensure consistent timestamps.

PROCESSING



PROCESSING

1. Calculate sleep quality score

- Sleep stage distribution:
 - Awake: 5%
 - Light: 45%
 - Deep: 25%
 - REM: 25%
- Penalize:
 - Heart rate spikes
 - HRV outside 30–100
 - Respiration outside 12–20 bpm
 - Snoring > 30 mins

**Sleep quality = good (score > 85)
= bad (score < 85)**

2. Explore correlation between environmental data and sleep quality using Smart Home data

- Models: Random Forest, SVM, Decision Tree
- Features: temperature, humidity, illuminance
- Target: Sleep quality

3. Explore correlation between environmental noise and sleep quality using Plaksha data

- Boxplot analysis to visualise difference in sleep quality between quiet and noisy environments.
- T-test to confirm the statistical significance of the difference in sleep quality between quiet and noisy environments.

ANALYSIS

SMART ROOM DATASET:

Model: Random Forest

	precision	recall	f1-score	support
0	0.76	0.70	0.73	74
1	0.56	0.64	0.60	44
accuracy			0.68	118
macro avg	0.66	0.67	0.66	118
weighted avg	0.69	0.68	0.68	118

Model: Support Vector

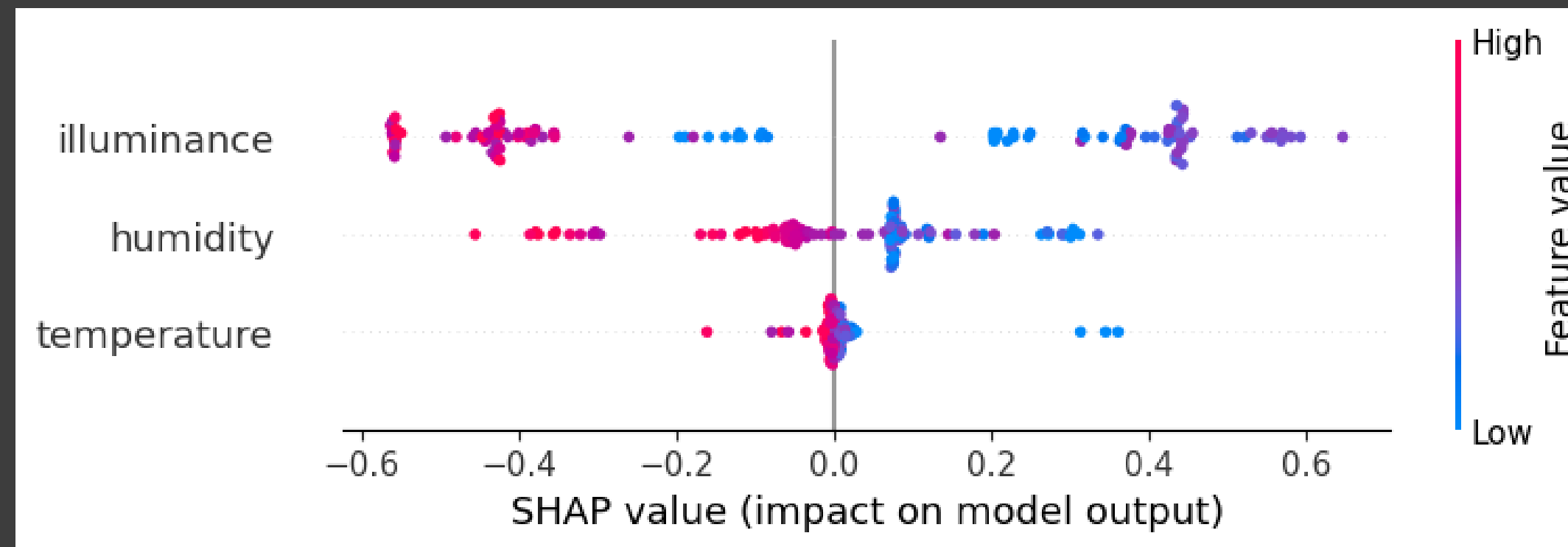
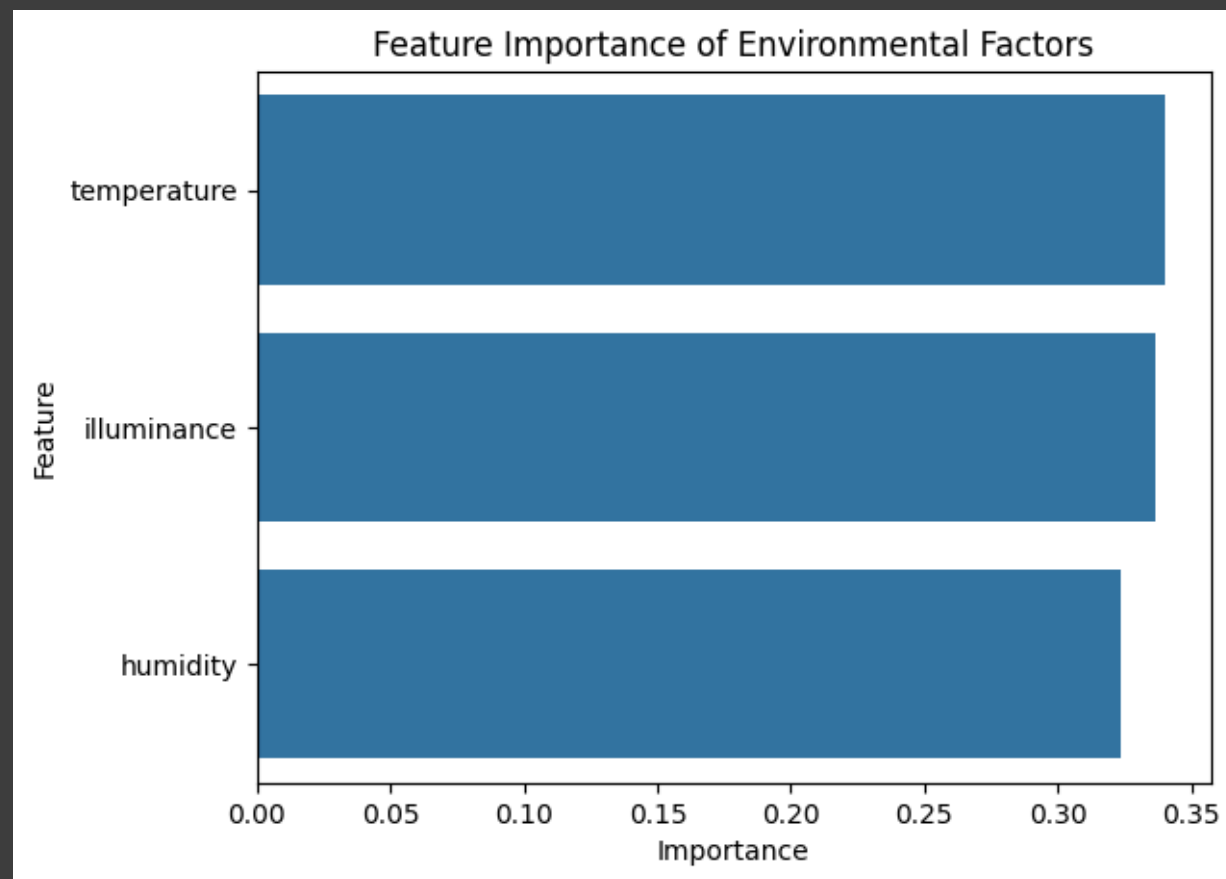
	precision	recall	f1-score	support
0	0.75	0.61	0.67	74
1	0.50	0.66	0.57	44
accuracy			0.63	118
macro avg	0.62	0.63	0.62	118
weighted avg	0.66	0.63	0.63	118

Model: Decision Tree

	precision	recall	f1-score	support
0	0.74	0.73	0.73	74
1	0.56	0.57	0.56	44
accuracy			0.67	118
macro avg	0.65	0.65	0.65	118
weighted avg	0.67	0.67	0.67	118

