Intelligent Lighting Design for Remote Workers: Enhancing Well-Being and Productivity in Home-Offices

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Resumo

Esta investigação explora o papel transformador do design de iluminação inteligente no aumento da produtividade e do bem-estar entre os trabalhadores remotos em ambientes de escritórios domésticos. Com a crescente prevalência do trabalho remoto, os espaços domésticos tornaram-se ambientes multifuncionais que exigem soluções de iluminação inovadoras. O estudo investiga como a iluminação centrada no ser humano (HCL), os sistemas de iluminação inteligentes e a iluminação de tarefas podem apoiar a saúde, o humor e a eficiência. Estas abordagens enfatizam fatores como a intensidade da luz e a temperatura da cor. Empregando uma abordagem de métodos mistos, a fase exploratória utilizou a pesquisa por questionário e sondagens culturais para compreender as necessidades do utilizador, enquanto a fase generativa empregou o mapeamento da jornada do utilizador para identificar pontos de contacto e a prototipagem para desenvolver e testar soluções.

As principais conclusões destacam a influência crítica da iluminação nos ritmos circadianos, no foco cognitivo e no conforto. A iluminação de tarefas e os sistemas de iluminação inteligentes surgiram como soluções eficazes para os trabalhadores remotos, oferecendo uma iluminação adaptável e personalizável, adaptada a atividades específicas e preferências pessoais. O design de iluminação inteligente, alimentado por tecnologias LED avançadas, permite ajustes dinâmicos que fazem uma transição perfeita entre os modos funcional e ambiente, promovendo a produtividade, o conforto e a eficiência energética. Apesar dos seus benefícios, a limitada sensibilização e adoção destas tecnologias continuam a ser barreiras, enfatizando a necessidade de educação entre os trabalhadores e as organizações remotas.

Esta investigação estabelece as bases para estudos futuros sobre o design de iluminação inteligente e centrado no ser humano em escritórios domésticos, com foco na iluminação de tarefas, tecnologias adaptativas e estratégias para promover a consciencialização e ambientes de trabalho remoto mais saudáveis e produtivos.

Palavras-chave:

Design de iluminação inteligente, Bem-estar, Produtividade, Trabalho remoto, Escritórios domésticos

Abstract

This research explores the transformative role of intelligent lighting design in enhancing productivity and well-being among remote workers in home-office settings. With the growing prevalence of remote work, home spaces have become multifunctional environments requiring innovative lighting solutions. The study investigates how human-centric lighting (HCL), intelligent lighting systems, and task lighting can support health, mood, and efficiency. These approaches emphasize factors such as light intensity and color temperature. Employing a mixed-methods approach, the exploratory phase utilized survey by questionnaire and cultural probes to understand user needs, while the generative phase employed user journey mapping to identify touchpoints and prototyping to develop and test solutions.

Key findings highlight the critical influence of lighting on circadian rhythms, cognitive focus, and comfort. Task lighting and intelligent lighting systems emerged as effective solutions for remote workers, offering adaptable and customizable illumination tailored to specific activities and personal preferences. Intelligent lighting design, powered by advanced LED technologies, enables dynamic adjustments that seamlessly transition between functional and ambient modes, fostering productivity, comfort, and energy efficiency. Despite their benefits, limited awareness and adoption of these technologies remain barriers, emphasizing the need for education among remote workers and organizations.

This research lays the groundwork for future studies on human-centric and intelligent lighting design in home offices, focusing on task lighting, adaptive technologies, and strategies to foster awareness and healthier, more productive remote work environments.

Keyword:

Intelligent lighting design, Well-being, Productivity, Remote work, Home-offices

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List of Acronyms and Abbreviations

WFH: Working from Home
WHO: World Health Organization
IEQ: Indoor Environmental Quality
WorldGBC: The World Green Building Council
SAD: Seasonal Affective Disorder
ipRGCs: Intrinsically Photosensitive Retinal Ganglion Cells
SCN: Suprachiasmatic Nucleus
ALAN: Artificial Light at Night
LAN: Light at Night
HCL: Human-Centric Lighting
CCT: Correlated Color Temperature
K: Kelvins
EEG: Electroencephalography
SAM: Self-Assessment Manikin
nm: Nanometers
LED: Light-Emitting Diode
IoT: Internet of Things
SDG: Sustainable Development Goals

Glossary

ALAN: Artificial Light at Night—Refers to artificial lighting sources present during nighttime, including streetlights, outdoor lighting, and indoor light pollution.

Affective Symptoms: Mood-related symptoms, such as sadness or irritability, often associated with mental health conditions like depression or bipolar disorder.

Burnout: A state of chronic physical, emotional, and mental exhaustion caused by prolonged work-related stress. It is characterized by emotional exhaustion, detachment, and reduced performance. Recognized by the World Health Organization (WHO) as an "occupational phenomenon."

CCT: Correlated Color Temperature—A measure of the color appearance of light, described in Kelvins (K), which influences mood and perception.

Chronotype: An individual's natural preference for sleep and activity times, categorized as morning, evening, or intermediate types, shaped by biological rhythms.

Cognitive Performance: The ability to carry out tasks requiring mental processes such as thinking, problem-solving, memory, attention, and decision-making. Influenced by factors like environment, health, and mental well-being, cognitive performance impacts learning, focus, and decision-making.

Color Rendering: The ability of a light source to reproduce colors accurately as they appear under natural light.

Daylight Harvesting: A method using sensors to adjust artificial lighting based on natural light levels, saving energy and maintaining consistent indoor brightness.

Dimmer: A device used to adjust the brightness of a light source by controlling electrical voltage, enabling the creation of different atmospheres or energy savings.

Eye Strain: A condition causing discomfort, fatigue, and irritation in the eyes, often resulting from prolonged screen time or other visually intensive tasks. Symptoms include headaches, dry eyes, and blurred vision.

Fatigue: A state of physical and mental exhaustion that reduces a person's ability to function effectively. It can persist due to underlying health issues, lifestyle factors, lack of sleep, or prolonged exertion, and is more severe than ordinary tiredness.

Flicker: Rapid fluctuations in the brightness of a light source, which can cause discomfort, distraction, or eye strain.

Glare: Excessive brightness or light reflections that cause visual discomfort, reduce visibility, or impair the ability to perform tasks effectively. It often results from poorly designed lighting systems or direct exposure to bright light sources.

HCL: Human-Centric Lighting—Lighting systems designed to mimic natural light patterns and support human health, productivity, and well-being by aligning with circadian rhythms.

Hybrid Work: A flexible work arrangement where employees split their time between working remotely and in a central workplace, combining the benefits of both environments.

IEQ: Indoor Environmental Quality—A measure of the quality of indoor environments, encompassing factors like lighting, air quality, and thermal comfort, which influence occupants' health and productivity.

ipRGCs: Intrinsically Photosensitive Retinal Ganglion Cells—Specialized cells in the eye that influence circadian rhythms and respond to light intensity and color.

IoT-Based: Systems or devices that operate within the Internet of Things (IoT), enabling connectivity, data exchange, and automation through the internet.

Jet Lag: A temporary disruption of circadian rhythms caused by rapid travel across time zones, leading to symptoms like fatigue, insomnia, and irritability.

LAN: Light at Night—General term for artificial or natural lighting present during nighttime hours.

LED: Light-Emitting Diode—A semiconductor device that emits light when an electric current passes through it, known for energy efficiency and long lifespan.

SCN: Suprachiasmatic Nucleus—A group of neurons in the brain responsible for regulating circadian rhythms, influenced by light exposure.

Sleep Drive: The body’s natural pressure to sleep, which builds during wakefulness and dissipates during sleep, helping regulate the sleep-wake cycle.

Subjective Alertness: An individual’s self-perceived level of wakefulness and focus, influenced by factors such as sleep quality, circadian rhythms, and environmental stimuli.

Sustained Attention: The ability to maintain focus on a task or activity over an extended period without becoming distracted.

Sustainable Development Goals (SDGs): A set of 17 global goals established by the United Nations in 2015 to address challenges like poverty, inequality, and climate change, aiming to promote peace, prosperity, and sustainability by 2030.

Thermal Comfort: Satisfaction with the temperature of the surrounding environment, influenced by factors like air temperature and humidity.

Theory of Planned Behavior: A psychological framework that predicts individual behavior based on intentions, attitudes, subjective norms, and perceived behavioral control.

WorldGBC: World Green Building Council—A global network promoting sustainable building practices to achieve net-zero carbon emissions by 2050, advancing occupant health and environmental sustainability.

World Health Organization (WHO): A specialized agency of the United Nations responsible for international public health.

1. Introduction

1.1. Introduction

The rise of remote work, propelled by technological advancements and the COVID-19 pandemic, has redefined the role of the home. Once primarily spaces for rest and family life, homes now serve as multifunctional environments that accommodate work, leisure, and daily living. This transformation highlights the critical need for home-office designs that support health, productivity, and overall well-being.

Lighting is a key factor in creating such environments. It significantly impacts mood, focus, and circadian rhythms, which in turn affect productivity and health. However, traditional home lighting systems are often ill-equipped to meet the demands of remote work. Issues such as limited adjustability, inadequate brightness, and lack of personalization frequently lead to discomfort, eye strain, and diminished productivity. As remote workers spend more time indoors, the need for intelligent, human-centric lighting solutions has become increasingly urgent.

Human-centric lighting (HCL) and intelligent technologies offer promising solutions to these challenges. By adapting light to individual needs and work patterns, they create environments optimized for diverse tasks and times of day. These innovations not only enhance productivity but also support physical and mental well-being. Despite their clear benefits, awareness and adoption of such systems remain limited.

This thesis explores the principles of human-centric and intelligent lighting in home-office settings, focusing on their impact on productivity, health, and comfort. By identifying effective lighting strategies for remote workers, this research aims to contribute to a broader understanding of sustainable, user-centric indoor environments.

The inspiration for this study stems from my personal experience as an immigrant adapting to a shared living space. Transitioning from a home with tailored lighting for work and relaxation to one with limited options underscored the importance of adaptable lighting in multifunctional spaces. This experience deepened my appreciation of lighting's role in well-being and productivity, driving my motivation to seek solutions for others facing similar challenges.

Ultimately, this research addresses the growing demand for adaptable lighting among remote workers, offering practical recommendations for bridging the gap between traditional and intelligent lighting systems. By placing lighting at the forefront of home-office design, the study aims to inspire innovation, improve work-from-home experiences, and support the well-being and productivity of remote workers worldwide.

1.2. Problematization and Research Questions

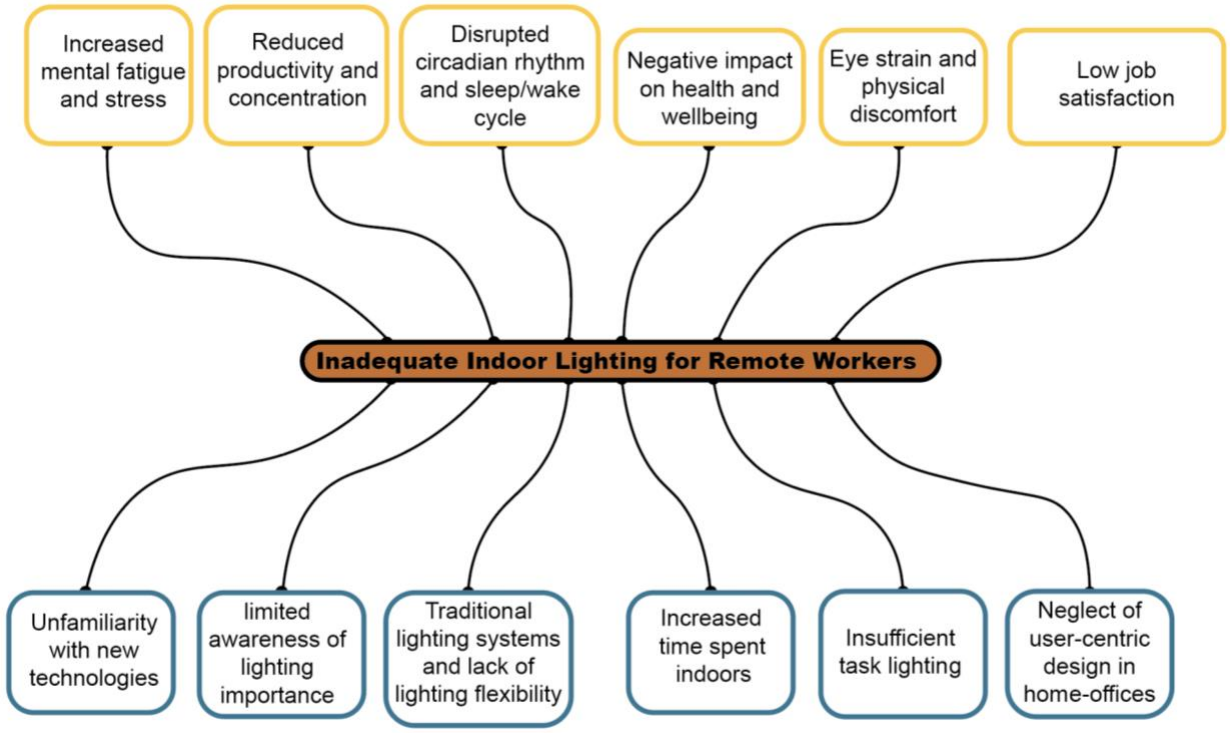

Figure 1: The Diagram of the Problematization

1.2.1. Problems Statement

The shift to remote work, accelerated by technological advancements and the COVID-19 pandemic, has fundamentally transformed how people use their homes. As spaces previously dedicated to rest and family life are increasingly repurposed for work, productivity, and daily living, the quality of home-office environments has become critical in supporting remote workers' health, productivity, and job satisfaction.

Lighting, in particular, plays a pivotal role in influencing mood, focus, and circadian rhythms, which directly affect well-being and performance. However, traditional indoor lighting systems lack the adaptability required for remote work's diverse demands. This inadequacy often results in discomfort, eye strain, poor sleep, and reduced productivity, negatively impacting both individuals and organizations. Despite the emergence of human-centric and intelligent lighting technologies, these solutions remain underutilized in home-office settings due to limited awareness and unfamiliarity with their potential benefits. (Figure 1)

This study aims to bridge this gap by exploring how human-centric and intelligent lighting principles can enhance productivity, well-being, and comfort for remote workers. It will provide practical recommendations, including strategies for personalized task lighting, to address the specific needs of remote workers and contribute to more effective, health-conscious home-office environments.

1.2.2. Research Questions

Main research question:

What are the main characteristics of lighting design that enhance productivity and well-being in home-office environments?

Secondary research questions:

- What factors in indoor environments will affect the health and productivity of remote workers?
- How does lighting affect the circadian rhythm and influence health and productivity in indoor environments?
- How do intelligent technologies support the principles of human-centric lighting to enhance well-being in indoor environments?
- What lighting strategies can be implemented to enhance productivity and comfort in home-office environments for remote workers?

1.3. Objectives

Main research objective:

To explore how intelligent lighting design can enhance the productivity and well-being of remote workers in home-office environments.

Secondary research objectives:

- To identify how the transition to remote work has influenced the need for effective indoor lighting solutions in homes.
- To characterize how lighting influences the circadian rhythm and its effects on health and productivity in indoor environment.
- To use the principles of human-centric lighting and define how intelligent technologies contribute to enhancing well-being in indoor environments.
- To explore and recommend effective lighting strategies that improve both productivity and comfort in home-office setups for remote workers.
- To highlight that raising awareness of human-centric lighting can influence market demand for intelligent lighting solutions.

1.4. Research design

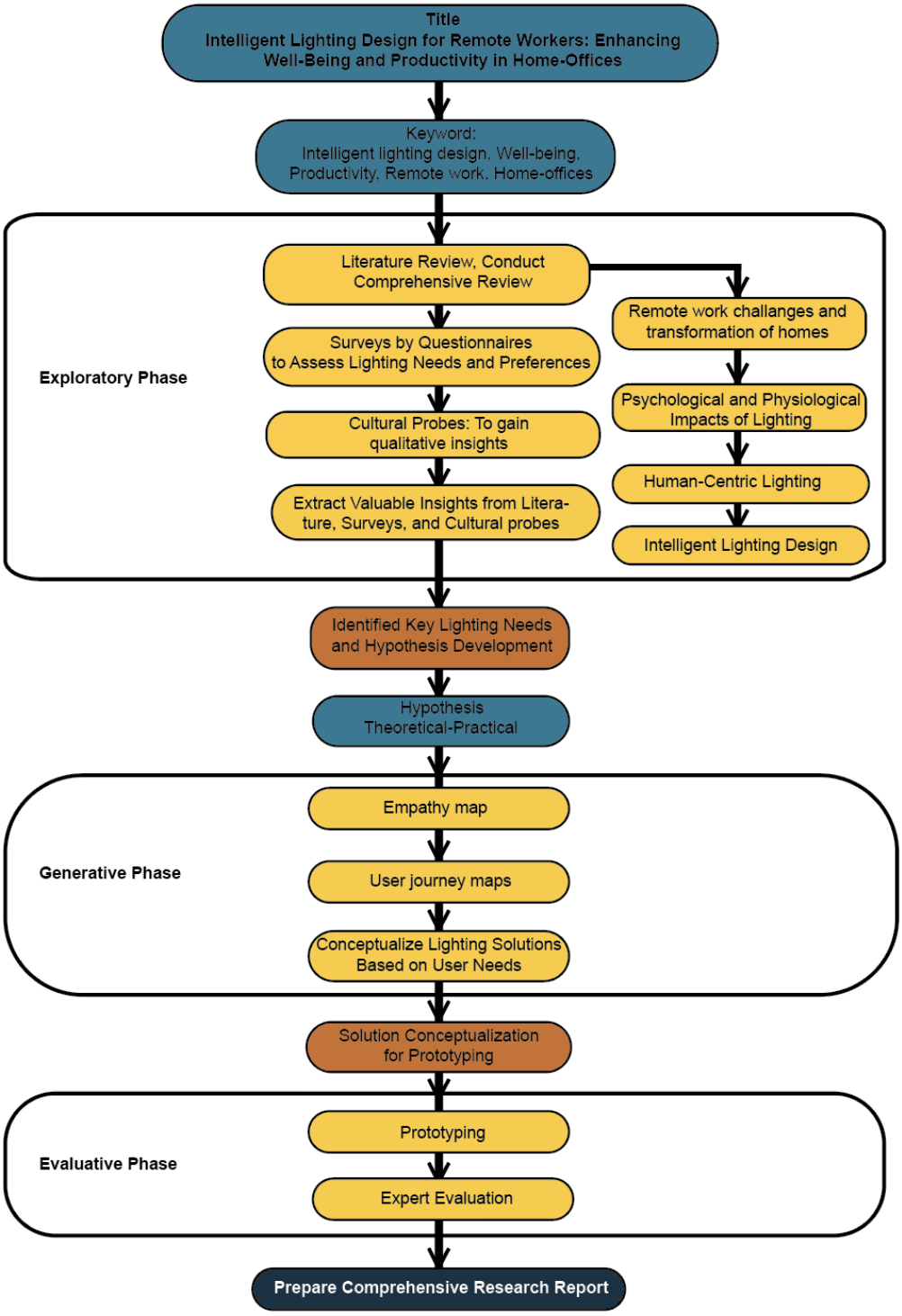

Figure 2: The Diagram of Research Design

This research adopted a theoretical-practical approach to investigate the effectiveness of intelligent lighting solutions in enhancing the productivity and well-being of remote workers in home-office settings. The study was structured into three phases: **Exploratory**, **Generative**, and **Evaluative**, with each phase building on the findings of the previous one. A mixed-methods approach was employed to comprehensively address both theoretical insights and practical applications. Figure 2 is the diagram of the research design.

1. Exploratory Phase: Understanding the Problem and User Needs

The exploratory phase established the foundation for the study by investigating the challenges of home-office lighting and identifying factors influencing productivity and well-being among remote workers. This aligns with Creswell's (2009) emphasis on the importance of exploratory research in understanding complex phenomena. A combination of theoretical exploration and empirical methods was used in this phase.

- **Literature Review**: A review of existing literature was conducted to examine:

- The transformation of homes into multifunctional spaces due to remote work.
- Psychological and physiological effects of lighting on productivity and comfort.
- Principles of human-centric and intelligent lighting design. This review helped identify gaps in current research and provided theoretical guidance for subsequent empirical methods.

- **Surveys by Questionnaires**: Surveys were distributed to remote workers to collect data on lighting conditions, preferences, and challenges in their home-office environments. The responses provided quantitative insights into common issues caused by unsuitable lighting.
- **Cultural Probes**: Cultural probes were utilized to gather deeper qualitative insights into how remote workers engaged with their home-office environments and indoor factors. Participants documented their daily experiences using diaries and photographs, capturing contextual information and revealing habits and challenges.
- **Synthesis of Insights**: The findings from the literature review, surveys, and cultural probes were synthesized to:

- Identify recurring lighting challenges and unmet user needs.
- Highlight actionable opportunities for improving lighting in home-office environments.
- Develop a hypothesis that intelligent, human-centric lighting solutions could enhance productivity and well-being compared to traditional lighting systems.

2. Generative Phase: Designing Human-Centric Solutions

Building upon the insights from the exploratory phase, the generative phase focused on developing practical, user-centered lighting solutions. This approach is consistent with Laurel's (2003) perspective on design research, which advocates for the creation of innovative solutions through participatory design methods.

- **Empathy Map**: An Empathy map was created to represent remote workers' emotional, cognitive, and functional interactions with lighting. It helped to clarify user frustrations, goals, and priorities.

- **User Journey Maps**: User journey maps were developed to outline how remote workers interacted with their lighting throughout a typical workday. This process pinpointed critical moments where lighting improvements could enhance focus, comfort, and productivity.
- **Conceptualization of Lighting Solutions**: Based on insights from empathy and journey maps, human-centric lighting concepts were developed. These concepts incorporated features such as:
- Circadian rhythm alignment through adjustable color temperatures.
- Task-specific lighting for activities requiring varying levels of focus.
- Personalization through smart controls and automation.

Prototyping Preparation: initial lighting solutions were refined and prepared for prototyping. These designs focused on functionality, adaptability, and aesthetic considerations to meet the ergonomic and psychological needs of remote workers.

3. Evaluative Phase: Testing and Refining the Solutions

The final phase involved testing and refining the proposed lighting solutions to ensure their practicality and effectiveness in real-world settings. This evaluative process is crucial for validating the practical applicability of design interventions, as highlighted by Hanington (2003).

- **Prototyping**: Functional prototypes of the lighting solutions were developed, incorporating features such as adjustable brightness, and personalized lighting settings tailored to user needs.
- **Expert Evaluation**: The prototypes were evaluated by experts. These evaluations provided valuable feedback on the usability, functionality, and effectiveness of the solutions.

The study concluded with the preparation of a comprehensive research report that synthesized findings from all phases. By systematically progressing through these phases, the study effectively combined theoretical insights with practical applications to develop and assess intelligent lighting solutions tailored to the needs of remote workers.

2. Theoretical Framework

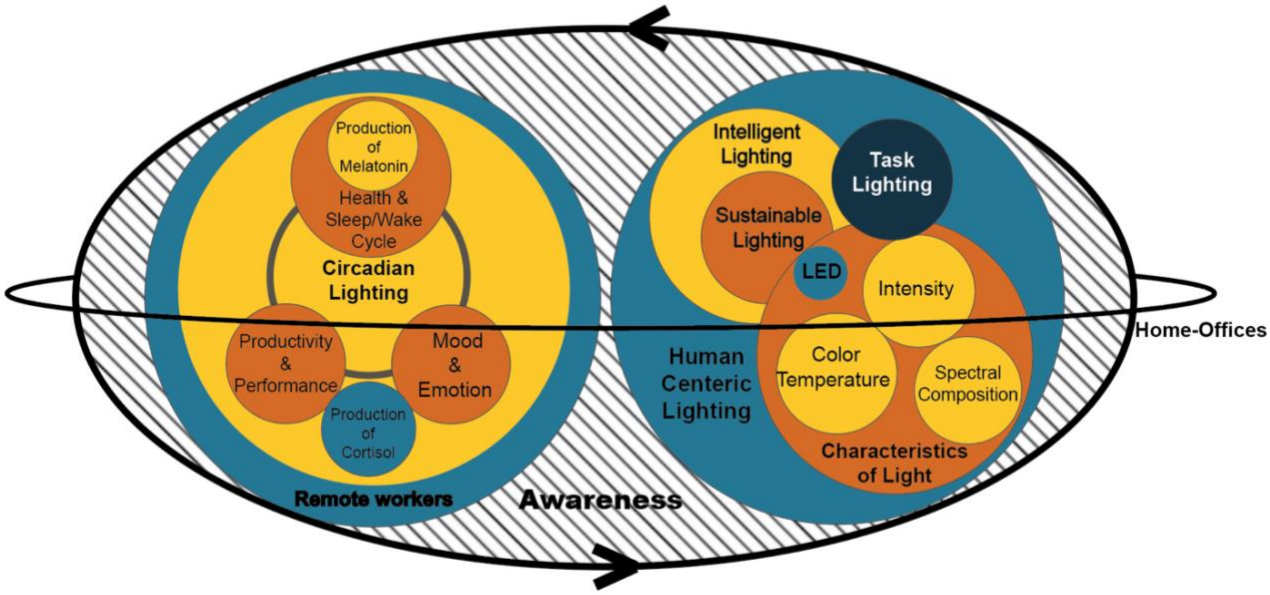

Figure 3: The Diagram of The Theoretical Contextualization

2.1. The Rise of Remote Work: Transforming Home Environments

The rapid advancement of technology and the rise of digital communication have dramatically changed the work landscape. The COVID-19 pandemic has further accelerated this shift, leading to a significant increase in remote workers. Homes are no longer places for rest and family interaction; they have evolved into multifunctional environments that serve as workspaces. This transformation has brought attention to the importance of health and productivity of remote workers, many of whom may spend days indoors without leaving their homes. Therefore, understanding the factors influencing well-being in these new living and working arrangements has never been more critical. Figure 3 illustrates the conceptual framework underlying this study, highlighting the intersection of circadian lighting and human-centric lighting within the context of home offices and remote work. The diagram emphasizes the relationship between lighting design, biological rhythms, and workplace productivity, positioning awareness as a critical factor bridging these domains.

The overarching theme of the diagram underscores the growing importance of lighting awareness in shaping effective and healthy remote workspaces. By integrating principles from both circadian and human-centric lighting, this study seeks to enhance lighting strategies tailored to the needs of remote workers.

This chapter discusses the essential role of indoor environmental factors, particularly focusing on indoor lighting, which is one of the most significant elements affecting the health and productivity of remote workers.

2.1.1. The Evolution of Remote Work: Exploring the Shift Toward Home Offices

In today's world, the rapid advancement of technology and the widespread use of digital devices along with greater internet accessibility have made telecommuting more feasible for a broader population, allowing more people to work remotely. This shift in working patterns has reshaped the perception of home environments, particularly during the coronavirus pandemic. According to Eurofound (2020), remote work saw a significant surge across Europe due to the pandemic, with up to 40% of employees working from home (WFH) during the lockdown periods, a significant rise from the pre-pandemic figure of just 5.5% who typically WFH. Nearly half of the employees surveyed in July 2020 reported working from home at least some of the time during the pandemic, and 75% of these respondents expressed a preference for continuing telework at least occasionally post-pandemic. However, only 47% of employees indicated that their employers had provided the necessary equipment for teleworking, underlining the ad-hoc nature of this transition. Research by Barrero et al (2021) also confirmed a dramatic rise in remote work in the United States, where up to 42% of the workforce was WFH at the peak of the pandemic. This shift occurred as companies quickly adjusted to ensure business continuity through telework. The pandemic highlighted that employees no longer need to be physically present in a traditional office setting to fulfill their responsibilities. Many have successfully transitioned to remote work, completing tasks from home or other locations, highlighting the need for employees and companies to adapt to and embrace this new way of working.

Remote work refers to tasks performed outside the traditional office setting and can be categorized into three types: **home-based**, **center-based**, and **mobile telework**. Home-based remote work involves completing tasks from a home office, effectively turning one's home into a workspace. Center-based remote work occurs in shared or co-working spaces, while mobile telework allows employees to work from various locations, using technology to stay connected.

Within the scope of home-based remote work, two primary models exist:

- **The partial home-centered model (Hybrid model):** Employees divide their time between working from home and the office.
- **Full-time home-based work:** All professional duties are conducted from home.

This study focuses on the home-based remote work model, examining its implications, challenges, and potential benefits in modern workforce dynamics.

Espitia et al (2022) and Madero Gómez et al (2022) discuss how the pandemic has necessitated adaptations in business practices, highlighting the shift toward remote work as a significant trend. Post-pandemic, many employees and employers have expressed a preference for flexible working models, such as hybrid work (Eurostat, 2022). This transition reflects ongoing changes in employment relationships and organizational structures. Now firms and individuals have had no choice but to adapt.

The European Commission's Joint Research Centre (2020) highlighted that this rapid shift to teleworking profoundly impacted work organization, autonomy, and job quality, revealing both the advantages and challenges of remote work arrangements. In a study by Dahik and colleagues, 93% of employees surveyed expressed a desire to retain the option of WFH even after the COVID-19 pandemic, with most favoring a hybrid work model. Reasons cited by employees included

increased perceived productivity and higher job satisfaction (Dahik et al, 2020). A study by McKinsey revealed that more than half of the surveyed workers supported hybrid work models. Furthermore, over a quarter of respondents indicated that they would consider changing jobs if their employer removed the option to work remotely (Alexander et al, 2021).

Remote work adoption offers cost-reduction and flexibility for work-life balance but faces communication, technical, and management challenges. (Ferreira et al, 2021) The Hybrid model allows for flexibility, enabling employees to benefit from the convenience of working remotely while maintaining a physical presence in the office for collaboration and face-to-face meetings. The full-time home-centered working model emphasizes complete remote work, offering maximum flexibility and autonomy. While it eliminates commuting and allows for a personalized work environment, it relies heavily on virtual communication. It can sometimes lead to challenges in maintaining team connections and work-life boundaries. The study by Ipsen et al (2021) investigated the experiences of 5,748 knowledge workers from 29 European countries who worked from home during the early stages of lockdown (11 March to 8 May 2020), identifying six key factors of advantages and disadvantages. Most participants reported positive experiences, with key benefits including better work–life balance, improved efficiency, and greater control over work. However, challenges such as home office limitations, work uncertainties, and inadequate tools were also noted.

Acknowledging the advantages of remote work and finding strategies to fully leverage them while addressing its challenges is vital for enhancing our quality of life and work. Remote work has varied impacts on employees' performance and well-being. It influences how individuals perceive themselves and their work environments and has significant implications for their physical and mental health. These effects are particularly noticeable in areas like work-life balance and stress management (Ferrara et al, 2022). Remote work can present individuals with various personal challenges, including difficulties distinguishing between home and work life, a lack of support and feedback, feelings of isolation, and struggles to disconnect from work responsibilities. Sardeshmukh et al (2012) explored these issues through the job demands and job resources model, emphasizing how remote work can lead to exhaustion when boundaries blur and support mechanisms are limited. This lack of separation between professional and personal life often contributes to increased stress and mental fatigue[1], highlighting the importance of effective management and support for remote workers.

Prolonged work hours have been linked to negative impacts on health, well-being, and sleep quality. A study by Majumdar et al (2020) identified several factors contributing to these issues, including disruptions to daily routines, increased levels of anxiety and stress, and excessive screen time. Remote workers reported higher instances of sleep disruption, depression, and somatic pain due to longer hours spent indoors, often blurring the boundaries between work and personal life. These prolonged work hours, combined with the lack of physical activity and increased screen exposure, contributed significantly to mental and physical health deterioration.
In contrast some studies found that employees who worked from home experienced greater job satisfaction due to the flexibility it provided, allowing them to balance their professional and

[1] Fatigue is a state of physical and mental exhaustion that reduces a person's ability to function effectively. It is more than just ordinary tiredness; fatigue can be persistent and is often a symptom of underlying health issues, lifestyle factors, lack of sleep, or prolonged exertion.

personal responsibilities more effectively. This flexibility was enhanced by the ability to personalize their work environments. (Seeber & Erhardt, 2023; Graham et al, 2023).

Consequently, our homes have evolved beyond mere living spaces into multifunctional environments where remote workers now spend a significant portion of their time, sometimes without even stepping out for days. To reduce the negative effects of remote work during the COVID-19 pandemic, Birimoglu Okuyan and Begen (2022) suggested creating a home office environment similar to traditional workspaces, particularly in terms of ergonomics. Their study emphasizes the need to address both physical and mental health challenges, such as increased stress, feelings of isolation, and physical discomfort from inadequate setups. Enhancing the home office environment can significantly improve the well-being and productivity of remote employees, making these changes critical as remote work becomes more prevalent.

2.1.2. Indoor Environmental Quality and Remote Work: Adapting to New Needs

According to the World Health Organization (WHO), improving housing quality can lead to substantial health benefits (WHO, 2018). Quality of indoor environment plays a crucial role in ensuring comfort and mental well-being of remote workers, Positive indoor environmental quality scores improved mental well-being and productivity when WFH. (Khalid et al, 2022)

Indoor Environmental Quality (IEQ) refers to the overall conditions inside buildings that affect occupant health, comfort, and productivity. It includes factors like **air quality**, **thermal comfort**, **lighting**, **acoustics**, and **ergonomic design**. Good IEQ ensures a healthy, comfortable environment, enhancing well-being and reducing issues such as fatigue or discomfort. (Figure 4)

Figure 4: Indoor Environmental Quality factors

Source: https://www.bfa-eng.com/2021/11/17/iqavsieq/

Indoor environmental quality, specifically thermal comfort, indoor air quality, visual comfort, and acoustic comfort, significantly impacts human health and productivity in both residential and commercial environments. (Mujan et al, 2019; Mewomo et al, 2023)

In the late 19th century, workers in industrialized nations such as the United Kingdom and Germany averaged between 2,700 and 3,500 working hours annually, equating to approximately 50 to 70 hours per week. This demanding schedule required individuals to spend the majority of their time outside the home, engaged in labor-intensive occupations (Herre, 2024). Over time, legislative reforms and labor movements advocated for shorter working hours, gradually reducing the time spent away from home for work-related activities.

In the evolving model of remote work, the home has become the center of daily activities. More than just living spaces, homes have transformed into multi-purpose environments where employees now carry out professional tasks for extended periods. This shift has brought profound changes to daily life, raising concerns about the physical and psychological impacts of staying indoors for long periods, such as reduced exposure to natural light, fresh air, and physical activity. The lack of clear boundaries between work and personal life further heightens the risk of burnout[2] and dissatisfaction with work-life balance. Have we sufficiently addressed the impact of this new lifestyle on the well-being and productivity of employees? Are our homes truly equipped to support this new way of living and working?

A cross-sectional survey was conducted in university offices across six countries (Brazil, Italy, Poland, Switzerland, Taiwan, and the U.S.) to examine the relationship between IEQ and productivity beliefs. The results showed that satisfaction with IEQ is the strongest predictor of occupants' productivity beliefs, with control over factors like light switches being the most significant. This effect was particularly strong in private offices, where personal control over the environment further enhanced productivity perceptions. (Chen et al, 2020)

According to World Green Building Council[3] (2020), office spaces that optimize key factors like air quality, lighting, and ergonomic layout lead to improved focus, reduced stress, and enhanced overall productivity, demonstrating the importance of thoughtful building design in modern work environments.
Remote workers are expected to become the new norm in the business world by 2025, with 70% of the workforce expected to work remotely at least five days a month. (Radulovic et al, 2022) Remote work demands greater self-discipline and organizational skills, particularly given the absence of the structured routines found in traditional office environments. The blurring of boundaries between work and personal life can make it difficult to mentally disengage from work responsibilities, leading to a sense of constant attachment to professional duties. Blurred work-life boundaries reduced happiness through increased emotional exhaustion. (Pluut & Wonders, 2020)

In this new home-centered lifestyle, the importance of optimizing our environments for multiple tasks has become increasingly clear. With technology advancing at a rapid pace, we must explore how it can be used to create spaces that promote both mental and physical well-being. Are remote workers and companies equipped with the knowledge needed to design effective home office environments? Are they aware of the environmental factors within the home that, if adjusted, could positively impact health and productivity?

The rapid acceleration of remote work has exposed both individuals and companies to potential challenges. Many employees face difficulties adapting to this new working model, including the absence of proper home office setups and a lack of structure in their daily routines. Meanwhile,

[2] Burnout is a state of chronic physical, emotional, and mental exhaustion caused by prolonged stress, often work-related. It is characterized by emotional exhaustion, detachment, and reduced performance, and is more persistent than ordinary stress. Common causes include excessive workload, lack of support, and poor work-life balance. Recognized by the World Health Organization as an "occupational phenomenon."

[3] The World Green Building Council (WorldGBC) is a global network that promotes sustainable building practices, aiming for net-zero carbon emissions in buildings by 2050. Through standards and collaborations with over 70 national Green Building Councils, WorldGBC supports environmental sustainability, occupant health, and policy advancements in the built environment.

companies struggle with issues of managing remote teams effectively, ensuring employee engagement, and maintaining health and productivity without direct supervision.
Despite these challenges, there are opportunities for innovation and growth. By understanding how environmental factors influence well-being and productivity, employees and employers can take proactive steps to ease the transition to remote work. This requires careful attention to creating optimal home office environments that support focus, comfort, and long-term mental and physical health. The evolving landscape of work and lifestyle is fostering a burgeoning desire among employees to embrace WFH arrangements, prompting companies to accommodate this trend. According to Barrero, Bloom, and Davis (2021), around 20% of full workdays are projected to be worked from home post-pandemic, compared to only 5% before the crisis. The shift to WFH is driven by better-than-expected experiences, investments in home setups, reduced stigma, health concerns, and technological advancements. We must embrace this new lifestyle and recognize the importance of optimizing living spaces to sustain living and working.

To navigate these challenges, remote workers must establish clear boundaries, schedule regular breaks for physical activity, and intentionally design their home office spaces to foster productivity and well-being. This thoughtful approach is essential to maintaining a healthy work-life balance. By prioritizing indoor environmental factors and making conscious efforts to create suitable workspaces at home, we can facilitate a smoother, more sustainable transition to remote work. Both employers and employees must recognize the importance of creating conducive work environments that enhance well-being and performance. This requires a commitment to improving home office settings in response to the needs of remote work.

Among the various environmental factors that affect the comfort of remote workers (temperature, humidity, noise and …) lighting stands out as one of the most critical factors. Proper lighting not only illuminates the workspace but also significantly impacts mood, energy levels, and cognitive performance[4]. Inadequate lighting can lead to eye strain[5], headaches, fatigue, and diminished concentration (Boyce, 2021). To enhance the well-being and productivity of remote workers, it is essential to understand the body's circadian rhythm and how light influences this natural biological process. The shift to remote work presents a unique opportunity to rethink how homes can adapt to meet workers' evolving needs.

[4] Cognitive performance refers to how effectively an individual can carry out tasks that require mental processes like thinking, reasoning, problem-solving, memory, attention, and decision-making. It includes aspects such as speed, accuracy, and efficiency in processing information and is influenced by factors like physical health, mental well-being, environment, and age, impacting one's ability to learn, focus, and make decisions.
[5] Eye strain is a condition characterized by discomfort, fatigue, and irritation in the eyes, often caused by prolonged screen time, reading, or other visual tasks. Symptoms include headaches, blurred vision, and dry eyes.

2.2. Illuminating the Circadian Rhythm: Light's Influence on Health and Productivity

The relationship between light and human biology, psychology, and productivity is deeply intertwined. This chapter explores the significant role that light plays in regulating the body's internal clock, known as the circadian rhythm, and how this regulation impacts various aspects of health, mood, and cognitive performance. Understanding the complex interaction between light exposure and circadian rhythms is essential for enhancing well-being and productivity, both in personal and professional settings.

The chapter delves into the influence of natural light in synchronizing biological processes, as well as the effects of artificial lighting on mood regulation, cognitive function, and overall health. Special attention is given to the impact of light pollution in indoor environments, which can disrupt sleep-wake cycles and hormonal balance, leading to adverse health outcomes. Additionally, the chapter explores the connection between light exposure and hormone production, including its role in conditions like seasonal affective disorder (SAD), highlighting how light plays a crucial role in maintaining physical and psychological well-being.

2.2.1. Understanding the Body's Internal Clock and Its Connection to Light

Before the widespread adoption of artificial lighting in the late 19th and early 20th centuries, human activities worldwide were primarily governed by natural light cycles. People's daily lives were closely aligned with the rhythms of the sun and moon. This consistent 24-hour cycle of daylight and darkness shaped human behavior and physiology, leading to the evolution of circadian rhythms. (Smith, 2022).

Humans have evolved in harmony with the earth's natural lighting cycle. due to the Earth's rotation, a consistent 24-hour cycle of daylight and darkness occurs across much of its surface. Humans have adapted by developing biological rhythms that align with the daily light-dark cycle, repeating approximately every 24 hours. These biological rhythms are known as circadian rhythms (Moore-Ede, Sulzman, & Fuller, 1982). Circadian rhythms regulate various physiological processes, including the sleep-wake cycle, hormone release, and body temperature, allowing humans to synchronize with the environment (National Institute of General Medical Sciences, 2020). In early human history, people spent most of their time outdoors, using natural light to guide their daily activities.

In contrast, modern life has drastically reduced our exposure to natural light. Today, most individuals spend their time indoors, often in environments that lack sufficient natural light. This shift not only affects how we experience our surroundings but also has profound impacts on the body's internal clock or circadian rhythm. (Figure 5)

Figure 5: Features of the human circadian biological clock

Source: https://www.news-medical.net/health/Circadian-Rhythm.aspx

Scientific understanding of circadian rhythms began to emerge in the mid-20th century with significant research contributions from the United States, Germany, and France. In the late 1930s, Nathaniel Kleitman and his student Bruce Richardson conducted pioneering research on human circadian rhythms, which significantly contributed to the understanding of internal biological clocks. In their famous **1938 Mammoth Cave experiment**, conducted in **Mammoth Cave, Kentucky, United States**, Kleitman and Richardson spent over 30 days in an isolated cave with no external cues of light or time. (Figure 6) The experiment aimed to determine how human physiological and psychological functions adapt in the absence of environmental time cues. Their findings showed that body temperature and sleep cycles continued to follow a roughly 24-hour

rhythm, demonstrating the presence of an internal biological clock independent of external stimuli (Kleitman & Richardson, 1938). This study laid the groundwork for future research into circadian rhythms, which were later formally named in the 1950s by Franz Halberg (Halberg, 1959).

Figure 6: Nathaniel Kleitman and Bruce Richardon, Mammoth Cave

https://storymaps.arcgis.com/stories/643b988969884874ac7a309f9b5c1890

Understanding the circadian rhythm and its intricate connection to light is essential for grasping how light exposure influences human physiology and behavior. Any disturbance or interference with the body's internal clock leads to circadian disruption. Disrupted circadian rhythms, such as jet lag[6], night-shift work, and artificial light exposure, can negatively impact mood and affective symptoms[7]. (Walker et al, 2020)

Circadian disruption has emerged as a growing concern in modern society due to irregular sleep patterns, shift work, and increased exposure to artificial light at night (ALAN). These disruptions interfere with the body's natural circadian rhythms, which are crucial for regulating sleep-wake cycles, metabolism, and hormone production. Prolonged circadian misalignment can lead to a wide range of health problems, including sleep disorders, fatigue, impaired cognitive function, and mood disturbances. (Lunn et al, 2017; Haus & Smolensky, 2013).

In addition to these psychological effects, circadian disruption has been linked to more serious long-term health risks such as obesity, diabetes, heart disease, and even breast cancer. The disturbance of natural light-dark cycles affects key biological processes like metabolism and cardiovascular function, making the body more susceptible to metabolic disorders and compromised immune function. (Touitou, Reinberg, & Touitou, 2017; Zeman et al, 2023) Research by Shi et al (2013) demonstrates that circadian misalignment can result in insulin resistance, contributing to the development of metabolic diseases like obesity and diabetes, due to disrupted glucose regulation and insulin signaling. Furthermore, Chellappa (2021) highlights that

[6] Jet lag is a temporary sleep disorder that occurs when a person's internal body clock is disrupted by rapid travel across multiple time zones, leading to symptoms like fatigue, insomnia, irritability, and difficulty concentrating.
[7] Affective symptoms are mood-related symptoms, like sadness or irritability, often seen in mood disorders such as depression and bipolar disorder.

individual differences in light sensitivity can exacerbate these effects, further disrupting sleep and circadian rhythms.

In modern life, we are exposed to artificial light for long hours due to our work and lifestyle choices. Now more than ever, it's crucial to understand the impact that both natural and artificial light have on our health. Are our homes providing the right balance of natural and artificial light to support our well-being and productivity?

Artificial lighting in homes plays a crucial role in enhancing well-being and productivity, particularly for remote workers. Remote workers not only spend extended periods indoors under artificial light but are also frequently exposed to light emitted from laptop and mobile screens. This prolonged exposure significantly impacts their health and sleep-wake cycles, especially when working in inadequately lit environments. Research by Figueiro (2018), the director of the light and health research center, highlights that exposure to ALAN particularly blue light, suppresses melatonin production, which is vital for regulating sleep-wake cycles. This suppression of melatonin can result in increased risks of cancer and other serious health conditions due to the misalignment of the body's circadian rhythm.

The following sections characterize how light influences the human body, highlighting the importance of minimizing light pollution in home environments. Understanding the effects of light on health and circadian rhythms is essential for creating home-office environments that support both well-being and productivity. As remote work becomes more common, homes increasingly serve as multifunctional spaces, making effective lighting control essential to provide appropriate illumination for different tasks within the same environment.