ANALYSIS

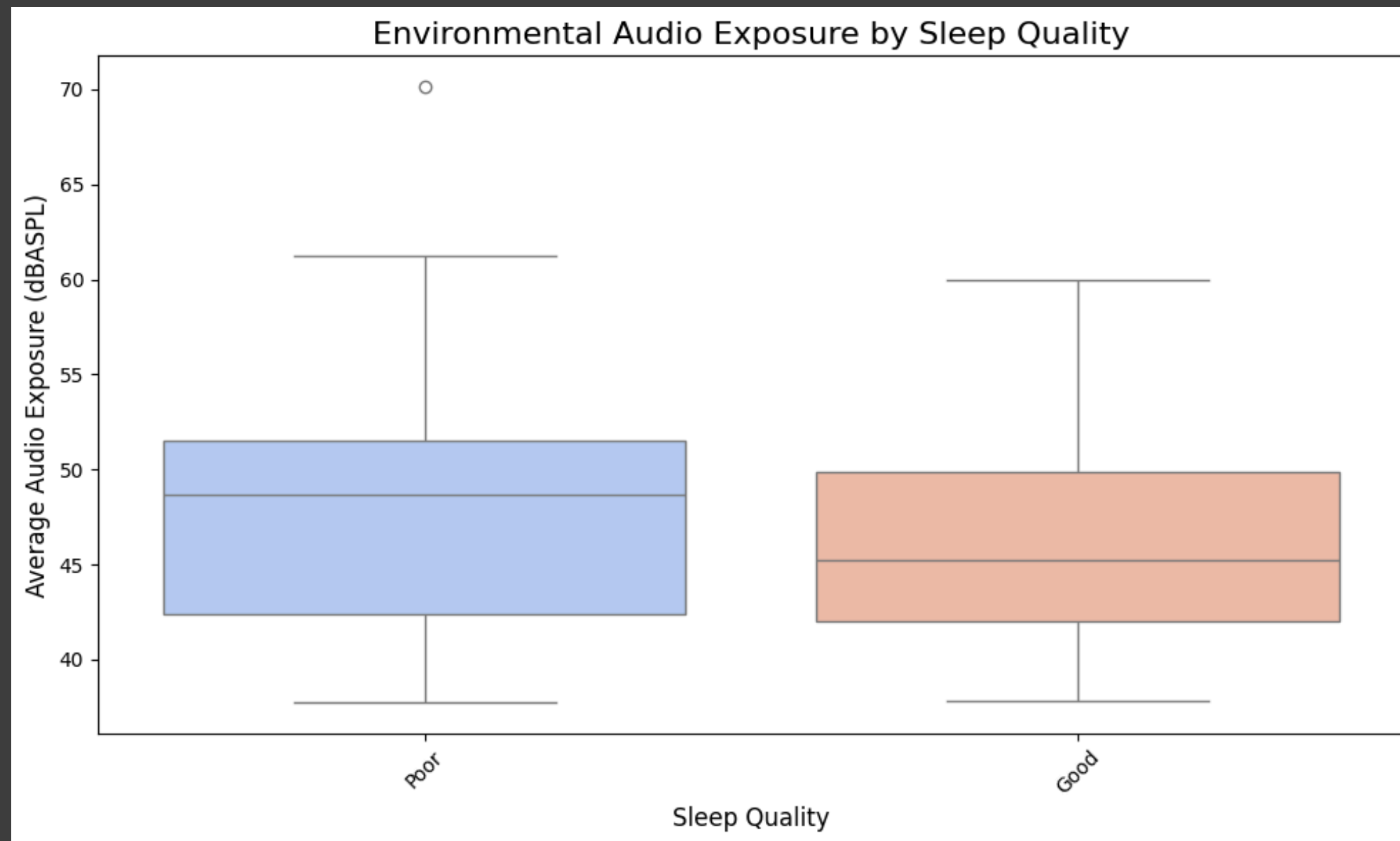
SMART ROOM DATASET:



illuminance	∞	1/sleep quality
humidity	∞	1/sleep quality
temperature	∞	1/sleep quality