2.2.2. Exploring the Effects of Light on Sleep-Wake Cycles, Mood Regulation, and Cognitive Performance

In the field of vision science, the discovery of intrinsically photosensitive retinal ganglion cells (ipRGCs) in 2002 by Berson and colleagues has significantly advanced our understanding of light's role beyond visual perception. Unlike traditional photoreceptors such as rods and cones, which are responsible for image-forming vision, ipRGCs are primarily involved in regulating non-image-forming visual functions, particularly the synchronization of the body's internal clock with the external light-dark cycle. These cells contain the photopigment melanopsin, enabling them to detect overall light intensity and transmit this information directly to the suprachiasmatic nucleus (SCN), the master circadian clock in the hypothalamus. (Figure 7) This communication plays a crucial role in aligning our circadian rhythms, which influence sleep-wake cycles, hormone secretion, and other physiological processes such as body temperature regulation (Berson et al, 2002; Do & Yau, 2010; Figueiro, 2013).

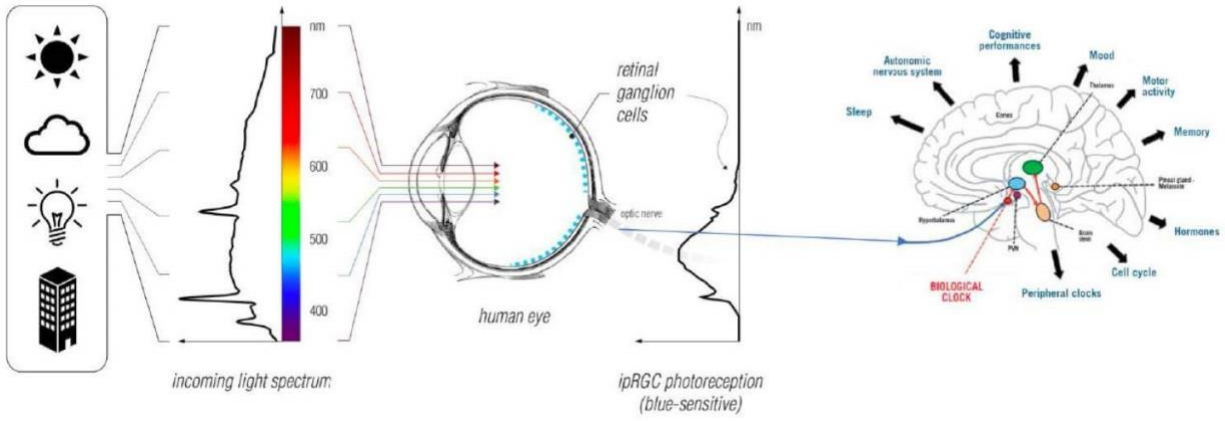

Figure 7: Diagram of the suprachiasmatic nucleus (SCN) and its role in regulating circadian rhythms

Source: https://lystechnologies.io/science/

In a study, Boubekri et al (2014) examined the effects of daylight exposure on 49 office workers and found that those working in environments with ample natural light reported significantly better sleep quality, longer sleep duration, and increased physical activity compared to those in windowless spaces. These findings highlight the crucial role of natural light in promoting overall health and well-being. Similarly, a survey by Jarboe and Figueiro (2021) involving 593 middle-aged adults revealed that increased daily outdoor time and brighter indoor environments were associated with reduced anxiety, depression, and fewer sleep disturbances. Begemann et al (1997) highlights that in contemporary office environments, exposure to natural light is greatly reduced, leading to various visual and biological responses. This reduction in natural light can disrupt circadian rhythms and impact overall well-being, particularly in environments dominated by artificial light.

Light serves as a critical trigger for activating the hypothalamus, which in turn regulates the body's biological clock and influences the secretion of essential hormones, including dopamine, serotonin, melatonin, and cortisol. These hormones play key roles in maintaining daily bodily functions, such as movement, sleep, and overall well-being. The synchronization of these hormones through exposure to light and darkness highlights the importance of natural circadian rhythms in promoting health. **Serotonin**, which regulates mood, appetite, and sleep, is produced in response to daylight exposure, playing an essential role in stabilizing emotional well-being. Similarly, **dopamine**, which affects cognition, motivation, and mood, increases with bright light exposure, leading to improved cognitive performance and mood (Blume, Garbazza, & Spitschan, 2019). The hormone **melatonin**, which controls the sleep-wake cycle, is suppressed by blue light exposure, leading to difficulties in falling asleep, particularly when exposed to artificial light in the evening (Chepesiuk, 2009). Additionally, **cortisol**, a hormone critical for metabolism and the stress response, is increased by morning light exposure, preparing the body for activity throughout the day (Czeisler et al, 1981).

Human evolution has adapted us to thrive in outdoor light conditions, where natural light levels are far higher than those typically experienced indoors. According to Luc Schlangen, a senior scientist and expert in lighting and circadian rhythms at Philips Lighting, a sunny day outdoors

can provide up to 100,000 lux, while even on a dull, cloudy day, light levels reach around 2,000 lux. In contrast, indoor light levels are often a fraction of this, generally providing a quarter of these levels or less. This stark difference between outdoor and indoor lighting can significantly affect circadian rhythms and overall well-being (Schlangen, 2014). (Figure 8)

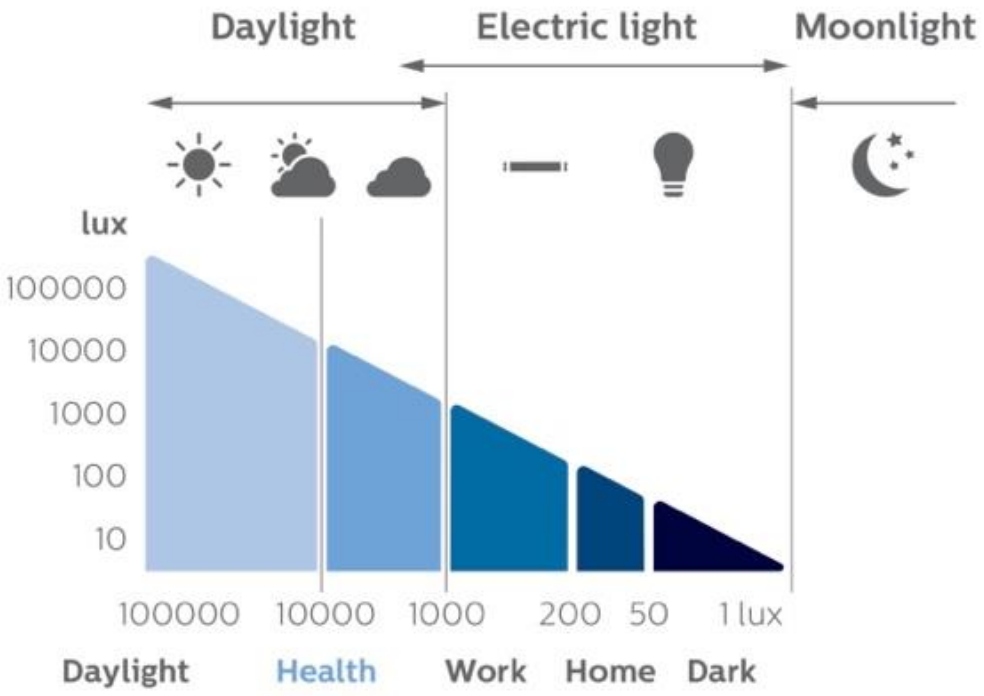

Figure 8: We have evolved outdoors where there is a huge amount of light, there is much less indoors

Source: Reproduced from "The effect of light on our sleep/wake cycle" by Luc Schlangen, Philips, 2014

Lighting in the built environment must be designed to support both circadian rhythms and visual performance. During the day, high levels of circadian light stimulation, such as daylight or well-designed artificial light, are crucial for maintaining alertness and overall well-being. At night, it is essential to minimize circadian light stimulation to promote healthy sleep while still providing low-level lighting for safe movement. This approach helps balance the biological need for circadian regulation and the practical need for effective visual lighting (Figueiro, 2008; Hanford & Figueiro, 2013).

Vandewalle et al (2006) demonstrated that light exposure enhances both alertness and cognitive performance during both nighttime and daytime. Their research also showed that light influences regional brain functions, particularly in areas associated with attention and cognitive processing. This supports the idea that light is not only crucial for visual functions but also plays a fundamental role in regulating non-visual cognitive processes.

2.2.2.1. The Effect of Light Pollution on Health and the Sleep/wake Cycle in Indoor Environments

Indoor light pollution refers to the excessive or inappropriate use of artificial lighting within enclosed environments, leading to unintended or unnecessary illumination. This is often caused by overly bright lighting, poorly directed or unshielded fixtures, and the use of light sources that emit high levels of blue light which interferes with sleep patterns, and can cause eye strain and discomfort. Moreover, it contributes to energy waste, as well as long-term health issues such as increased risks of sleep disorders and metabolic disruption (Chepesiuk, 2009; Blume, Garbazza, & Spitschan, 2019). Sleep deprivation has been shown to contribute to the onset of mental health disorders, such as anxiety, depression, and even suicidal ideation. Research indicates that poor or insufficient sleep disrupts emotional regulation and increases vulnerability to stress, which can exacerbate these conditions (Columbia University Psychiatry, 2022).

Exposure to ALAN has been linked to a higher risk of various health issues, including cancer, metabolic disorders, and mood disorders. ALAN is linked to a higher risk of breast cancer due to its disruption of circadian rhythms and melatonin suppression (Walker et al, 2020; Prajapati et al, 2023). Higher exposure to light at night (LAN) is significantly associated with increased odds of overweight and obesity. (Lai et al, 2020)
Poor sleep quality is associated with increased affective symptoms, negative cognitive bias, and decreased sustained attention[8] to non-emotional stimuli, regardless of stress, chronotype[9], or time of day. (Gobin et al, 2015)

Given the autonomy over their working hours, many may find themselves using screens extensively in the evenings and just before bed, potentially disrupting their sleep-wake cycles. Blue light emitted by LED screens from devices like smartphones, tablets, and computers can significantly impacts sleep by suppressing melatonin. This disruption leads to delayed sleep onset and reduced sleep quality, especially when individuals are exposed to blue light in the evening (Silvani et al, 2022; Touitou & Dufier, 2022).

2.2.2.1.1. Production of Melatonin

Critical to our sleep/wake cycle is melatonin, a hormone that promotes sleep. Melatonin, a hormone produced by the pineal gland in the brain, is released in response to decreasing light levels, whether natural or artificial. Melatonin's synthesis and secretion is controlled by light and dark conditions, with light decreasing its production and darkness increasing its production.
It is a widely held view that melatonin is responsible for increasing tiredness and regulating sleep cycles. Czeisler et al (1995) demonstrated that a brief exposure to light at night can significantly suppress melatonin levels. In the study, subjects experienced a sharp drop in melatonin following a light pulse, but melatonin levels rebounded within 30 to 90 minutes once they returned to

[8] Sustained attention is the ability to maintain focus on a task or activity over an extended period without becoming distracted.
[9] A chronotype refers to a person's inherent tendency for optimal sleep and activity times, typically identified as morning, evening, or intermediate patterns, shaped by internal biological rhythms.

darkness, allowing them to resume sleep. This highlights the sensitivity of melatonin production to light exposure.

Melatonin regulates the sleep-wake cycle, body temperature, and circadian rhythm disorders, and its treatment may be effective in treating jet lag and delayed sleep phase syndrome. (Brown, 1994) Melatonin plays a crucial role in regulating various body functions, including timekeeping, antioxidant properties, and immune-enhancing effects, and has potential therapeutic applications for various sleep disorders. (Pandi-Perumal et al, 2006)

Exposure to light, particularly natural light during the day, signals to the suprachiasmatic nucleus (SCN) that it is daytime. This triggers the suppression of melatonin production, promoting wakefulness and alertness. In contrast, the absence of light in the evening and nighttime signals to the SCN that it is time for rest, leading to an increase in melatonin production, which facilitates the onset of sleep. Maintaining a regular sleep-wake cycle is crucial for optimal performance and overall health, as it ensures the proper functioning of our circadian rhythms and promotes physical and mental well-being. Research by Green et al (2017) shows that evening exposure to light from computer screens significantly disrupts sleep by increasing sleep latency, which is the time it takes to fall asleep. This disruption is primarily due to the suppression of melatonin. Prolonged screen exposure before bedtime not only affects the timing of sleep but also impacts overall sleep quality and biological rhythms, which in turn can impair attention abilities the following day.
Evening use of light-emitting tablet computers can delay bedtimes, suppress melatonin secretion, and impair next-morning alertness, potentially impacting health and safety (Chinoy, Duffy, & Czeisler, 2018). The heavy reliance of remote workers on computers and electronic devices, especially during evening hours, can significantly disrupt their sleep patterns. Both total and partial sleep deprivation negatively impact cognitive performance, impairing attention, working memory, and decision-making, with recovery processes being more demanding in partial sleep restriction. (Alhola & Polo-Kantola, 2007)

A study by Santhi et al (2011) investigated the effects of different evening light exposures on sleep. The results showed that blue-enriched light, particularly bright blue-enriched light, had the most disruptive impact on sleep, delaying the onset of sleep and reducing melatonin levels. In contrast, yellow light and normal room lighting were less disruptive, while darkness had the least impact on sleep. This emphasizes the importance of minimizing blue light exposure in the evening for maintaining healthy sleep patterns.

2.2.2.1.2. Production of Cortisol

As we wake up, our cortisol levels, a stress hormone, rise naturally. Cortisol levels increase in the morning and prepare the body for activity. It's often referred to as the body's built-in alarm system, as it helps us become more alert and responsive to our environment. (Chrousos, 2009).

Philips collaborated with the University of Basel to study the effects of their wake-up light, which simulates a sunrise by gradually increasing light levels before the alarm goes off. (Figure 9) The study demonstrated that this dawn simulation light increases cortisol levels immediately after waking compared to waking in darkness. Additionally, the light exposure was shown to improve subjective well-being, mood, and cognitive performance throughout the day (Gabel et al, 2015)

Figure 9: Philips wake-up light

Source: https://www.philips.co.uk/c-p/HF3531_01/smartsleep-wake-up-light

Early morning light exposure significantly increases morning cortisol levels, while evening cortisol levels remain unaffected by light. (Scheer & Bujis, 1999)
Bright light exposure increased cortisol levels the most compared to dim white, red, or blue light. (Petrowski et al, 2020) Exposure to bright light in the morning, ideally within the first one to two hours after waking, helps synchronize the body's internal clock and enhances wakefulness. This practice promotes better alertness and well-being throughout the day, emphasizing the importance of proper light management for healthy sleep and cognitive functioning (Schlangen, 2014).

2.2.2.2. Light's Influence on Mood, Alertness and Productivity

Moods and emotions, while both affective states, differ in their intensity and specificity. Emotions are typically more intense and are often triggered by specific events or stimuli, whereas moods are more generalized, less intense, and not necessarily tied to any identifiable cause. Moods also tend to last longer than emotions and can influence a broader range of feelings and mental states (Robbins & Judge, 2015). (Figure 10) Moods, observed across different species, play an adaptive role by integrating environmental and physiological factors to optimize behavioral decisions, which has relevance for understanding mood disorders in humans. (Nettle & Bateson, 2012)
Moods influence our overall mental state and can subtly affect behavior, thoughts, and perceptions over time. They are generally classified as positive or negative, commonly referred to as being in a "good" or "bad" mood, and can shape one's psychological and emotional well-being over extended periods.

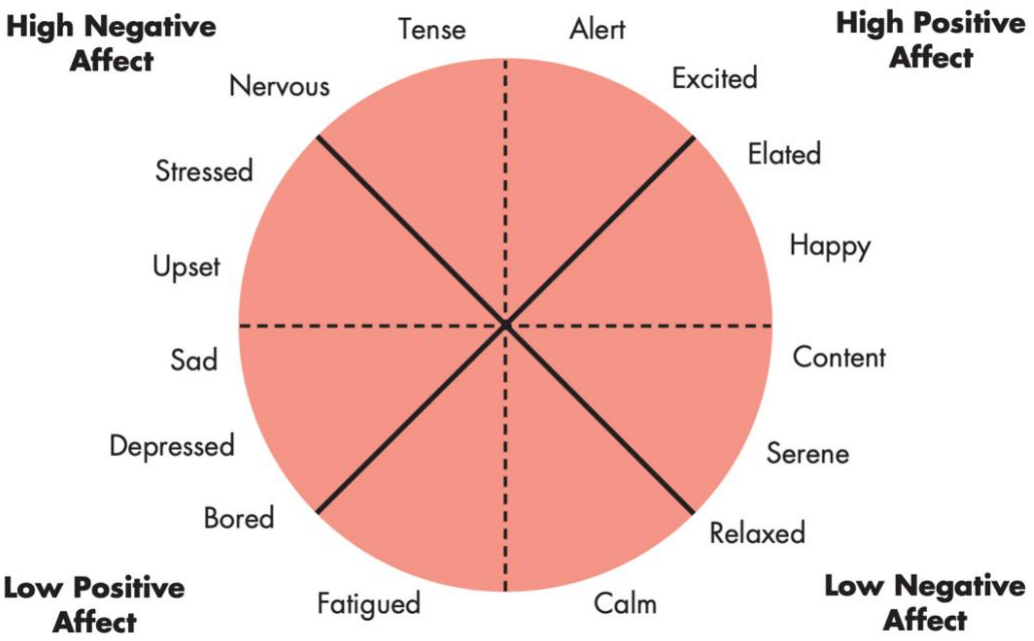

Figure 10: Structure of mood

Source: Reproduced from "Organizational Behavior," by S.P. Robbins & T.A. Judge, 2015

Research by Aan het Rot and colleagues found that exposure to bright light is linked to improved mood and more positive social interactions. Their study, conducted on mildly seasonal individuals, revealed that participants exposed to higher levels of bright light reported better moods and more agreeable behaviors, with fewer quarrelsome interactions, demonstrating a clear connection between bright light exposure and enhanced mood over short periods (Aan het Rot, Moskowitz, & Young, 2008).

Figueiro and colleagues investigated the impact of circadian-effective light exposure on office workers' sleep patterns and mood. Their research found that individuals exposed to high levels of morning light fell asleep more quickly, particularly during the winter months, and experienced better overall sleep quality. Moreover, those who had sustained exposure to circadian-effective light throughout the workday reported lower levels of depression and improved mood. The study suggests that consistent exposure to bright light during the day may also increase alertness and vitality in office workers (Figueiro et al, 2017). Bright light exposure reduces sleepiness and boosts mood, while low "cool" lighting causes the least positive mood and slows responses in cognitive tasks. (Zhu et al, 2019) High illuminance levels increase arousal[10] and alertness, but too high a

[10] Arousal is a state of alertness and readiness involving physiological and psychological activation, which influences responsiveness, focus, and emotional reactions.

level can reduce valence[11] and alertness, providing guidance for human-centered lighting control. (Cai et al, 2021)

Conditioning mood in the workplace does not mean to change the existing mood but to maintain a mood that is positive. The presence of plants in a room, or the arrangement of shelves and magazines, can improve the mood of the occupants of that room. (Shibata & Suzuki, 2004) Lighting and color in the workplace influence mood, with optimal lighting conditions improving mood and overly dark or overly bright conditions leading to mood declines. (Küller et al, 2006; Lan et al, 2020) Disrupted circadian rhythmicity is associated with increased risk of mood disorders, poorer mental health, and reduced happiness, wellbeing, and cognitive function. (Lyall et al, 2018)

Moods in the workplace are associated with influencing productivity. Positive mood leads to productivity as it activates motivation and increases concentration. Environmental pressure can disturb the mood of workers and indirectly cause a decrease in work performance as negative mood can be influenced by inappropriate lighting or noise.
A longitudinal study on 114 office workers over 8 months found that inadequate IEQ, such as poor lighting and noise, significantly reduced self-reported work performance and objectively measured cognitive performance by between 2.4% and 5.8% in most situations, and up to 14.8% in rare cases. These environmental stressors lowered motivation, increased fatigue, and negatively impacted cognitive function, leading to decreased productivity. Improving IEQ was shown to yield small but consistent productivity gains. (Lamb & Kwok, 2016)

A study conducted by Viola and colleagues, in collaboration with Philips and the University of Surrey, examined the effects of Philips ActiViva lights in office environments. The study found that exposure to blue-enriched white light improved workers' alertness, performance, and reduced evening fatigue. Additionally, participants experienced better sleep quality, emphasizing the role of proper daytime light exposure in enhancing well-being and productivity (Viola et al, 2008). Blue-enriched white light in the morning improves students' cognitive processing speed and concentration. (Keis et al, 2014)

Climate and weather can also affect a person's mood. The impact of these two factors varies in each individual, with their response depending on the duration of daily light exposure received by that person.

Seasonal Affective Disorder (SAD) is a type of depression that occurs at specific times of the year, typically in the fall and winter when daylight hours are shorter. This condition is linked to reduced exposure to natural sunlight, which can negatively impact mood and overall well-being. SAD may cause sleep disturbances, decreased alertness, and a general sense of low mood. This highlights the importance of light exposure in regulating mood and sleep patterns, particularly in individuals affected by SAD.

Symptoms of SAD include feelings of sadness, hopelessness, fatigue, changes in appetite or weight, difficulty concentrating, and social withdrawal, similar to major depression. SAD can

[11] Valence refers to the emotional value of a stimulus, indicating whether it is perceived as positive, negative, or neutral.

significantly impact daily functioning and overall quality of life. (Magnússon & Boivin, 2003; Jacobsen et al, 1987) Light therapy shows promise in preventing SAD and improving patient-centered outcomes (Nussbaumer et al, 2015) SAD can be effectively treated with bright artificial light, and lighting standards in homes and workplaces should be re-evaluated to improve lighting conditions for seasonal changes. (Jacobsen et al, 1987)

The profound influence of light highlights the critical need for appropriate lighting solutions in indoor environments. In today's rapidly evolving world, the focus on human-centric lighting design has become more essential than ever. As we adapt to new ways of living and working, it is important to recognize the significant impact light has on every aspect of our daily lives.

For remote workers who now spend extended hours in indoor spaces that are often not optimized for modern needs, there is an increasing demand for these environments to evolve accordingly. When our homes become our primary living and working spaces, they should emulate natural environments, fostering a harmonious relationship between lighting and our physiological needs. To achieve this, raising awareness and understanding of human-centric lighting is crucial. Consumers need to make informed decisions by selecting lighting solutions that promote well-being and efficiency in home-office environments. While these products may come at a premium, the long-term benefits of healthier and more conducive indoor spaces make the investment worthwhile.

2.3. Human-centric Lighting: Putting People First in Lighting Design

The growing recognition of lighting's impact on human health and well-being has elevated the importance of human-centered design in lighting systems. Understanding the principles of human-centric lighting is essential to creating environments that support physical, mental, and emotional health. This chapter outlines the foundational principles of human-centric lighting by discussing key characteristics of light, including color, intensity, and spectral composition, and their effects on human health, productivity and mood. It emphasizes the significance of tailoring lighting to individual preferences and needs, enhancing personal comfort and satisfaction. Additionally, the chapter highlights the transformative potential of LED technology in human-centric design, due to its adaptability, energy efficiency, and environmental benefits. Through this exploration, the chapter underscores how modern lighting can be both functional and supportive of human well-being.

2.3.1. Lighting for Healthier Living: Understanding Human-Centered lighting Principles

Human-Centric Lighting (HCL) is a lighting approach designed to support human health, wellbeing, and performance. HCL considers both visual comfort and non-visual effects, such as circadian rhythms and mood regulation. (Houser & Esposito, 2021) This concept has gained attention for its potential to improve quality of life by mimicking natural light patterns and addressing circadian rhythms. This approach integrates scientific understanding of light's impact on human physiology and psychology into practical lighting solutions. HCL systems adjust light intensity, color temperature, and spectral composition throughout the day to mimic the natural changes in daylight. This synchronization with the body's circadian rhythms has been shown to improve mood, cognitive function, productivity, and sleep quality. (Figure 11)

Figure 11: Human Centric Lighting

Source: *https://www.humancentriclighting.org/human-centric-lighting/*

The concept of HCL can be described as a means of improving emotional well-being, health, sleep quality and productivity through the proper control of existing lighting in various environments including our home-offices. Lighting concepts based on human physiology are particularly relevant for people who often spend long periods of time in their homes like remote workers with little or no daylight.

The study by Hübner et al (2016) supported the hypothesis that lighting characteristics, such as color temperature, can influence thermal perception and overall comfort. This underscores the importance of understanding lighting characteristics for designing systems that cater to the specific needs of different environments and tasks. Mordeglia (2021) developed the Home-Office Lighting Kit, designed to improve lighting conditions in student apartments by enhancing visual ergonomics and supporting circadian rhythms. The kit allows users to adjust lighting based on personal preferences and task requirements, resulting in improved focus and comfort (Mordeglia, 2021).

2.3.2. Characteristics of Light

Understanding the characteristics of light is fundamental in exploring how it interacts with both objects and spaces, shaping visual perception and directly influencing biological processes. In HCL applications, optimizing these characteristics can profoundly impact productivity, well-being, and overall health. By thoughtfully adjusting light intensity, color temperature, direction, and distribution, HCL systems create environments tailored to human needs, promoting focus and supporting natural circadian rhythms. Here are the key characteristics of light that form the foundation for effective HCL design:

2.3.2.1. Color Temperature

Correlated Color Temperature (CCT) is a crucial measure in lighting design, defined in Kelvins (K), that describes the visual warmth or coolness of light emitted by a source. Higher CCT values, above 5000K, are associated with cooler, bluish light, while lower values, below 3000K, produce warmer, yellowish tones. This scale, ranging from roughly 1000K to 10,000K, plays a significant role in determining how lighting affects the atmosphere and functionality of a space. (Figure 12)
The hue-heat hypothesis suggests that environments with warm colors (such as red, orange, and yellow) are perceived as warmer in terms of temperature and comfort, while those featuring cooler colors (such as blue and green) are perceived as cooler. This phenomenon highlights the important role of color selection in designing spaces that achieve specific thermal comfort[12] objectives (Tsushima et al, 2020; Ziat et al, 2016).

Figure 12: Color temperature of light

Source: https://www.inlineelectric.com/color_temperature

[12] Thermal comfort is the perceived satisfaction with surrounding temperature, influenced by factors like air temperature, humidity, and air movement.

In a study by Winzen, Albers, and Marggraf-Micheel (2014), the influence of colored lighting on passenger thermal comfort in aircraft cabins was explored. The researchers conducted an experiment in a simulated aircraft cabin environment, exposing participants to various lighting conditions. They aimed to assess how different colors of light affected passengers' perceptions of temperature and overall comfort. The results demonstrated that cooler-colored lighting, such as blue or green, made passengers feel cooler, while warmer-colored lighting, like red or orange, led to a warmer thermal perception, despite the physical temperature remaining constant. This study supports the hue-heat hypothesis, showing that the color of ambient light can significantly influence thermal comfort in enclosed spaces like aircraft cabins.
Light influences Thermos physiological responses and perception of thermal comfort, with red light tones leading to warmer perceptions than blue light tones. (Kulve et al, 2016) The choice of color temperature is vital for setting the desired mood and ensuring alignment with human circadian rhythms, which are sensitive to different light temperatures throughout the day. During the day, cooler and bluer light with higher color temperatures suppresses melatonin production, fostering alertness and regulating the sleep-wake cycle. In contrast, warmer and redder light with lower color temperatures in the evening signals relaxation, priming the body for sleep.
Lighting can partially compensate for thermal discomfort by resulting in higher perceived visual comfort, potentially improving indoor environmental workplace satisfaction. (Kulve, Schlangen, & Lichtenbelt, 2018) Personalized lighting environments in office buildings can improve productivity, attention, and reduce stress, while reducing fatigue and enhancing neuro-behavioral functions[13]. (Sun, Lian, & Lan, 2019) Low color temperature light effectively lowers central nervous system activity, making it suitable for environments like bedrooms to facilitate lowered physiological activity. (Noguchi & Sakaguchi, 1999)

In the context of home office design, understanding CCT is invaluable for selecting lighting that supports both productivity and comfort. By carefully choosing lighting based on CCT, we can create environments that not only meet the practical need for adequate illumination but also enhance the visual comfort and mood of the workspace. This customization helps to craft a work environment that feels inviting while promoting focus and efficiency, which is essential for remote working environments.

2.3.2.2. Intensity

Light intensity refers to the amount of light emitted or received per unit area, measured in lumens (total light output) or lux (light on a surface). In HCL, intensity is key to controlling brightness, which affects visibility, comfort, mood, and circadian rhythms. Properly adjusting light intensity helps enhance visual conditions and supports biological processes, making it essential for both productivity and well-being in indoor environments. Bright light exposure reduced sleepiness and increased vitality and happiness. (Smolders & Kort, 2014) Intense early morning illumination improves mood and alertness but negatively affects sustained attention, highlighting the need for adequate lighting for both non-visual and visual demands. (Leichtfried et al, 2015) Daytime electric light exposure can increase alertness and improve simple task performance, but its effects

[13] Neuro-behavioral functions are brain-based processes that influence behavior, cognition, and emotions, including memory, attention, emotional regulation, and motor coordination.

on complex task performance depend on factors like sleep drive[14] and exposure time. (Siraji et al, 2022)
Küller and Wetterberg (1993) explored how lighting intensity affects physiological responses, including electroencephalography (EEG) measurements, which track brain activity linked to alertness and sleepiness. Their findings indicated that higher lighting intensity can enhance alertness, while lower intensity may promote relaxation. This research highlights the significance of appropriate lighting intensity for fostering productivity and well-being in office environments. According to Azmoon et al (2013) Thermal comfort and light intensity positively impact sleep quality and eye fatigue in shift nurses. Appropriate light intensity can prevent eye strain, enhance comfort, and improve task performance.

According to Souman et al (2017), increasing the intensity of polychromatic white light generally results in higher subjective alertness[15], with brighter environments often enhancing alertness and cognitive performance. In contrast, dimmer[16] lighting tends to be more conducive to relaxation and sleep. This suggests that carefully adjusting light can help tailor lighting environments to suit various needs, from promoting focus and productivity to supporting rest and relaxation.
Darkness and dim illumination improve creative performance by promoting a sense of freedom from constraints and enabling an explorative processing style. (Steidle & Werth, 2013)

In a study investigating the effects of lighting on emotional responses and adjustment behaviors, 27 participants were exposed to 17 different lighting conditions, combining seven illuminance levels (45–780 lux) and seven correlated color temperatures (1500–7500 K), within a virtual reality (VR) office environment. Using VR controllers, participants adjusted the lighting to their preference, and their emotional responses were measured using the Self-Assessment Manikin (SAM) scale, which assessed emotional valence (happiness) and arousal (alertness). The study found that initial lighting conditions strongly influenced participants' final adjustments (anchor effects[17]), with significant gender differences in lighting preferences. The study highlights important gender differences in responses to lighting. Women generally preferred lower levels of both illuminance and CCT compared to men. Women also exhibited stronger emotional reactions to changes in brightness, underscoring the need to consider gender when designing lighting systems for emotional well-being and comfort (Mostafavi et al, 2024).

2.3.2.3. Spectral Composition

In the context of light, nanometers (nm) are used to measure the wavelength of light within the electromagnetic spectrum. Visible light spans wavelengths from approximately 400 nm, corresponding to violet light, to 700 nm, which corresponds to red light. This range defines the portion of the spectrum that is detectable by the human eye. (Figure 13) Understanding these

[14] Sleep drive is the body’s natural biological pressure to sleep, which builds up the longer one is awake and helps regulate the sleep-wake cycle.
[15] Subjective alertness refers to an individual's self-assessed level of wakefulness and focus, influenced by factors like sleep quality, circadian rhythms, and external stimuli.
[16] A dimmer is a device used to adjust the brightness of a light, allowing for changes in lighting intensity to create different atmospheres or save energy.
[17] The anchor effect is a cognitive bias where an individual relies heavily on the first piece of information encountered (the "anchor") when making decisions or judgments, even if it may not be relevant.

wavelengths is essential when designing lighting systems, as different wavelengths can influence color perception, mood, and physiological responses in various environments.

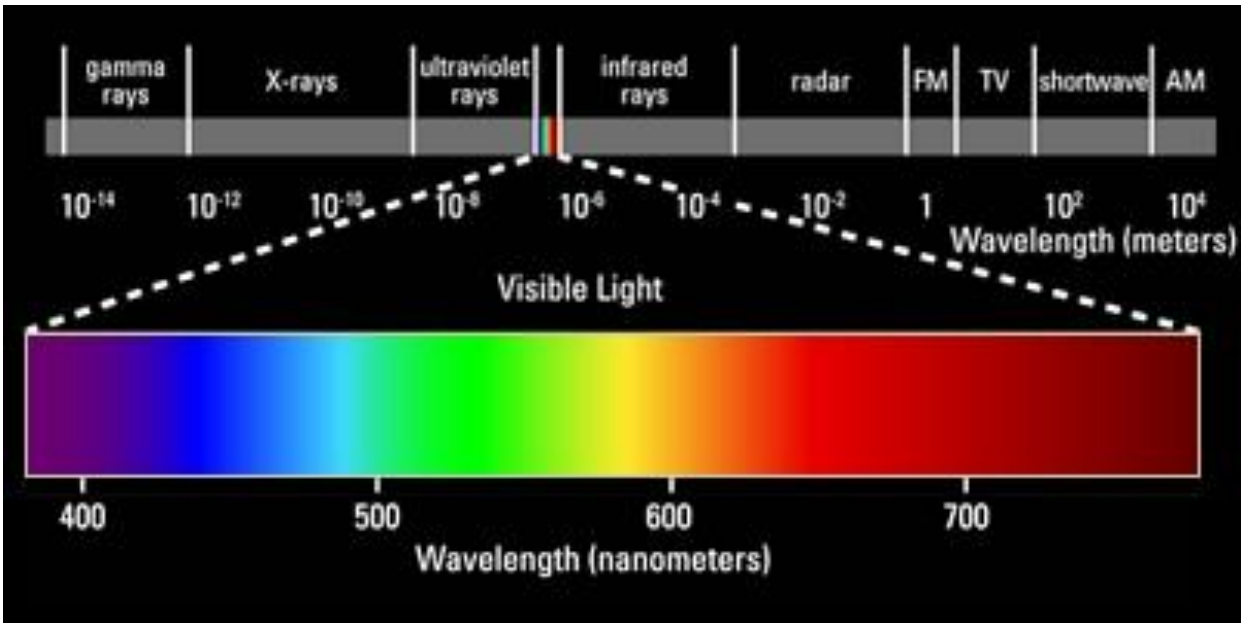

Figure 13: Visible light to human eye

Source: http://www.illinoislighting.org/lightcolor.html

The spectral composition of light refers to the specific wavelengths emitted by a light source, which affect color rendering[18] and visual perception. Sunlight, as a natural light source, has a broad and evenly distributed spectrum across the visible range, allowing for accurate color representation and improved visual comfort. In contrast, artificial light sources, such as LEDs and fluorescent lights, often have uneven or more limited spectral compositions, which can result in less accurate color perception. Understanding the differences between natural and artificial light spectra is essential for designing lighting systems that mimic natural light and optimize both visual and physiological comfort. Research by Jägerbrand and Bouroussis (2021) demonstrates that blue wavelengths significantly impact the circadian rhythms of humans, insects, and other vertebrates. Many organisms are particularly sensitive to shorter wavelengths like blue light, which has a more pronounced effect on circadian synchronization compared to longer wavelengths. This heightened sensitivity makes organisms more susceptible to the negative effects of artificial light pollution, especially blue light, which can disrupt biological processes and ecosystems. The findings underscore the importance of managing blue light exposure to mitigate its ecological and health-related impacts.

Short-wavelength light (blue light) has a greater impact on melatonin suppression, alertness, and core body temperature compared to longer wavelengths (green or red light). (Cajochen et al, 2005) Research by Wahl et al (2019) emphasizes that in modern society, where individuals are increasingly exposed to blue light from electronic devices, there is a pressing need to address the

[18] Color rendering refers to the ability of a light source to accurately reproduce the colors of objects as they appear under natural light.

effects of this exposure on well-being, cognitive function, and sleep. Proper light management is essential for mitigating these impacts.

A study by Lee, Moon, and Kim (2014) investigated the effects of illuminance levels and color temperature on visual comfort and mood in office environments. The research found that higher color temperatures (6,500 K) at lower illuminance levels (500 lx) provided better visual comfort, while lower color temperatures (3,000 K) at higher illuminance levels (750 lx) caused more visual discomfort due to glare[19]. The study concluded that a balance of 4,000 K at 500 lx or higher illuminance is optimal for improving both visual comfort and mood in office settings. Flicker[20] and glare from artificial lighting can cause eye strain, headaches, and discomfort. In sensitive individuals, flicker may even trigger seizures. Glare further contributes to visual discomfort and reduces productivity (Ticleanu, 2021).

Effectively understanding and managing the characteristics of light is essential for regulating healthy circadian rhythms and promoting overall well-being. Human-centric lighting, which aligns artificial light with natural biological processes, plays a pivotal role in enhancing health, productivity, and comfort in modern environments. Proper lighting design can optimize mood, cognitive function, and physical health, making it a key factor in improving the quality of life. Exploring affordable and innovative lighting solutions allows us to break away from traditional approaches and embrace new possibilities. Rapid advancements in LED technology, smart sensors, and adaptive lighting systems offer transformative opportunities to create environments that prioritize both energy efficiency and user comfort. These innovations provide a pathway to more personalized and responsive lighting that supports human health, productivity, and sustainable living.

2.3.3. Advancements in LED Technology: Enhancing User Experience and Efficiency

Innovative luminaires for office rooms can achieve energy efficiency, improved color effects, and circadian lighting by combining variable color temperatures, high color rendering indices, and circadian lighting. (Müller, 2017) Energy-efficient light-emitting diode (LED) technology, in particular, allows for dynamic adjustments in light intensity and color temperature, making it possible to customize lighting for specific tasks and individual preferences. LEDs are available in a broad spectrum of color temperatures and can be easily dimmed or controlled. (Figure 14) This adaptability underscores the flexibility of modern lighting systems, which not only improve energy efficiency but also enhance indoor environments by supporting human-centric design. These systems can align with our natural circadian rhythms, improve productivity, and boost overall well-being by delivering tailored lighting conditions for different times of the day and activities.

LEDs are renowned for their high efficiency in converting electrical energy into light, making them a preferred choice across a wide range of applications, including lighting systems, electronic displays, and indicator lights. LED systems with dimmable and tunable features can improve residential lighting energy performance by up to 38%, while maintaining circadian rhythms and

[19] Glare is excessive brightness that causes visual discomfort or impairs the ability to see, often resulting from direct or reflected light.
[20] Flicker is the rapid, repeated change in brightness of a light source, which can cause visual discomfort, distraction, or even eye strain.

reducing glare. (Kaymaz & Manav, 2022) Recent advancements in LED technology have significantly improved their energy efficiency, durability, and versatility, positioning them as a leading solution in modern lighting.

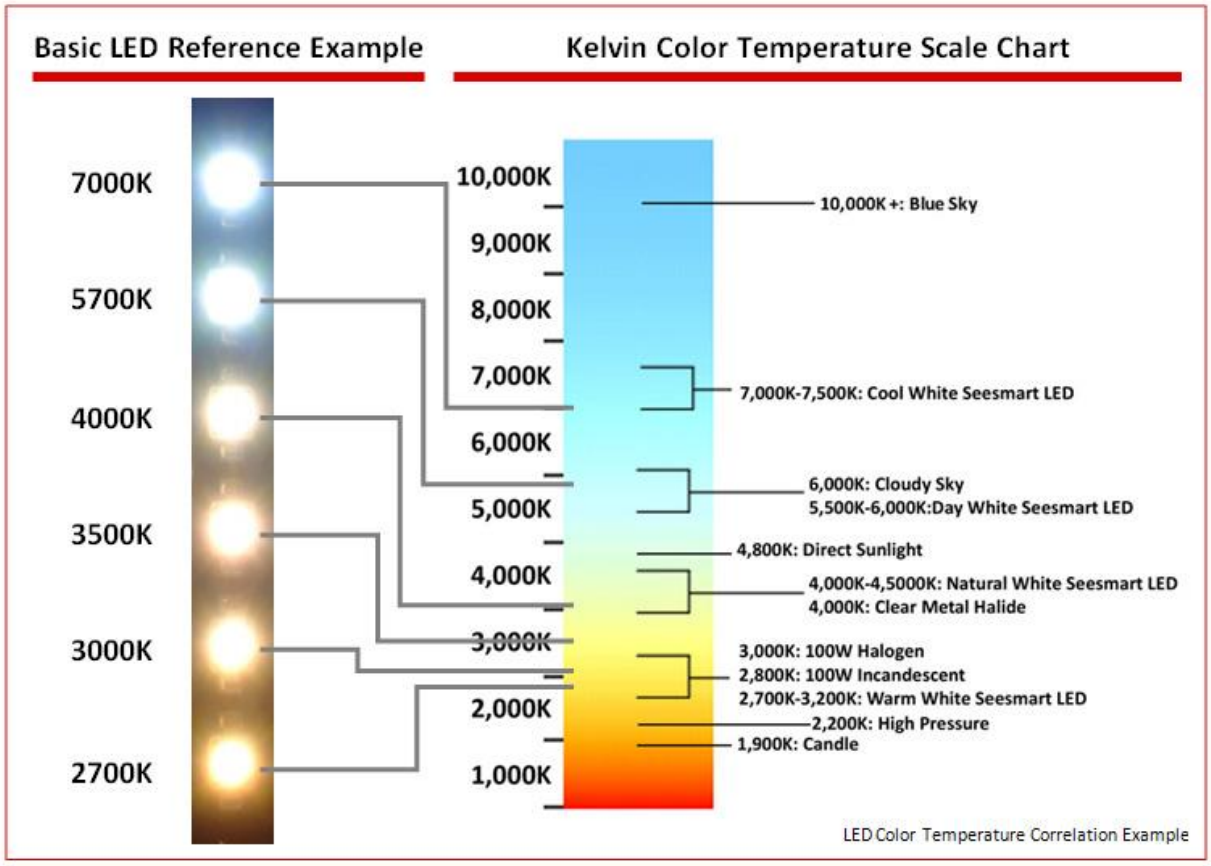

Figure 14: LED color temperature correlation example

source: www.seesmartled.com

Kwon, Baek, and Jeon (2021) explored the integration of intelligent lighting systems with LED technology in the context of HCL development. They emphasize that LED technology, due to its energy efficiency, long lifespan, and adaptability, is pivotal in enabling dynamic lighting environments that respond to user needs. When paired with intelligent technologies such as IoT-based[21] systems, LEDs allow for the real-time adjustment of lighting conditions to align with users' biological rhythms, promoting well-being and enhancing productivity in indoor spaces. Their study also highlights the importance of developing sustainable business models for HCL systems, incorporating LED technology and intelligent controls to create flexible and personalized lighting solutions. This approach not only supports health and comfort but also contributes to energy savings and sustainability in modern lighting systems. (Kwon, Baek, & Jeon, 2021)

[21] IoT-based refers to systems or devices that operate within the Internet of Things (IoT), enabling connectivity, data exchange, and automation through the Internet.

Efficient light-source technologies, such as LEDs, can reduce global greenhouse gas emissions by more than a factor of 7 by 2050, allowing for a 2.5 to 2.9 times growth in global lighting demand without increasing metal depletion. (Bergesen et al, 2016)

Fu et al (2023) examined the effects of LED lighting's CCT and illuminance on visual comfort during sustained attention tasks. Testing with 46 college students, they measured both subjective comfort and task performance under various lighting conditions. Results indicated that a CCT of 3300 K with 300 lx illuminance yielded the highest comfort, with 4000 K also positively impacting comfort and performance. Thus, LED lighting at 3300 K or 4000 K CCT and 300 lx illuminance is optimal for visual comfort in focused tasks.

The use of energy-efficient LEDs and smart connected systems allows for precise control of lighting conditions to meet HCL criteria. (Northfield, 2018) The integration of these technologies highlights the growing role of lighting innovation in improving our living spaces and demonstrates how affordable solutions can be both practical and transformative, helping us transition away from outdated lighting models while enhancing comfort and health.

One often overlooked factor in housing quality is the role of lighting in the home. Introducing advanced light sources and innovative lighting systems to the market is a vital step toward creating healthier, more productive indoor environments, particularly for remote workers. This highlights the need to integrate HCL principles into design practices, optimizing the WFH experience and enhancing overall well-being. Intelligent lighting systems are increasingly recognized for their significant role in improving workspace environments. Designed with human-centric principles, these systems adapt to users' needs, supporting circadian rhythms and enhancing productivity. As awareness grows about the positive impacts of intelligent lighting on well-being and energy efficiency, the demand for innovative, sustainable solutions is expected to rise, fostering continued advancements in this field. The next chapter will further explore how these systems are applied to optimize lighting for health and productivity.

2.4. Lighting Strategies: Intelligent Design for Productive and Comfortable Home-office Environments

In this chapter, we explore the intersection of lighting design and remote work, addressing how intelligent, human-centered lighting can transform home-office environments. The shift towards remote work requires not only individual adaptation but also systemic changes in how we think about workplace environments. Remote workers, companies, and designers must work together to create spaces that are not only comfortable but also supportive of long-term health and productivity. Are our home-office setups conducive to productivity, and how does awareness of optimal lighting strategies influence purchasing decisions?
This chapter explores the critical role of intelligent task lighting in enhancing productivity and comfort in home-office environments, also highlighting the importance of raising awareness about human-centered lighting, which can influence the demand for innovative, sustainable lighting products.