ANALYSIS

PLAKSHA DATASET:



RESULTS OF T-TEST:

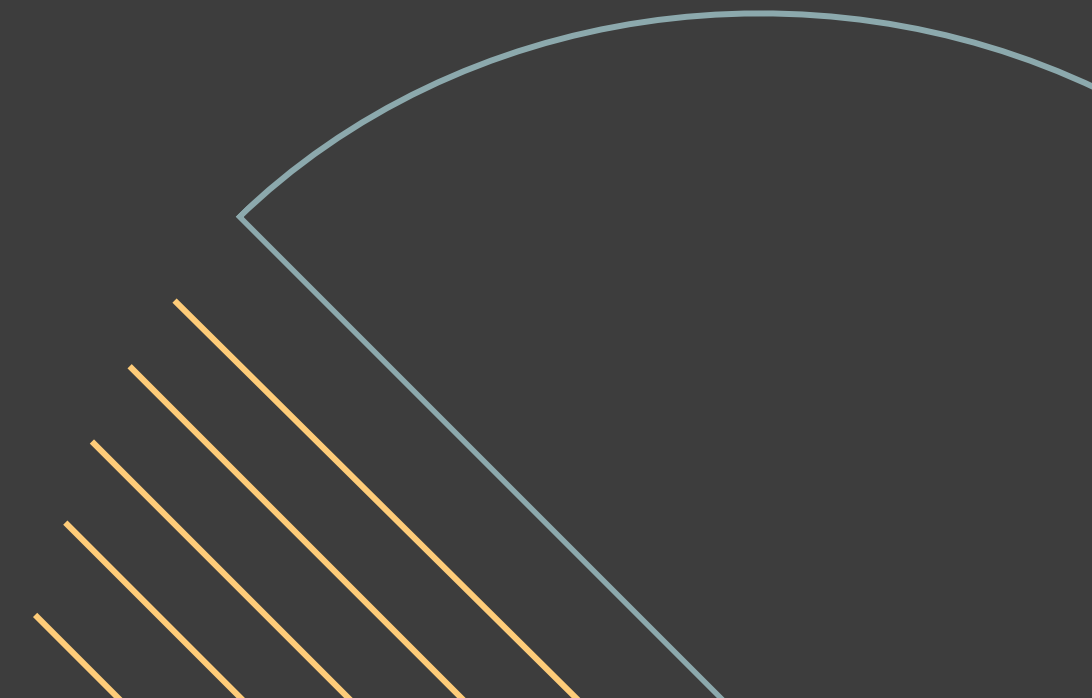
t-statistic: -3.690685171784704

p-value: 0.0002573614827664

- The negative value suggests that sleep quality was higher in the quiet environment compared to the noisy environment.
- The small p-value suggests strong statistical evidence to conclude that the difference in sleep quality between the quiet and noisy environments did not occur by chance - it is a real, significant effect.

CHALLENGES


- Due to unavailability of sensors, we could not collect environmental data like temperature, luminescence & humidity
- Inconsistency in different versions of apple watches - some watches had InBed & Asleep data while others did not
- Dataset diversity: Majority of the data collected was from one person only.
- Apple watch being unreliable for sleep detection at times (inbed time < asleep time)
- Features used to calculate sleep quality scores are not enough. Subjective scores like PSQI (Pittsburgh Sleep quality index) should be considered.





SUMMARY

By identifying which environmental factors have the most significant effect on sleep quality, we can inform future research, policy-making, and everyday sleep improvement practices. This could lead to better sleep environments in homes, workplaces, and healthcare settings, ultimately improving health outcomes globally.



The background is a dark charcoal grey. In the corners, there are abstract geometric patterns. The top-left corner features a series of parallel, slightly curved lines in a light blue and a golden-yellow color. The top-right and bottom-left corners contain clusters of semi-circles in white, golden-yellow, and a teal color. The bottom-right corner features a large, light blue semi-circular outline with several parallel golden-yellow lines radiating from its center.

THANK YOU