2.4.1. Intelligent Lighting Design: Customization and Personalization for Individual Preferences

Ensuring healthy lives and promoting well-being (SDG 3[22]) highlights the critical role of proper lighting in enhancing physical and mental health, reducing eye strain, and supporting circadian rhythms. Intelligent lighting design, incorporating efficient solutions like LEDs and smart systems[23], not only advances individual well-being but also contributes to sustainability by reducing energy consumption and enabling access to affordable, reliable, and modern energy (SDG 7[24]). Furthermore, intelligent lighting solutions contribute to sustainable development goals[25] by fostering inclusive economic growth and improved work conditions, aligning with the aim of promoting full and productive employment and decent work for all (SDG 8[26]). By balancing energy efficiency with human-centered design, intelligent lighting bridges the gap between environmental sustainability and human health, supporting the overarching goals of SDGs 3, 7, and 8. (Figure 15)

[22] SDG 3, one of the United Nations Sustainable Development Goals, aims to ensure healthy lives and promote well-being for all ages, addressing issues like maternal health, disease prevention, and access to healthcare.
[23] A smart system is an interconnected setup that uses sensors, data processing, and automation to make autonomous decisions and optimize performance.
[24] SDG 7, one of the United Nations Sustainable Development Goals, seeks to ensure access to affordable, reliable, sustainable, and modern energy for all.
[25] The Sustainable Development Goals (SDGs) are a set of 17 global goals established by the United Nations to address issues like poverty, inequality, climate change, and promote peace and prosperity by 2030.
[26] SDG 8, one of the United Nations Sustainable Development Goals, aims to promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all.

Figure 15: Sustainable Development Goals

https://sdgs.un.org/goals

Intelligent lighting systems are essential in modern, adaptable, and sustainable workspaces, integrating advanced technologies like sensors, automation, and adaptive controls to enhance user comfort and energy efficiency. These systems support HCL by dynamically adjusting lighting based on time of day, user activity, and environmental conditions, promoting well-being and productivity. By replicating natural daylight patterns, tailoring light to specific tasks, and using daylight harvesting[27], these systems optimize both comfort and sustainability. Integration with smart home ecosystems, energy management systems, and IoT devices enables intelligent lighting to function as part of a seamless, energy-efficient environment, minimizing unnecessary energy use and contributing to sustainability goals. Sustainable lighting design focuses on energy efficiency and the use of environmentally friendly materials. Techniques such as daylight harvesting and the application of energy-efficient lighting solutions like LED technology reduce environmental impact and operational costs while maintaining high-quality illumination (Ozenen, 2023). A real-world case study was conducted to evaluate the effectiveness of an intelligent human-centric lighting system designed to enhance mental well-being. The system adjusted lighting based on users' emotional states, detected through facial recognition. Participants reported improved mood and well-being, though some suggested smoother transitions between color changes would be beneficial (Cupkova et al, 2019).

[27] Daylight harvesting uses sensors to adjust artificial lighting based on natural light levels, saving energy and maintaining consistent indoor brightness."

In human-centric lighting design, innovative materials and technologies are being explored to enhance living environments. Marjan van Aubel's *Sunne* exemplifies this approach, offering an organic and intuitive illumination experience with its three settings that mimic natural sunlight moments. Sunne is a self-powered solar light that captures energy from the sun through photovoltaic cells and stores it in an integrated battery, eliminating the need for external power sources. (Figure 16) This innovation highlights a new relationship between natural illumination and human environments, combining aesthetic sophistication with efficient energy absorption (Van Aubel Studio, 2021).

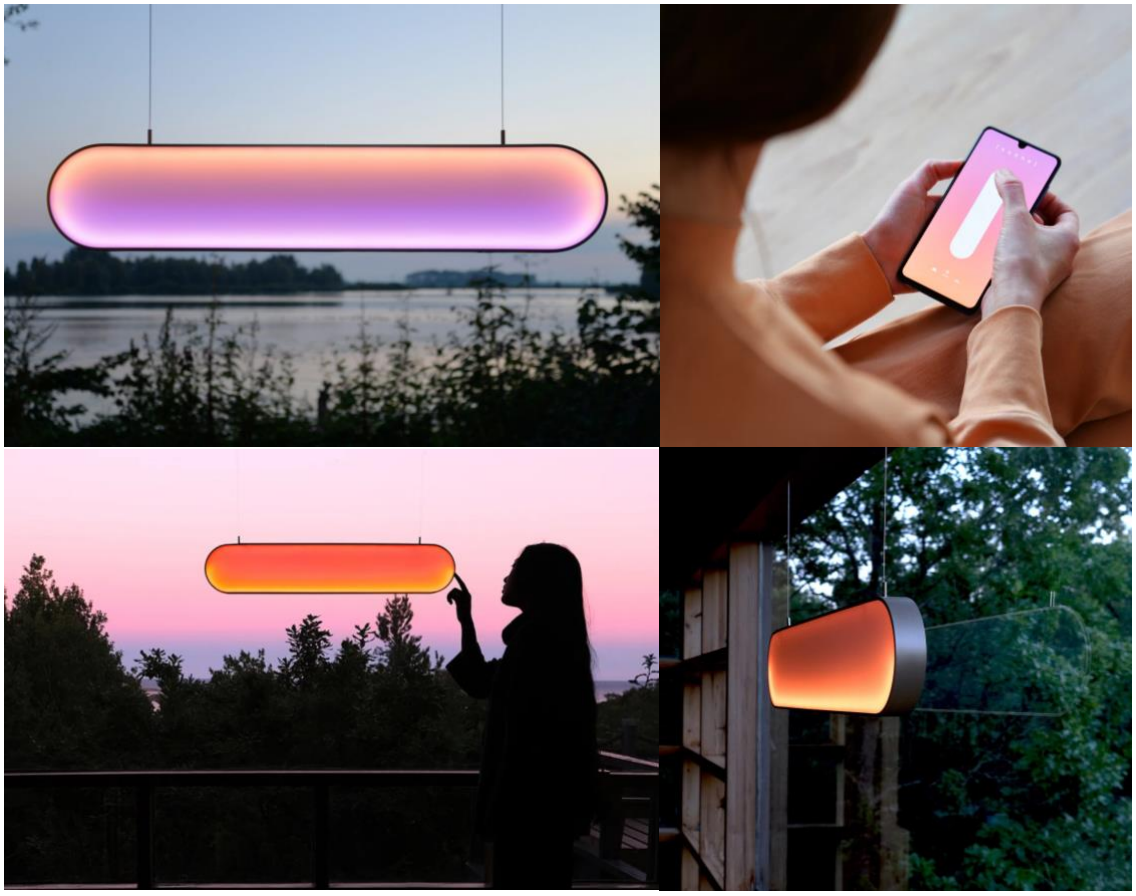

Figure 16: Sunne is a self-powered solar light

https://www.marjanvanaubel.com/sunne

Another intelligent lighting design is The Sleepace Nox Smart Sleep Light designed to enhance sleep quality through intelligent use of light and sound that aligns with the user's natural body clock. It employs red wavelengths to stimulate melatonin production, promoting sleep onset, and uses soothing sounds for relaxation. (Figure 17)
The Sleepace Nox ability is to monitor sleep patterns through its companion app. The app tracks data such as sleep cycles, movements, and environmental factors like room temperature and noise levels. Based on this information, it offers personalized suggestions to improve sleep conditions. Additionally, the Nox features a smart alarm that wakes users during the lightest phase of their sleep cycle by gradually increasing light intensity, simulating a natural sunrise, ensuring they wake

up feeling refreshed. This intelligent system supports the creation of comfortable, personalized sleep environments and aligns with advanced lighting control systems. (The Test Pit, 2018)

Figure 17: The Sleepace Nox smart sleep light

https://www.thetestpit.com/2018/01/review-sleepace-nox.html.

Understanding light's transformative impact on health and daily life encourages the adoption of innovative lighting technologies. The fusion of intelligent design with LED advancements creates efficient, sustainable lighting solutions that enhance well-being while remaining cost-effective. Highlighting these benefits builds trust and supports widespread adoption.
The integration of technology with human-centric design opens up significant potential to optimize lighting for both work and relaxation in home settings. Pursuing optimal lighting not only enhances personal comfort but also promotes collective well-being[28] and reduces environmental impact. This journey underscores the vital role of light in shaping healthier, more efficient spaces that

[28] Collective well-being refers to the overall health, happiness, and quality of life experienced by a group or community, influenced by social, economic, and environmental factors.

contribute to both individual wellness and broader ecological responsibility, moving us toward a sustainable and health-centered future.

In home-office settings, optimized lighting, particularly through task lighting, supports productivity and comfort, creating healthier and more effective work environments for remote workers. Task lighting can significantly enhance energy efficiency and improve visibility in office environments. By positioning lighting closer to work surfaces, task lighting reduces the need for higher general lighting levels, which can result in energy savings. Additionally, task lighting minimizes common issues like glare and veiling reflections[29], thereby increasing worker comfort and productivity (Wolsey and Miller, 1994).

2.4.2. Task Lighting for Home Offices: Enhancing Remote Workers' Health and Productivity

In home-office design, task lighting is essential for enhancing both health and productivity. It optimizes visual contrast by focusing light precisely on work areas, ensuring specific spaces are illuminated for activities that require attention to detail. This targeted lighting approach reduces eye strain and promotes sustained focus, which are crucial for productivity in remote work settings. A well-balanced lighting system that integrates task and ambient lighting minimizes visual discomfort, preventing eye fatigue by reducing shadows and glare. Adjustable task lighting provides brightness exactly where needed, creating a comfortable and efficient workspace that supports ergonomic design and promotes well-being. In a field study by Joines et al (2015), the use of adjustable LED task lights in office environments was found to significantly reduce discomfort, eye fatigue, and improve posture and perception of job tasks. Participants reported increased musculoskeletal[30] comfort and visual comfort, and their assessments of the lights' usability and desirability were positive, with no negative effects noted from using the adjustable task lighting.
In a study conducted in a Finland luminaire factory, a controllable task-lighting system was tested to assess its impact on productivity. For a period of 16 months a task-lighting system was installed above 10 individual workstations. The system allowed workers to select higher lighting levels at their workstations, resulting in a statistically significant productivity increase of 4.5% compared to a reference group. Controllable task-lighting systems can significantly increase productivity in industrial processes, potentially due to improved visual performance, biological effects of light, or psychological effects. (Juslén, Wouters, & Tenner, 2007)

Escuyer and Fontoynont (2001) investigated how office workers reacted to having control over their lighting environment. The experiment involved providing workers with adjustable lighting controls and observing how it affected their satisfaction, comfort, and productivity. Office workers prefered automatic dimming systems with manual control, optional task lighting, and user-friendly control, to maximize daylight and benefit from artificial light. The results showed that employees who could personalize their lighting reported higher levels of well-being and productivity. This underscores the importance of adaptable lighting solutions in enhancing workplace satisfaction.

[29] Veiling reflections are unwanted reflections on a surface, such as a screen or workspace, that reduce contrast and impair visibility by overlaying a distracting layer of light.
[30] Musculoskeletal refers to the system of muscles, bones, tendons, ligaments, and other structures that support the body and enable movement.

Nicol, Wilson, and Chiancarella (2006) also investigated the illuminance levels on office desks across 26 offices in five European countries—France, Greece, Portugal, Sweden, and the UK. The research focused on how outdoor conditions affect indoor lighting preferences, as well as the role of task lighting in occupant satisfaction. The findings revealed that office workers adapt to varying light intensities using controls and prefer consistent lighting levels. Offices with greater access to daylight showed higher self-reported productivity, emphasizing the importance of natural light and personalized lighting control in enhancing comfort and efficiency in the workplace.
Task light usage patterns and preferences vary significantly between paper and computer work. Task-lighting should be designed with form factor, interface, and lighting control characteristics in mind to optimize energy use and user comfort in both paper and computer work environments. (Papinutto et al, 2021)

Interior lighting design utilizes both natural and artificial light to achieve different effects. Techniques such as ambient, task, accent, and decorative lighting are used to enhance the functionality and atmosphere of interior spaces, allowing designers to tailor lighting schemes to specific needs and aesthetics (Ozenen, 2023). In lighting design, directionality, how light is distributed within a space, is one of the characteristics of HCL that often receives less attention compared to color temperature or intensity. Directional light can be diffused or focused, and each approach serves distinct purposes. Diffused light spreads uniformly across a room, softening shadows and creating a comfortable, inviting ambiance, often preferred in ambient lighting. In contrast, directional light concentrates illumination on specific areas, making it essential for task lighting where precision is required, such as reading or detailed work. When thoughtfully applied, directionality enhances both the functionality and ambiance of a space, adapting lighting to diverse needs and making it integral to effective HCL design.

The BenQ e-Reading Desk Lamp embodies intelligent task lighting principles by providing wide illumination, adaptive brightness, and color temperature controls tailored to HCL. Its unique "Smile Curve" design ensures 150% more desk coverage than typical lamps, with an ambient light sensor that switches seamlessly between "Screen Mode" and "Paper Mode" to optimize user comfort and reduce eye strain. With a patented ball-joint, the lamp provides easy adjustability to meet multi-angle lighting needs, enhancing its functionality across various tasks and spaces. The lamp's high CRI and flicker-free LED light source further enhance visual clarity and comfort, making it a refined choice for ergonomic workspaces. (BenQ, 2024) (Figure 18)

Figure 18: BenQ., e-Reading Intelligent Desk Lamp (BenQ, 2024)

Source: https://www.benq.eu/en-eu/lighting/e-reading-desk-lamp/e-reading.html

Awarded "Best for Sleep" by *GQ* Magazine in the UK in 2021, the Dyson Solarcycle Morph is an intelligent task light that adjusts to natural light conditions to enhance user comfort and visual performance. (Dyson, 2021) This lamp uses advanced sensors to adapt brightness and color temperature based on factors such as time of day, user activity, and age, supporting HCL principles. Its flexible positioning and multiple lighting modes provide optimal lighting for eye health, concentration, and various tasks. (Figure 19)

Figure 19: Dyson, Solarcycle Morph Intelligent Task Light (Dyson, 2021)

Source: https://www.dyson.pt/iluminacao/solarcycle-morph

Task lighting offers a practical solution for improving both well-being and productivity in home-office environments for remote workers. By reducing eyestrain and enhancing visibility, adjustable lighting options such as desk lamps, under-cabinet lighting, and floor lamps enable individuals to customize their lighting based on their specific needs. Additionally, energy-efficient LED task lighting options provide long-term benefits by improving performance while reducing energy consumption. As remote work becomes more common, prioritizing ergonomic and effective lighting solutions is essential for creating productive and comfortable home-office spaces.

2.4.3. Raising Awareness: Driving Demand for Innovative and Sustainable Human-Centered Lighting

In home-office environments, where many people now spend extended hours, HCL offers the potential to significantly boost productivity and well-being. It not only improves the quality of the lighting but also helps combat the negative effects of artificial lighting, such as eye strain and disrupted sleep. While implementing HCL systems may involve higher upfront costs, studies show that the long-term benefits, including better health outcomes and increased workplace efficiency, make it a valuable investment. HCL has sound motivations and should be integrated into design, considering both visual and non-visual responses for optimal human health and well-being. The marketing of HCL often includes promises of health benefits, which can influence consumer interest and demand, despite some claims being exaggerated. (Houser et al, 2020) Consumers are

more likely to adopt eco-friendly smart home services when they have positive attitudes, perceived behavioral control, information publicity, environmental consciousness[31], and compatibility. (Zhang & Liu, 2021) Environmental consciousness measures are closely linked to environmentally-responsible purchasing behavior. (Schlegelmilch, Bohlen, & Diamantopoulos, 1996) Consumers' knowledge, commitment, and general awareness of green products influence their green consciousness and decision-making while choosing green products, including environmental benefits, economic benefits, reliability, and appearance. (Maniatis, 2016)

Lighting uses about 20% of total electricity consumption in the U.S. and similar fractions in the European Union and developing countries. (Azevedo, Morgan, & Morgan, 2009) In a study by Nagy et al (2015), adaptive lighting control systems in office spaces, based on occupancy sensor data and occupant behavior, achieved significant energy savings. The research found that using dynamic, occupant-centered control strategies led to 37.9% energy savings compared to standard lighting settings and 73.2% savings in comparison to worst-case scenarios. This approach tailors lighting conditions to individual behaviors and needs, providing both energy efficiency and occupant comfort.
The study explored key elements that drive consumers to buy environmentally friendly products. It identifies three core influences: cognitive factors, individual characteristics, and social factors. Cognitive factors include consumers' perceptions of green product value, quality, and risk. Individual characteristics involve environmental concerns and trust in green products, while social factors refer to societal norms and collective attitudes toward sustainability. The study integrates the Theory of Planned Behavior[32] and the Attitude-Behavior-Context framework to explain how these factors shape green purchase intentions (Zhuang et al, 2021).

Lembcke (2023) concludes that while awareness of HCL is generally low, there is a clear interest in its potential benefits, especially among health-conscious consumers. Age and income significantly influence willingness to pay for HCL solutions, with older and higher-income individuals showing greater interest. The study highlights the need for increased consumer education about the well-being benefits of HCL to drive adoption and suggests that businesses can leverage this interest to promote health-conscious lighting solutions in the market.

[31] Environmental consciousness is an awareness and concern for protecting the environment, often leading to behaviors and practices that reduce environmental impact.
[32] The Theory of Planned Behavior is a psychological framework that predicts individual behavior based on intentions, attitudes, subjective norms, and perceived behavioral control. It suggests that people are more likely to engage in a behavior if they intend to do so, if they view the behavior positively, if they feel social pressure, and if they believe they have control over performing it.

2.5. Conclusive Synthesis

This study has provided a comprehensive exploration of how intelligent lighting design can significantly impact the productivity and well-being of remote workers, addressing the unique challenges that home-office environments present. With the rise of remote work, the transformation of homes into multifunctional spaces has underscored the need for optimal indoor environments, with lighting emerging as one of the most critical factors affecting health, productivity, and comfort. Through the exploration of HCL principles, this research highlights the significant role of light in regulating circadian rhythms, mood, and cognitive function, which are essential to creating a supportive and productive workspace.
Key findings demonstrate that various characteristics of light like color, intensity, spectral composition and direction can impact productivity and well-being, underscoring the need for lighting systems tailored to individual needs.

Human-centric lighting, particularly through advanced LED technology, presents flexible solutions capable of adapting to individual needs throughout the day. LEDs offer not only the benefits of energy efficiency and environmental sustainability but also unique adaptability in creating tailored lighting environments that support circadian rhythms, enhance focus, and alleviate eye strain, all of which are critical for maintaining productivity and well-being.
HCL principles and intelligent technologies offer solutions that can adapt to the diverse requirements of remote workers, providing customizable lighting that supports both professional tasks and personal well-being. Intelligent lighting strategies, such as adjustable task lighting and circadian-friendly lighting systems, have shown promise in enhancing comfort and focus while also mitigating adverse effects, such as eye strain and disrupted sleep-wake cycles.

Responsibility for creating optimized home-office lighting environments should not rest solely on individual remote workers. Companies with remote workforces have a vested interest in supporting the health, productivity, and satisfaction of their employees, making it essential for them to consider intelligent lighting as a strategic investment in workforce well-being. As health-conscious consumers increasingly seek personalized solutions, organizations have an opportunity to lead by integrating human-centric lighting support into remote work policies, either by offering guidance on optimal lighting setups or even subsidizing smart lighting solutions. Companies that proactively support advanced lighting solutions not only contribute to their employees' well-being but also foster a more productive, sustainable, and health-conscious remote work culture.
As this is a relatively new area of study, further research is needed to deepen our understanding of how personalized, adaptive lighting can optimize home-office setups for individual users. Future studies should also focus on investigating long-term effects of human-centric lighting to provide comprehensive guidelines that support both well-being and productivity for remote workers.

In conclusion, as remote work becomes a permanent aspect of the modern work environment, it is imperative to prioritize intelligent and human-centric lighting design in home-office settings. By raising awareness and understanding of these lighting principles, this study aims to drive innovation and adoption of intelligent lighting solutions that meet the needs of today’s remote workforce. Adopting these strategies will not only enhance individual productivity and health but also contribute to the broader goal of sustainable and user-focused indoor environments.

2.6. Practical Guidelines for Optimized Home-Office Lighting

These guidelines offer practical insights for designers, organizations, and individuals to create optimized home-office lighting that enhances well-being and productivity. Grounded in HCL principles and leveraging advanced LED and intelligent technologies, they focus on aligning lighting with circadian rhythms, task-specific needs, and sustainable practices. By prioritizing adaptable, personalized, and health-conscious lighting solutions, these strategies aim to foster a productive and comfortable remote work environment while supporting long-term health and sustainability.

1. **Design with Human-Centric Lighting Principles**

- **Understand Circadian Needs:** Align lighting design to support natural circadian rhythms by integrating lighting solutions that mimic natural daylight patterns.
- Use cooler, brighter light in the morning and midday to promote alertness and focus.
- Transition to warmer, dimmer light in the evening to encourage relaxation and prepare for restful sleep.
- **Balance Light Intensity and Distribution:** Ensure task areas are well-lit with focused lighting while maintaining ambient lighting to reduce eye strain and glare.

2. **Embrace Advanced LED Technology**

- **Flexible and Adaptive Lighting:** Leverage the adaptability of LED systems to create lighting that is both energy-efficient and customizable to individual preferences.
- **Spectral Composition:** Choose LED lighting with tunable white or multi-spectrum capabilities to match activity and time of day.
- **Sustainability:** Prioritize LED lighting solutions for their long-term energy efficiency and reduced environmental footprint.

3. **Incorporate Intelligent Lighting Systems**

- **Personalized Lighting Control:** Utilize smart lighting technologies that allow remote workers to adjust color temperature, brightness, and intensity according to their needs and tasks.
- **Automation and Scheduling:** Implement automated lighting systems that adjust throughout the day to maintain optimal circadian support.
- **Integration with IoT Devices:** Consider smart hubs or voice-controlled systems for seamless integration of lighting into the home-office ecosystem.

4. **Address Task-Specific Needs**

- **Adjustable Task Lighting:** Provide task-specific lighting, such as adjustable desk lamps, for focused work while reducing shadows and glare.
- **Directional Lighting:** Position lights to avoid screen reflections and eye discomfort during prolonged computer use.

- **Ambient Lighting Balance:** Pair task lighting with ambient sources to minimize contrast and create a comfortable visual environment.

5. **Advocate for Organizational Support**

- **Employer Initiatives:** Encourage organizations to provide employees with resources or subsidies for smart lighting solutions tailored to home-office setups.
- **Lighting Education:** Offer guidelines or workshops to help employees understand the importance of intelligent lighting and how to optimize their workspace.
- **Health and Productivity Metrics:** Highlight the impact of intelligent lighting on reducing eye strain, fatigue, and mood-related issues, demonstrating its value as a strategic investment.

6. **Foster Awareness of Lighting's Impact on Well-Being**

- **Educate Remote Workers:** Develop materials that explain the relationship between lighting, health, and productivity, empowering workers to make informed choices.
- **Promote Long-Term Research:** Support ongoing studies into the physiological and psychological effects of human-centric lighting, with an emphasis on remote work contexts.

7. **Design for Sustainability**

- **Energy-Efficient Practices:** Incorporate lighting systems that are eco-friendly and reduce energy consumption.
- **Durable Solutions:** Select lighting products with a long lifespan to minimize waste and support environmental goals.

8. **Support Future-Proof Designs**

- **Scalable Systems:** Implement lighting setups that can adapt to changes in technology and user needs over time.
- **Integration with Emerging Trends:** Anticipate advancements in smart home technologies and ensure compatibility for a seamless experience.

3. Hypothesis (Theoretical-Practical)

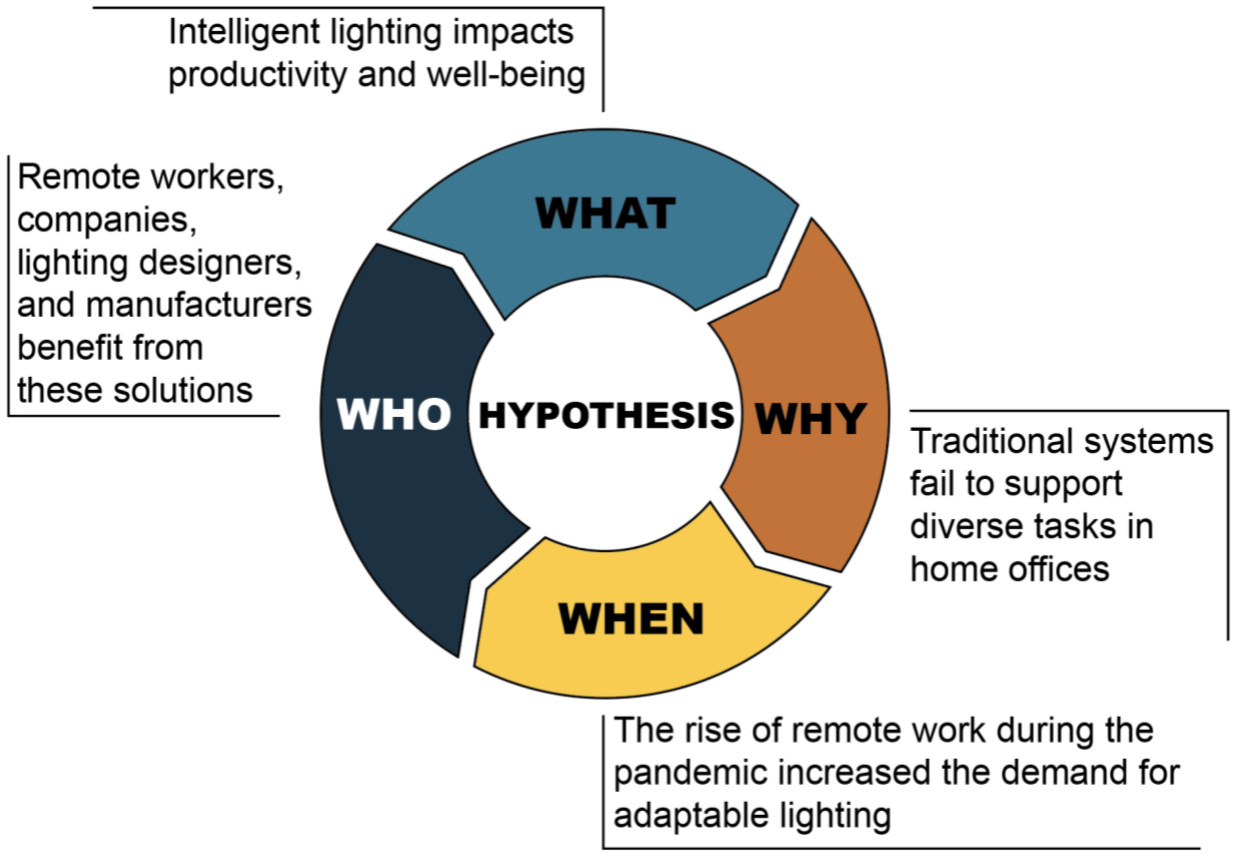

Figure 20: Formulation of the hypothesis

The figure 20 outlines the process of formulating the hypothesis. The **WHAT** highlighted the potential benefits of intelligent lighting in improving both productivity and well-being. The **WHO** identified key stakeholders—remote workers, companies, lighting designers, and manufacturers—who benefited from such solutions. The **WHY** explained that traditional lighting systems failed to meet the diverse demands of home office tasks, creating a gap in the market. Finally, the **WHEN** connected the rise of remote work during the pandemic to an increased need for adaptable lighting. These insights ultimately led to the development of the hypothesis and the focus of this research.

The Hypothesis:

"Intelligent lighting design, informed by human-centric principles and offering customization options improves the productivity and well-being of remote workers in home-office environments."

4. Research

4.1. Exploratory

In the exploratory phase of this research, a **mixed-methods approach** was employed, utilizing both a **survey by questionnaires** and **cultural probes** to gather comprehensive data on remote work experiences. This combination of methods enabled a robust understanding of the quantitative aspects of remote work (through survey by questionnaires) and facilitated a deeper qualitative exploration of participants' personal experiences and interactions within their home-office environments (through the cultural probes). This mixed-methods approach ensured a well-rounded perspective, addressing both measurable patterns and context-rich insights.

All participants in both the questionnaire and cultural probes were employees working remotely from home. This criterion was set to ensure that the data collected accurately reflected the experiences and challenges faced by individuals in a remote work lifestyle.

4.1.1. Survey by questionnaires

4.1.1.1. Introduction

The decision to employ a survey by questionnaires[33] was supported by its effectiveness in capturing broad patterns and generalizable data on participant demographics, work environments, and behaviors. Surveys are effective for collecting mass data to represent conditions or trends, making them valuable for comprehensive research undertakings. (Segel, 1942)

4.1.1.2. Preparation

The semi-structured questionnaire was designed to gain a comprehensive understanding of the experiences of employees who WFH. To ensure inclusivity and accessibility for a diverse participant group, the questionnaire was available in three languages: English, Portuguese, and Persian. It comprised 20 questions, 17 closed-ended and 3 open-ended, organized into three distinct sections, each aimed at capturing specific aspects of the remote work experience, providing quantitative data while also allowing for initial qualitative insights.

The **first section** focused on collecting basic demographic information and employment details. Participants were asked to indicate their gender, age group, and work model (e.g., full-time remote or hybrid). Additionally, this section included a screening question to ensure that only individuals currently employed and working part-time or full-time from home participated. This filtering step was implemented to ensure that responses reflected the specific experiences of remote workers, enhancing the accuracy and relevance of the data.

The **second section** explored participants' home work environments, with particular attention to lighting conditions. Questions in this section addressed whether participants had a dedicated workspace separate from their living or rest areas, access to natural light, and adjustable artificial

[33] For the full questionnaire, see Appendix A, section 7.1

lighting. Participants were asked about their satisfaction with the lighting in their home offices by rating scale and also whether they used specific lighting tools, such as desk lamps, to supplement ambient light. This section aimed to provide insight into how physical workspace setups and lighting arrangements impact the daily experiences of remote workers.

The **third section** assessed participants' awareness of the relationship between lighting and health. Questions explored their knowledge of how lighting affects well-being and mood, Participants were also asked about factors influencing their willingness to invest in advanced lighting solutions for their home-offices. The section concluded with open-ended questions, inviting participants to share any discomfort they might experience due to lighting in their environment and whether their employers had taken any steps to improve their working conditions. These open responses provided additional qualitative data, offering richer insights into the challenges and preferences of remote workers regarding their home-offices. (Appendix, section 7.1.1)

The questionnaire was shared through digital platforms, including Instagram, WhatsApp groups, and email, reaching a wide audience that included friends, acquaintances, academic contacts, and broader social media followers.

4.1.1.3. Results

A total of 137 individuals participated in the questionnaire, including 79 women and 58 men. The largest age group was 26 to 40 years old, making up 53%[34] of participants. To ensure the quantitative method was conducted effectively, it was essential to gather over 100 responses, as this threshold allowed for more reliable and statistically relevant data. Since the research focused on remote workers, the sample included a diverse group of participants, representing Portuguese, Iranian, and international English-speaking cultural perspectives. After filtering for those working full-time from home or in a hybrid setup, 133 remote workers were identified and included in the analysis. The sample consisted of 63 Portuguese participants, reflecting the research's grounding in Lisbon. Additionally, 47 Iranian participants were included, leveraging existing professional and personal connections in Iran to enrich the study with cross-cultural insights. To ensure worldwide participation and further enhance the cultural diversity of the study, 23 international participants who completed the survey in English were also included. This deliberate approach ensured that the research incorporated a well-rounded, multicultural perspective, enhancing the validity and applicability of the findings. (Figure 21) (Appendix, section 7.2.1)

[34] Percentages are rounded to the nearest whole number: decimals below 0.5 are rounded down, and 0.5 or above are rounded up. Exact values are shown in charts for precision.

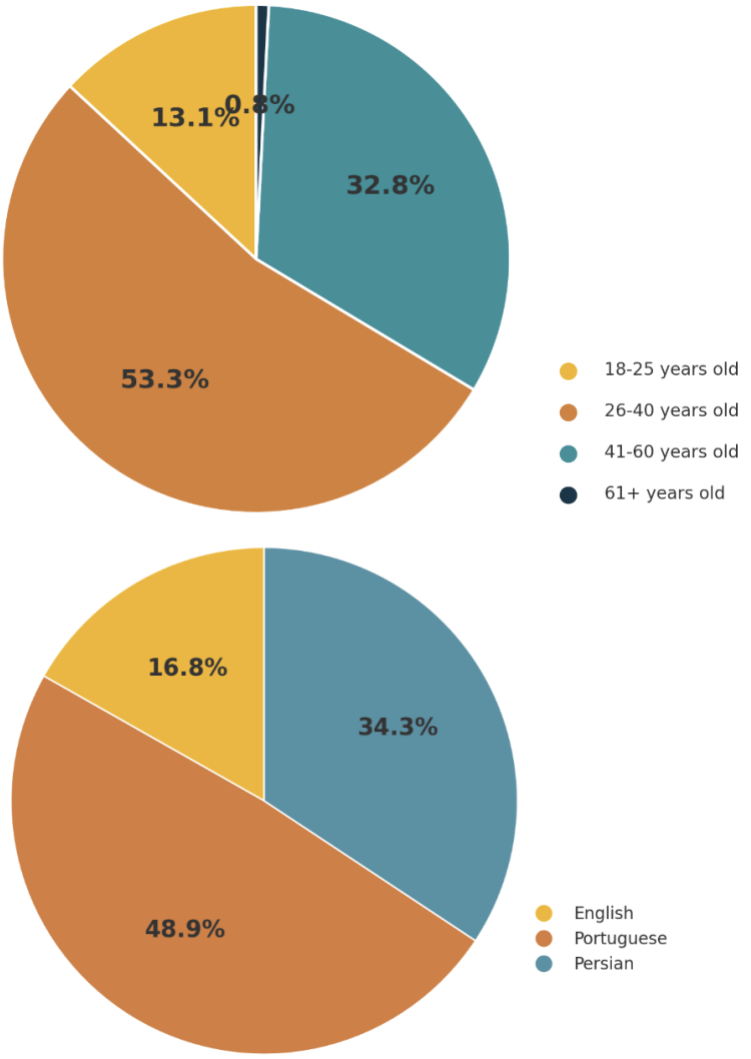

Figure 21: Age and language distribution of the surveyed population

Source: Parastoo Shahpari

Work Environment and Lighting Conditions:

- 32% of participants used the same room for work, rest, and sleep, and 29% used separate spaces within their homes which means 61% didn't have a dedicated room for working and separate from where they sleep and relax, it shows the importance for having different lighting situation so it will be suitable for both working and rest.
- 27% reported limited access to natural light in their workspace at homes, and 5% had no access to it at all. (Figure 22)

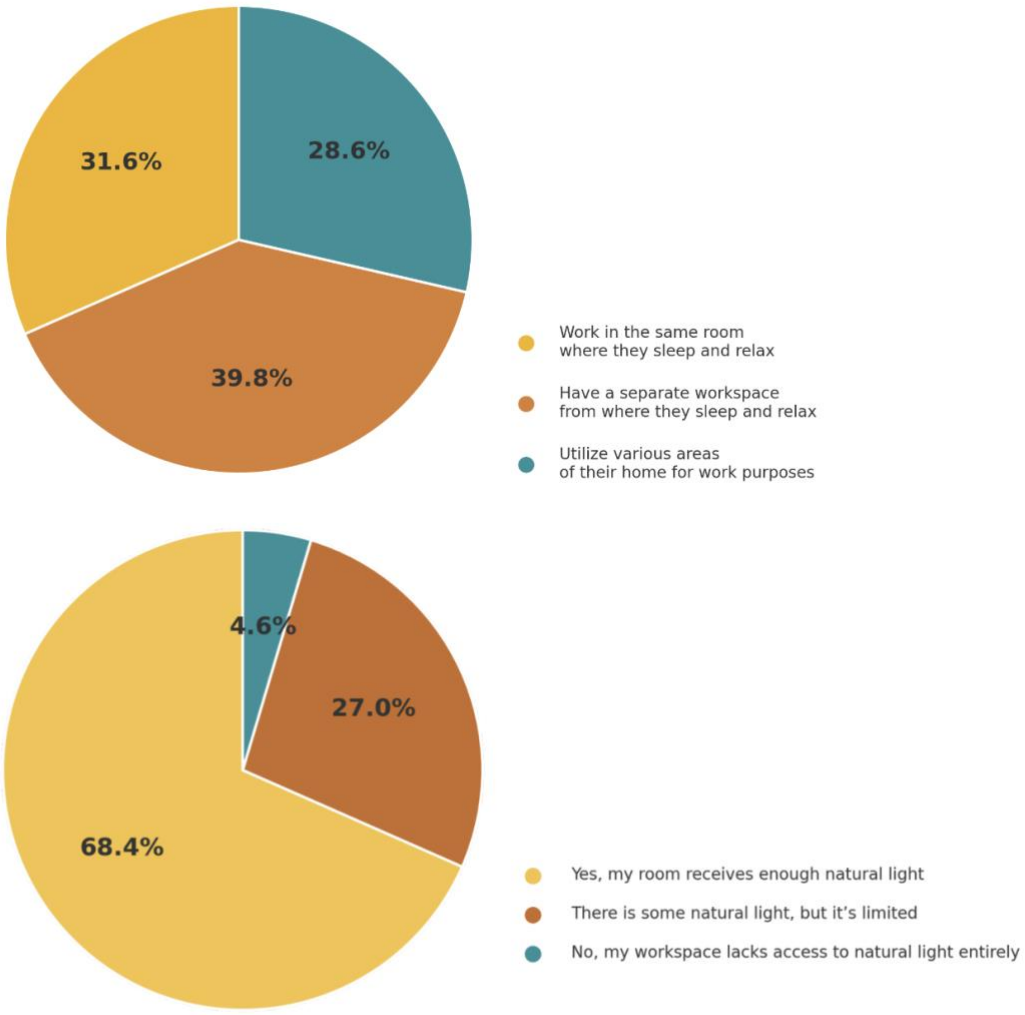

Figure 22: Workspace and lighting situation

Source: Parastoo Shahpari

- Notably, 85% of desks were placed near a natural light source. If the table is not positioned correctly in relation to natural light, the intensity may cause glare or strain the eyes. (Figure 23)

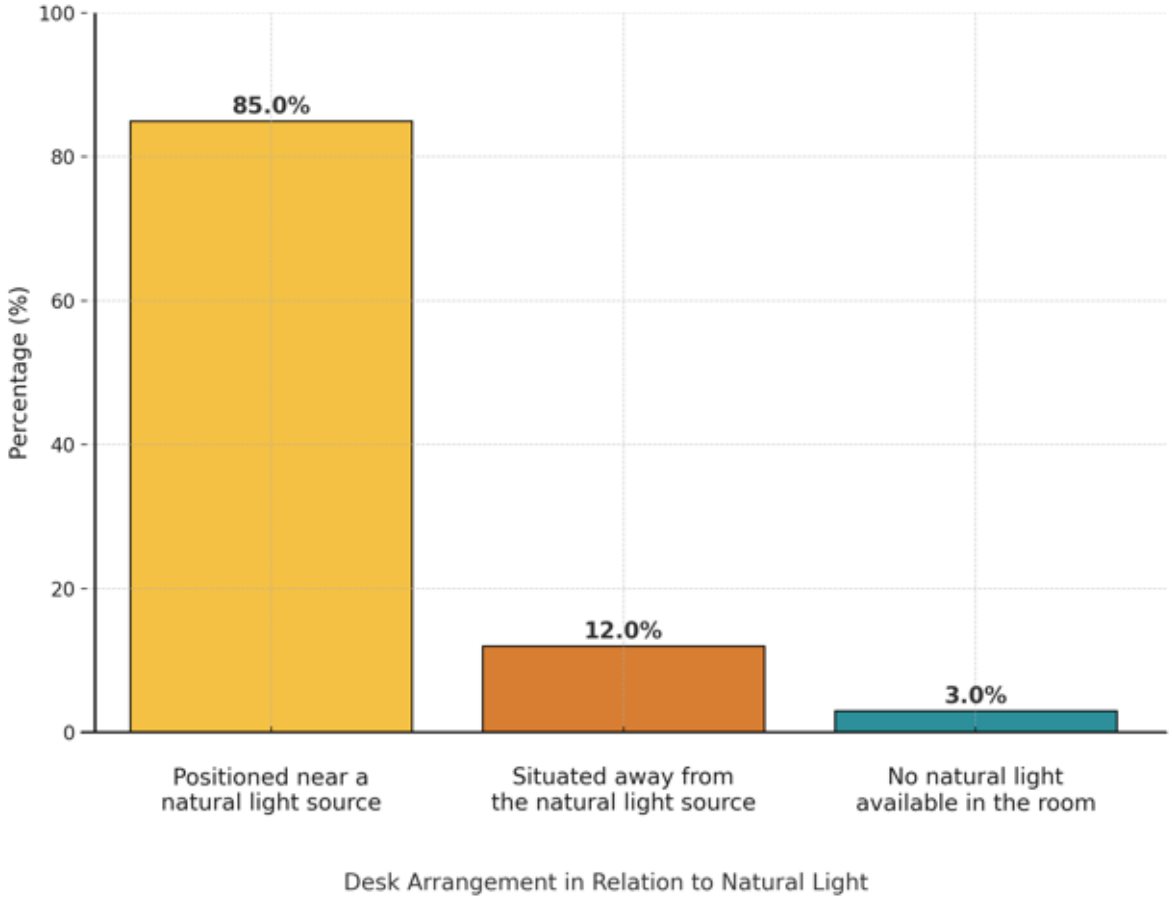

Figure 23: Desk arrangement in relation to natural light

Source: Parastoo Shahpari

Further detailed figures related to the work environment and lighting conditions are provided in Appendix, Section 7.2.2.

Lighting Preferences and Adjustability:

- Only 2% of participants could adjust the color of their lighting, and 50% could not alter either the color or intensity of ambient light. (Figure 24)

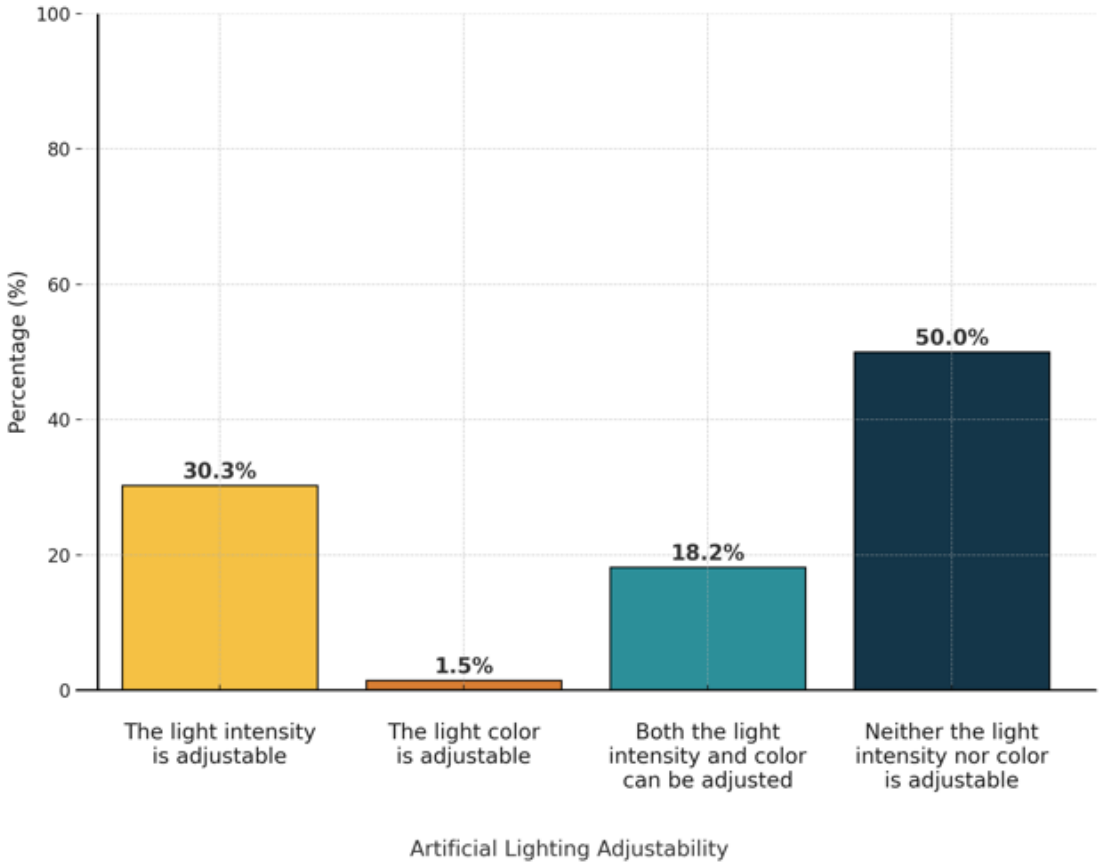

Figure 24: Artificial lighting adjustability

Source: Parastoo Shahpari

Just 18% had the flexibility to adjust both color and intensity, while in Portugal, 55% and in Iran, 43% lacked the flexibility to adjust both color and intensity of light.

- Around 60% of participants expressed satisfaction with their lighting conditions (rating 7-10), while the remaining 40% were neutral or dissatisfied. (Figure 25)

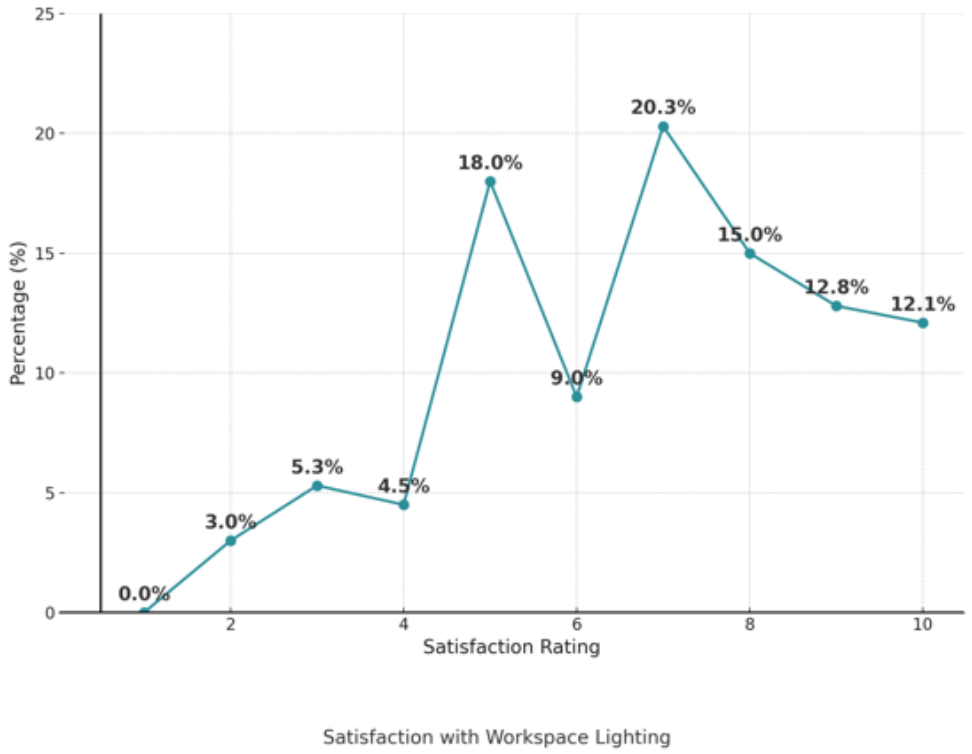

Figure 25: Satisfaction with workspace lighting

Source: Parastoo Shahpari

- 38% of respondents preferred warm lighting, with only 8% favoring cool light. Adjustable lighting was the most desired feature, with 53% indicating a demand for customizable lighting to better suit their home-office needs. (Figure 26)

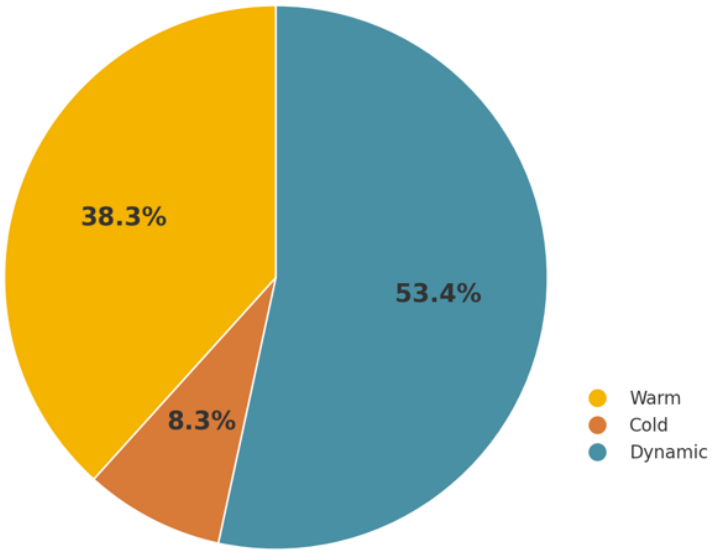

Figure 26: Light temperature preferences

Source: Parastoo Shahpari

- Desk lamps or task lights have been identified as beneficial for enhancing productivity and health in home office environments. Despite this, 47% of respondents reported not using a desk lamp, and among those who did, 40% had desk lamps without manual light direction adjustment capabilities (Figure 27). In Portugal, while 65% of respondents used desk lamps, 40% of these lacked the ability to adjust light direction. These findings highlight a significant opportunity for innovation and improvement in the design of lighting products to better meet the needs of home-office users.

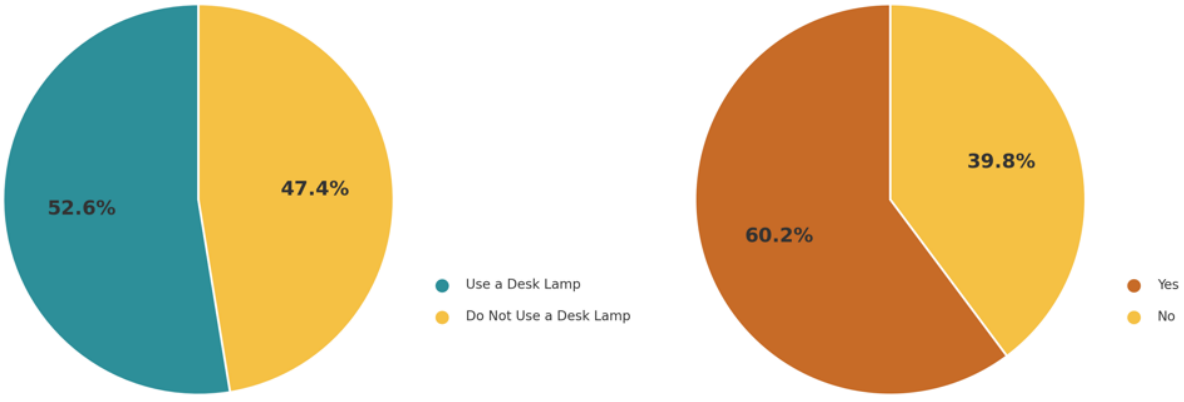

Figure 27: Desk lamp and direction adjustment

Source: Parastoo Shahpari

- For adjusting lighting in their home offices, adoption of new technologies was relatively low, with only 2% of participants preferring motion sensors and 15% choosing mobile apps. In contrast, 32% favored traditional physical switches, and 41% preferred a combination of methods. This tendency to rely on conventional controls may be due to limited familiarity with newer technologies, making participants more comfortable with familiar, manual options for managing lighting. (Figure 28)

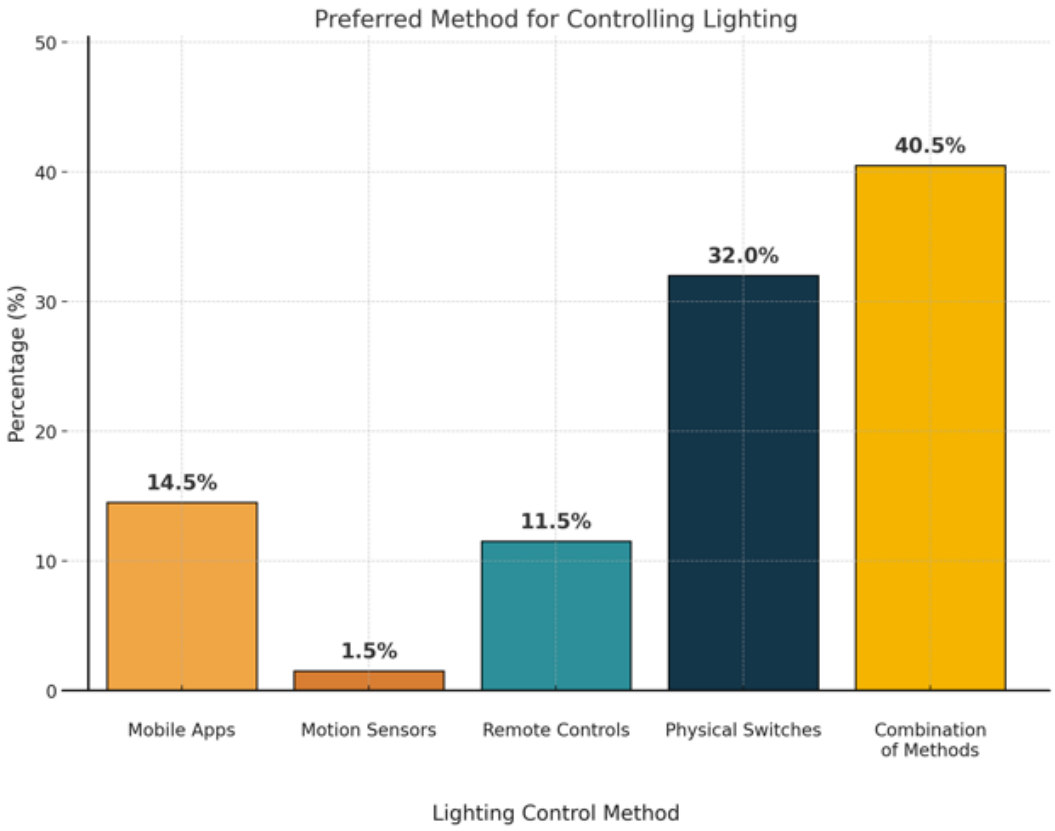

Figure 28: Lighting control preferences

Source: Parastoo Shahpari

Further detailed figures regarding Lighting Preferences and Adjustability are provided in Appendix, Section 7.2.3.

Work Routine and Chronotypes:

- Participants had varied chronotypes, with 44% working during morning and evening hours, and 20% working at night. Of these, 22% felt misaligned with their work hours

(considering time zone and …) which can negatively impact their health and productivity. (Figure 29)

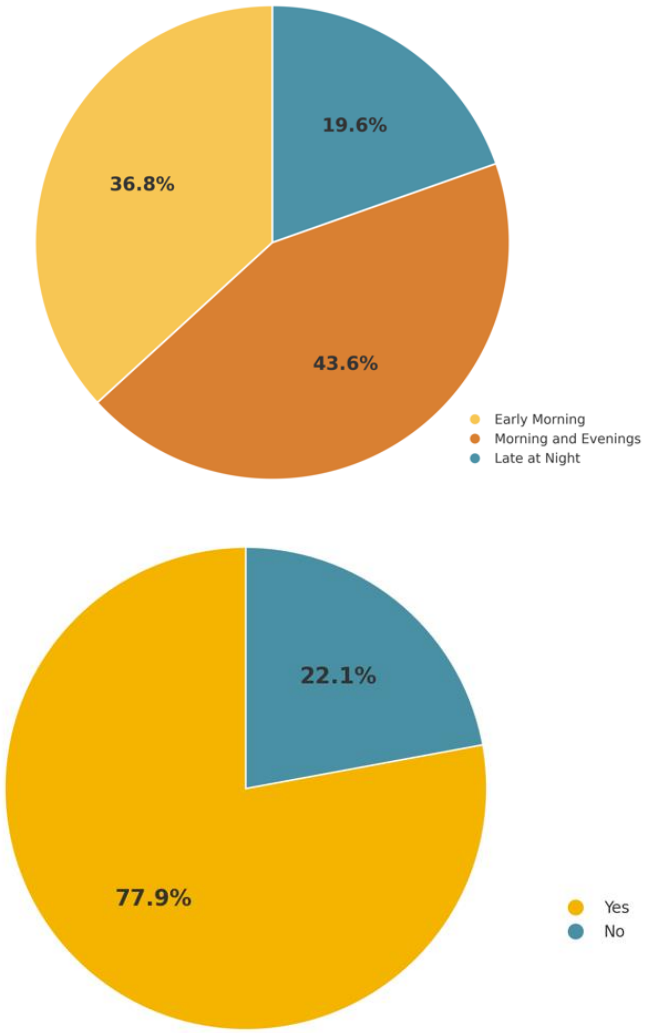

Figure 29: Working routine and satisfaction

Source: Parastoo Shahpari

- Seasonal light changes were also significant, with 53% rating these changes (scoring 7-10) as impactful on their mood. This effect was particularly noted in Portugal, where 45% (scoring form 7-10) attributed seasonal mood shifts to cloudy autumn and winter weather. (Figure 30)

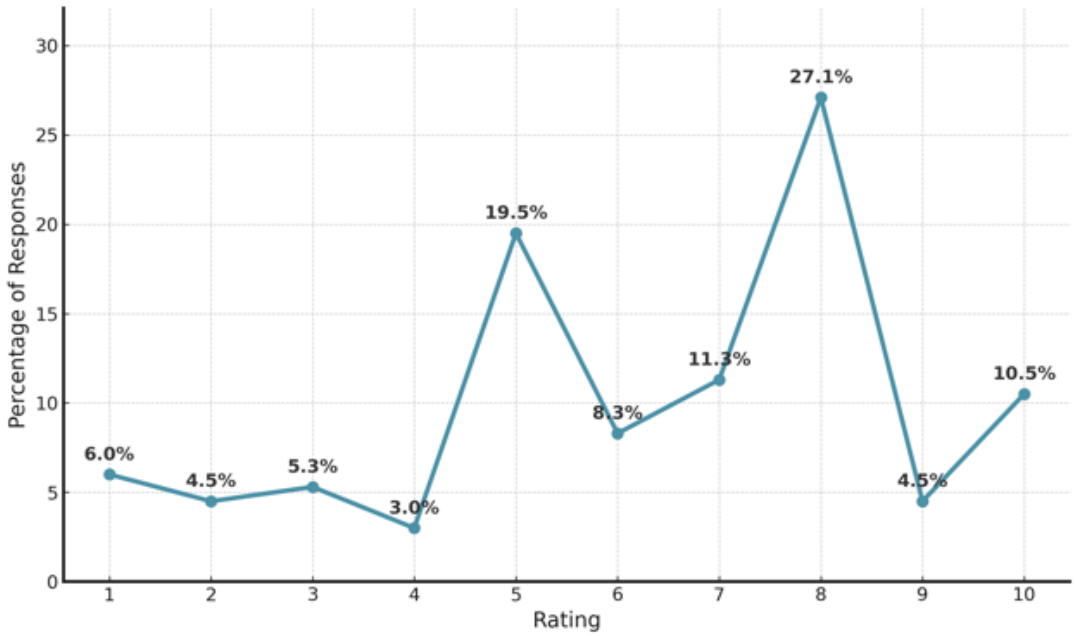

Figure 30: Seasonable light changes on mood

Source: Parastoo Shahpari

Further detailed figures regarding work routines and chronotypes are provided in Appendix, Section 7.2.4.

Investment in Advanced Lighting Solutions:

- 39% of participants expressed a willingness to invest in advanced, energy-efficient lighting solutions. However, 50% said they might consider an investment if they better understood the benefits, indicating that awareness is key to motivating remote workers to improve their work environments. (Figure 31)

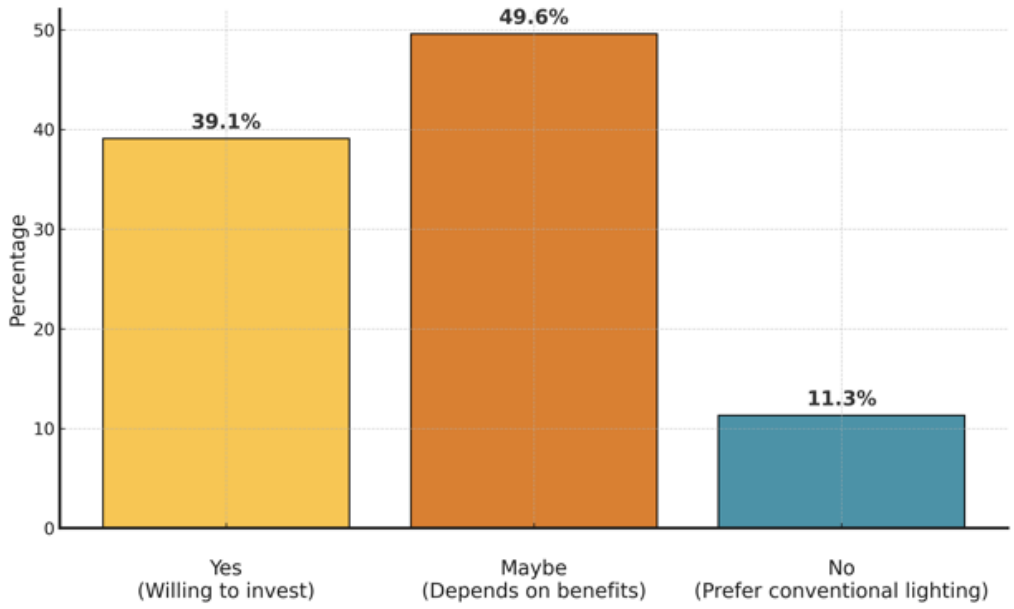

Figure 31: Willingness to invest in advanced lighting solution

Source: Parastoo Shahpari

- 22% of respondents had no knowledge of lighting's impact on health and productivity, and 47% had only partial knowledge. (Figure 32) In Portugal, 43% had partial knowledge and 18% were unaware, while in Iran, 49% had partial knowledge and 30% were unaware.

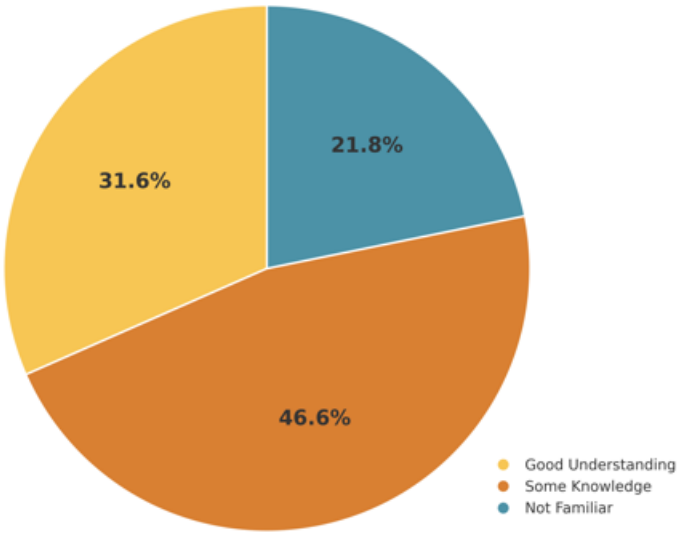

Figure 32: Knowledge of lighting's impact on health and productivity

Source: Parastoo Shahpari

In Portugal, 60% of remote workers were open to investing in energy-efficient lighting solutions once they understood the benefits. In Iran, 45% believed that long-term energy savings justified the investment, indicating a potential demand for advanced lighting solutions.

Further detailed figures regarding investment in advanced lighting solutions, are provided in Appendix, Section 7.2.5.

In response to the question on lighting discomfort in home-offices, participants highlighted five key areas of concern. The table below summarizes these themes with representative responses from participants. (Table 1)

Table 1: Lighting-related discomforts in home-offices environments

Theme	Summary	Sample Responses
Control and Adjustability Preferences	Control over light intensity and color was essential for reducing discomfort and enhancing focus.	- *"I would like to be able to adjust the light intensity."* - *"I believe you should be able to adjust the light in your home office, and it doesn't matter if it's natural sunlight or artificial light."*
Seasonal and Natural Light Variability	Participants noted the need for lighting that adjusts to seasonal changes, especially during overcast months.	- *"Live in Sweden which means from Nov-Apr is overcast. I need light that brings back sun to my life during those dark months."* - *"At some parts the lighting is poor, especially on rainy days when the weather is cloudy..."*
Physical Discomfort and Visual Strain	Eye strain, headaches, and fatigue were commonly due to inadequate or intense lighting.	- *"Fatigue associated with insufficient artificial lighting at night."* - *"Currently, the light source on my desk emits direct light, which often causes visual discomfort..."* - *"Too much artificial light bothers me... it causes dizziness, and I feel nauseous."* - *"Headache and eye irritation."* - *"During the morning I place my table in front of the big window, and sometimes I get tired of too much natural light in my eyes and I feel my eyes are burning."* - *"fatigue affected by unbalanced lighting."*
Emotional Effects of Poor Lighting	Insufficient lighting was linked to negative emotions, reduced motivation.	- *"The number of light sources in the house are limited, and not enough to light up the space, and it has a feeling of sadness and boredom."* - *"I am an editor, and it is very important for me to be able to reduce the ambient light during the day and control it during the night, so that I don't lose my focus on the monitor and also see everything in the room."*

Ergonomic and Practical Challenges	Reflections, spotlights, and other limitations led to discomfort and frequent adjustments.	- *"Reflections on workspace level are not optimized."* - *"Ceiling spotlights are not the best option."* - *"Because of the light reflection on the laptop, I should often change the settings."* - *"The light from the window on the monitor irritates my nerves."* - *"Yes, sometimes I don't notice the time due to the intensity of my work, and I might be working for an hour or two in a very bad light condition, when slowly the weather gets dark, and I just notice it suddenly and realize that it's dark."* - *"The lighting source I have at home is not mobile, so I cannot change the light to my liking and needs."*

Source: Parastoo Shahpari

In response to the question on whether employers or employees have taken steps to improve home-office environments, participants shared a range of experiences. The table below summarizes the types of support provided by employers and the self-initiated actions taken by employees to enhance their workspace for health and productivity. (Table 2)

Table 2: Employer and employee actions for home-office improvement

Theme	**Summary**	**Sample Responses**
Employer-Supported Equipment and Ergonomics	Some employers provided ergonomic equipment, such as desks and chairs, and occasionally additional equipment like monitors.	- *"The company provides the necessary equipment, monitor, and chair."* - *"They provided things like ergonomic desks or chairs, screens, … but about lighting they haven't done anything."* - *"My employer provided certain products (computer, screen, keyboard, mouse, headphones, and camera), but regarding lighting, nothing was provided."*
Employer Financial Support or Expense Reimbursement	A few employers offered financial support or reimbursement for home-office improvements.	- *"My employer does pay any expense I need to 'support' my home office configuration."* - *"Yes, the company pays for the purchase of tables, chairs, and standard monitors."* - *"Yes, it contributes by providing ergonomic desks and chairs."*
Employer Visits and Work Environment Assessments	Some employees reported that their employer conducted home visits to assess and support their work environment.	- *"I have my manager visiting me at home every couple of months to check my working environment."* - *"Yes, actually. We've been using some methods since last year."*
Self-Supported Adjustments and Purchases	Employees often took personal steps to enhance their workspace, including buying ergonomic	- *"I separated my office from the bedroom, changed my desk to a stand desk."* - *"I recently replaced the light bulbs in the room where I work with more efficient LED bulbs with greater light intensity."*

	furniture, plants, and lighting.	- *"I brought home a big screen and a standing desk anti-fatigue mat."*
Lack of Employer Support for Home-Office Setup	Some participants noted that their employers did not provide any support or improvements for the home-office environment.	- *"My employer has not taken any action."* - *"No, but I want to."* - *"unfortunately they don't, and they say that you can come to the office!"*

Source: Parastoo Shahpari

Many participants reported that their employers provided basic ergonomic office equipment, such as desks, chairs, and monitors, to improve comfort and productivity. In contrast, lighting support was generally overlooked, with several respondents noting that employers did not address this aspect of their home offices. These findings highlight the variability in remote work support across organizations and suggest that addressing lighting, environmental quality, and work-life balance could further enhance remote workers' health and productivity.

Participants shared additional feedback and suggestions regarding lighting products for home-office environments. The table below summarizes the key themes and sample responses provided by participants. (Table 3)

Table 3: Feedbacks and suggestions on lighting for home-offices

Theme	**Summary**	**Sample Responses**
Adaptability and Customization	Participants desired lighting that can adapt to different needs, such as changing intensity, color, and direction.	- *"I think that the light could be adjusted according to needs, and that it could have modes created by the creator instead of the user."* - *"Color adjustment, mobile, height and proximity adjustment."*
Aesthetic Appeal and Comfort	Aesthetics and visual comfort were considered as important as functionality in lighting products.	- *"Aesthetics as equally as important as function."* - *"According to my personal taste, before paying attention to the quality and effect of light, I think about the beauty of the light source."* - *"Old light boxes and lampshades make the space warm and lovely. I think it is not good for work, but if it can be adjusted, it will be great."*
Energy Efficiency and Environmental Impact	There was a focus on energy-efficient and environmentally friendly lighting options, such as solar-powered or low-energy lights.	- *"I think it's important to invest in energy-efficient advanced lighting solutions for home-office environments."* - *"I prefer hidden lights. The more indirect the lights are, the more attractive they are. Solar panel-powered lights are also preferred."*
New Technologies in Lighting	Suggestion for integrating new technologies in lighting products.	- *"Use lights which can be adjusted with a mobile application."* - *"Using artificial light with a combination of warm and cold colors and adjustable intensity is an exciting idea."*

		- *"I enjoy working with a beautiful light source that can be adjusted by direction and intensity."* - *"A personal suggestion is that lighting products were more advanced (such as changing color and light intensity, electrical savings)."*
Indirect and Non-Intrusive Lighting	Suggestions included using indirect lighting sources that provide sufficient light without causing visual discomfort.	- *"It would provide a great focus using indirect lighting sources, but still provide enough light."* - *"I'm going to install LED strips on the ceiling rails to increase the diffuse light in the room at night."* - *"I prefer hidden lights; indirect lighting makes spaces feel more attractive."* - *"I would like the lighting to be inconspicuous, especially when natural light is low."*
Enhanced Natural Light and Minimal Artificial Lighting	Participants emphasized the value of maximizing natural light and using minimal artificial lighting only when necessary.	- *"Maximum natural light."* - *"I find it more useful and effective to use natural light during the day to increase my work efficiency!"* - *"I only use artificial lighting in the winter from 4pm onwards, as I have excellent natural lighting during the day."*
Cost and Accessibility	Some responses highlighted the need for affordable lighting solutions that cater to varied financial situations.	- *"Cheaper lighting products."* - *"In my country, purchasing power has influenced the ideal choice…light design is not my priority."* - *"Due to limited resources, cost-effective lighting is essential."*
Lack of knowledge	Unawareness of the lighting impacts	- *"I wish I could give any suggestions but due to lack of information I can't."* - *"I Don't know the solution."*

Source: Parastoo Shahpari

This table suggests that participants value lighting solutions that are adaptable, aesthetically pleasing, energy-efficient, and non-intrusive. Many respondents emphasize the importance of natural light, with artificial light used primarily as a supplement. There's also a preference for more affordable lighting solutions.

4.1.1.4. Conclusive synthesis

The survey findings provide a comprehensive view of the challenges and preferences that remote workers experience regarding their home-office environments, with a particular focus on lighting. The data reveals that while remote workers recognize the importance of effective lighting, many lack adequate setups and are constrained by limited adjustability and outdated controls. These limitations impact their comfort, productivity, and well-being, highlighting opportunities for improvement.

A significant portion of participants do not have dedicated workspaces, instead using shared spaces for work, rest, and relaxation. This underscores the need for adaptable lighting solutions that can seamlessly shift between functional and ambient modes to support both work and leisure activities. Although most participants positioned their desks near natural light sources, limited access to natural light remains a common issue, with some reporting that it creates glare or strain.

Adjustable lighting emerged as a top priority, yet over half of the participants could not modify their lighting's color or intensity. This lack of customization contributes to common issues such as eye strain, headaches, and fatigue. Moreover, there is a clear preference for warm lighting, with many expressing a desire for control options that adapt to different tasks and times of day. However, familiarity with advanced lighting technology remains low, with most respondents favoring traditional physical switches over newer methods like motion sensors or mobile app controls. This indicates a need for user-friendly technology integration that bridges the gap between familiarity and innovation.

Seasonal light variations were also noted to impact mood, particularly in regions with extended periods of cloudy weather. Participants expressed a desire for lighting that could mimic natural light changes, especially during darker months, suggesting that dynamic lighting solutions could help mitigate seasonal mood shifts and improve mental well-being.

While there is a moderate willingness to invest in advanced lighting solutions, a substantial portion of participants would consider such investments only if they better understood the benefits. This points to a knowledge gap in the awareness of lighting's impact on health and productivity, indicating that educational efforts could play a pivotal role in encouraging the adoption of improved lighting setups.

In conclusion, these findings highlight a clear demand for adaptable, energy-efficient, and customizable lighting solutions that can cater to the diverse needs of remote workers. Addressing gaps in awareness and integrating intuitive technology will be crucial in helping individuals create home-office environments that promote health, comfort, and productivity. By focusing on solutions that bridge the gap between traditional and advanced lighting options, employers and lighting designers can enhance the remote work experience and foster a more supportive and effective work environment at home.

4.1.2. Cultural probes

4.1.2.1. Introduction

"What I hear, I forget. What I see, I remember. What I do, I understand"

(Fulton Suri, 2003, as cited in Mattelmäki, 2006, p. 67).

In addition to the questionnaire, it was necessary to gather more detailed information about the lifestyle, perceptions, and environmental interactions of remote workers. One of the limitations in this research was the challenge of accessing the daily experiences and mental and physical states of employees working remotely from their homes. Direct, continuous observation was not feasible. To capture these complex aspects of their life and work experiences, the cultural probes method was employed. This approach allowed to collect richer qualitative data, offering insights into the employees' mental and physical well-being, their relationship with their workspace environment, and their exposure to and interaction with natural and artificial light in their home-offices. As described, "Cultural probes gather insights into users' experiences, attitudes, and needs, particularly in settings where researchers cannot be present, allowing participants to reflect on and interpret their own experiences." (Mattelmäki, 2006, p. 59)

Additionally, the use of cultural probes encouraged remote workers to become more mindful of their home-office environment, drawing attention to the indoor factors that impact their work experience. "The probe tasks can help users to observe their experiences from different angles" (Mattelmäki, 2006, p. 60). This approach enabled the collection of qualitative data, offering a richer and more accurate understanding of the conditions and experiences of remote workers. The cultural probes provided insights into their work environments by encouraging participants to document daily interactions with their spaces and reflect on elements such as lighting, comfort, and overall well-being through diaries and photographs. This qualitative method complemented the quantitative data gathered from the questionnaire, creating a more comprehensive view of the remote work experience.

4.1.2.2. Preparation

To gain insight into the experiences and behaviors of remote workers in their home-office environments, and to identify environmental factors influencing their mood and health, a digital kit was designed, comprising daily tasks over the course of one week. This kit prompted participants to observe and document their workspace and emotional responses through diaries and photographs.
Email was used for all communication to ensure consistency and simplicity in the interaction, enhancing participant engagement. This format also allowed participants to reach out with questions, fostering a supportive environment that encouraged openness and reflection.

Mattelmäki (2006) notes that probe tasks help users reflect on their experiences, ideally with 5–10 participants. Nine remote workers participated in this study, completing brief daily tasks over the course of one week. Each participant received tasks via email, with new tasks sent daily. The initial

instructions included basic questions such as participants' name, age group, remote job role, and whether they had a dedicated workspace or used the same room for both work and sleep.

The first task was repeated each day: participants were asked to stop their work, take a photo of their workspace (focusing on their desk), document their immediate feelings, and note any influencing factors for what they feel. This repetition served two main purposes:

1. **Awareness Development**: Repeated reflection helped participants become more conscious of environmental factors and the factors that shaped their feelings and potentially helping them recognize recurring issues or sources of discomfort.
2. **Inclusivity for Hybrid Workers**: Given that some participants worked in hybrid arrangements, spending only part of the week at home, the repeated task ensured they could complete it on multiple days, even if they weren't at home every day.

Collecting images and reflections over time also allowed to observe environmental factors that varied, such as lighting and workspace arrangement. (Figure 33)

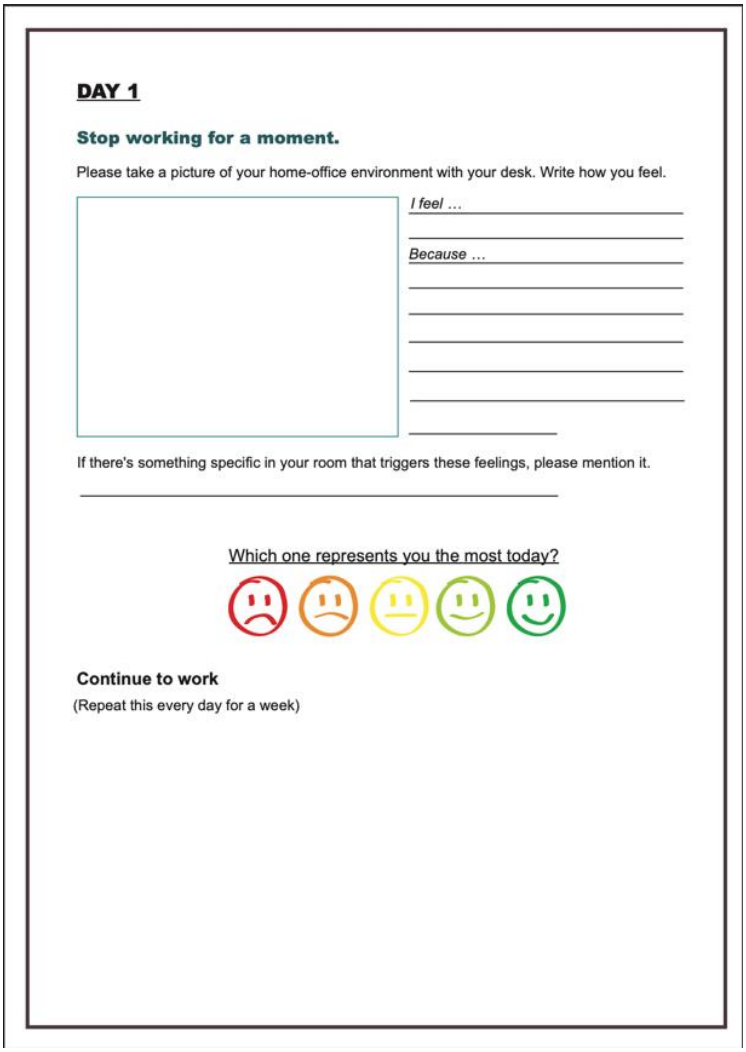

Figure 33: First task

Source: Parastoo Shahpari

The second task changed daily, encouraging participants to consider specific aspects of their workspace needs and preferences. This gradual progression moved participants from observing their environment to envisioning an ideal workspace and potential adjustments. The daily breakdown of tasks was as follows:

- **Day 1**: Complete Task 1
- **Day 2**: List essential elements for their desk.
- **Day 3**: Choose an image from a curated selection that closely resembles their ideal home office, describing appealing elements. (photos of home offices were sent separately to the participants so that they could pay more attention to the details)
- **Day 4**: Find and share an image (from Pinterest or anywhere else) of their ideal home-office setup which promotes focus and feels refreshing.
- **Day 5**: Photograph the most comfortable and uncomfortable areas of their home-office, reflecting on contributing environmental factors.
- **Day 6**: Identify changes they would make to improve their workspace, such as adjustments to lighting, furniture, or decor. On this day, a specific inquiry was made about lighting to see if participants would naturally recognize its impact before this prompt.
- **Day 7**: Summarize insights gained or changes experienced from the week's tasks, reflecting on how these exercises influenced their awareness and satisfaction with their home-office.

The structure of the second task followed a gradual progression: initially, participants focused on their immediate environment, then on identifying aspects of an ideal space, and finally on considering adjustments to bridge the gap between the two. This flow was designed to encourage self-awareness and help participants understand what aspects of their environment could enhance their comfort and productivity.
At the end of each day's task, participants selected an emoji that best represented their mood, ranging from happy to sad. This simple tool allowed for accessible mood tracking, enabling participants to observe daily emotional fluctuations in relation to workspace conditions.

The digital kit designed for the cultural probes is provided in Appendix, Section 7.3

4.1.2.3. Result

The primary goal of cultural probes design was to identify the main characteristics of home-office environments that influence productivity and well-being, with a particular focus on lighting. This approach aimed to provide insights into the following:

- How participants perceive and interact with their home-office spaces on a daily basis.
- Which environmental factors have the greatest impact on their comfort, focus, and mood.
- How these findings can inform human-centered design strategies for lighting home-office products.

The responses analyzed in this study are from remote workers who agreed to participate, offering valuable insights into their perceptions, challenges, and cultural influences. This research aimed to understand the opinions of remote workers and explore how this might shape the design of

future products. By observing their working experiences over the course of a week, the study identified limitations and challenges from the participants' perspectives, highlighting the interplay between individual preferences and cultural contexts.
The findings underscored a strong demand for personalization, a user-centric approach, and innovative design solutions that cater to diverse cultural and individual needs.
This process provided clarity on what they valued most in their workspace, emphasizing the importance of designing future products that account for diversity and foster productivity and satisfaction.

Repeating Task 1 daily helped participants develop greater awareness of how their surroundings influenced their mood and productivity. The table below summarizes the key factors that affected participants' mood and focus. (Table 4)

Table 4: Remote workers who participated in the cultural probes

Participant	Age Range	Gender	Country	Profession	Work Environment	Key Insights
1	26-40	Woman	Poland	AI Marketing and Content Specialist	Different spaces at home	Affected by air quality and kitchen's state; needs separate environment and better lighting
2	41-60	Woman	Portugal	Product Designer (Urban Design)	Living room	Unsatisfied with workspace, needs separate environment; she used shutters to filter light.
4	26-40	Man	Portugal	UI/UX Designer	Use living room	Dissatisfied with workspace, could lead to burnout; reflection issue on computer screen
5	18-25	Woman	Portugal	Design System Working Student	Bedroom and living room	Focused on managing light, she used shutters to filter light; satisfactory workspace overall
6	26-40	Woman	Portugal	Unspecified Role	Separate room	Mood highly influenced by natural light; prefers desk location despite glare issues; used shutters to filter light
7	41-60	Man	Portugal	Business Strategy	Alternates between two rooms	Ergonomics and air conditioning affect satisfaction; needs better cooling
3	26-40	Man	Canada	Software Engineer	Separate room	Satisfied with his workspace, he needed

						to change the color temperature of light
8	26-40	Man	Iran	Video Editor	Separate room	Realized need for less clutter; uses desk lamp
9	26-40	Woman	Iran	Virtual Administrative and Communications Manager	Living room and yard	Satisfied with outdoor space; sometimes uses living room despite poor layout

Source: Parastoo Shahpari

On the third day of the cultural probe tasks, participants were presented with photos of various home-office setups and asked to choose the one that best aligned with their ideal workspace. This task aimed to help participants identify specific elements that contribute to a desirable work environment, focusing on details such as lighting, furniture, and overall atmosphere. (Figure 34)

The photos were intentionally selected, with the second photo specifically chosen to evoke a sense of warmth at first glance. The table below provides an overview of the rationale behind the selection of each home-office setup, as well as participants' feedback on their choices. (Table 5)

Figure 34: Third day task

Source: Parastoo Shahpari

Table 5: Participants feedback on third day task

Photo	Overview	Result	Participant Feedback
1	Cool-toned workspace with ceiling lighting; no desk lamp. Lighting may be annoying and unsuitable for night use	None of the participants chose Photo 1 as their ideal workspace.	N/A

	without color adjustment.		
2	Warm and inviting tones with natural light from a window and warm light from a desk lamp; plants and comfortable furniture.	Most popular choice, selected by 5 participants (56%). Participants appreciated the warm and natural lighting, comfortable setup, and decorative elements.	- *"I thought it was the most attractive at first glance…I like the yellow light, the fact that the window is next to the table is very pleasant."* - *"It aligns closely with my personal beliefs… key elements are the abundance of natural light and warm tones, creating a balanced and harmonious workspace."* - *"The room feels warm, and the window and plants make it comfortable."* - *"It has a light input on the left and directable artificial lighting."* - *"The room feels warm because of the window and plants."*
3	Spacious desk with ergonomic seating, organized shelves, and desk lamps; lacks natural light.	Selected by 2 participants (22%) who valued the large desk, organization, and functional design. They did not mind the lack of natural light.	- *"It has a bigger table and it makes me feel good…the artificial light increases my concentration. It is also good for night work."* - *"The desk is my favorite. I love wide and long desks with a lot of space…I can easily access everything by moving my chair."*
4	Well-organized desk with natural light from the side. The light from the window can cause reflections on the monitor, possibly requiring the use of a curtain. A desk lamp is available.	Selected by 2 participants (22%). Participants appreciated the placement of natural light and comfortable layout.	- *"Because the natural light is in the right place."* - *"The presence of plants gives a sense of freshness to the environment. Second, a big and comfortable chair!"*

Source: Parastoo Shahpari

Common Themes and Insights

- **Importance of Lighting**: Lighting was a primary focus for all participants. Natural light was particularly valued, with many noting that it provides warmth, comfort, and boosts motivation. Artificial lighting was preferred when it complemented natural light with warm tones, as seen in Photo 2. This preference aligns with the 38% of questionnaire respondents who indicated they preferred warm lighting in their workspace.
- **Furniture and Layout**: Participants appreciated functional and comfortable furniture, such as spacious desks and ergonomic chairs, which they felt contributed to a more productive environment, but they didn't mention the necessity of adjustable task lighting or desk lamp.
- **Greenery and Aesthetics**: Decorative elements like plants and organized shelving were seen as enhancing the workspace's appeal, making it feel fresh and inviting. Greenery, in particular, was associated with a sense of well-being and relaxation.

On fourth day participants were asked to share images of home-office setups that make them feel focused and refreshed. A common theme across all the photos was the presence of both natural and artificial light, often creating a warm ambiance, a preference also highlighted by many respondents in the questionnaire who desired a warm or dynamic atmosphere. Additionally, the photos frequently depicted comfortable equipment, such as ergonomic desks and chairs, along with plants, which added a touch of nature to the workspace. (Figure 35)

Figure 35: Ideal home-offices

Source: Parastoo Shahpari

On the fifth day, it was asked from participants to photograph the most comfortable and uncomfortable areas of their home office and explain why they feel this way. One of the participants identified the combination of natural and artificial lighting as the most comfortable aspect of the workspace, describing it as creating a pleasant and productive environment.

On the other hand, the participant found discomfort in using the same space for work and rest. This response highlights the importance of dedicated, well-organized spaces to support both comfort and productivity in a home-office setup. (Figure 36)

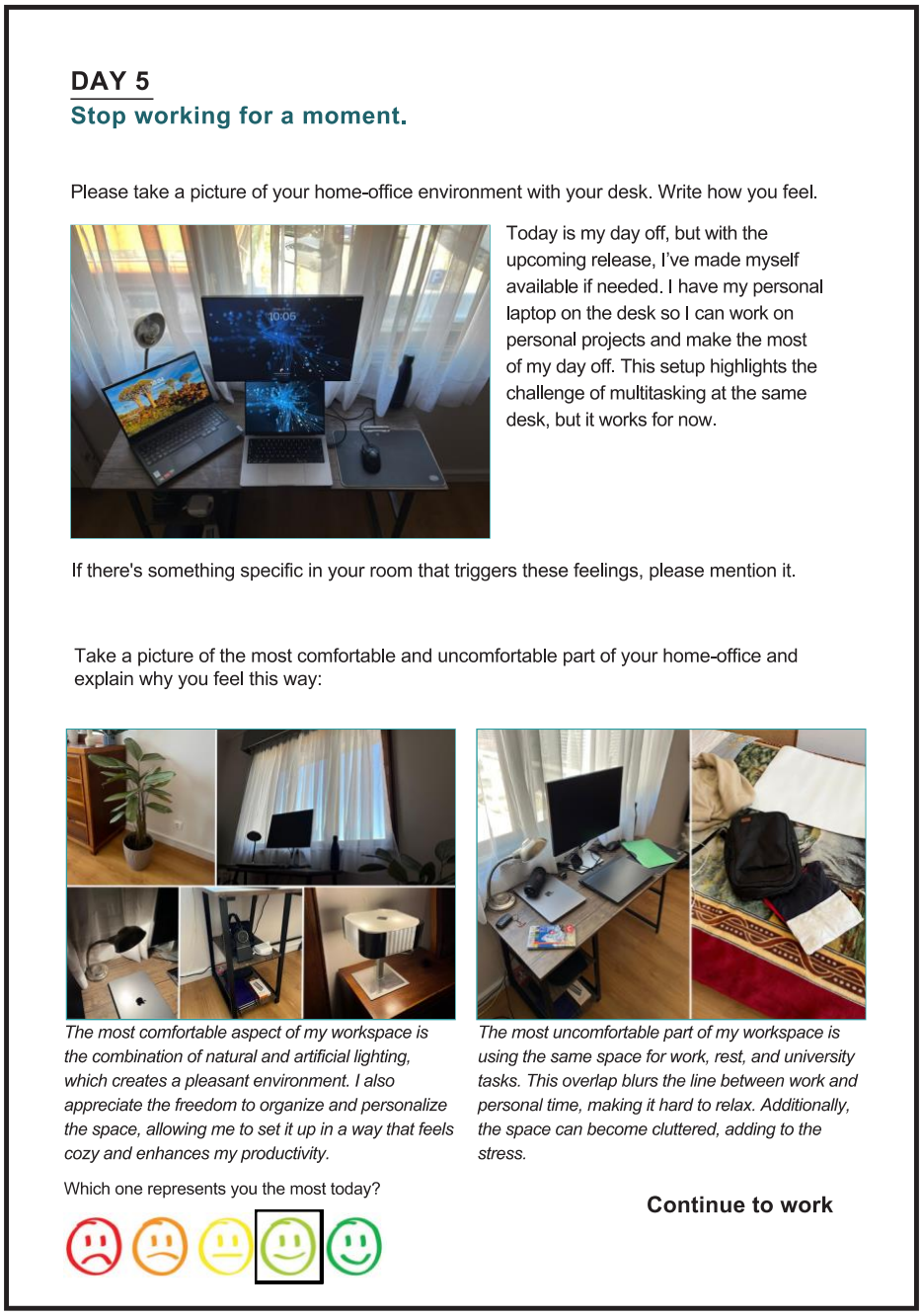

Figure 36:Fifth day task

Source: Parastoo Shahpari

Through cultural probes, participants shared their vision of a workspace that feels comfortable, motivating, and personal. The insights highlight key desires for comfort, focus, personalization, and the significant impact of lighting on productivity and mood. The table below provides a

detailed summary of participants' insights, preferences, and opinions regarding their ideal home-office environment, including suggested enhancements and challenges. (Table 6)

Table 6: Insights and opinions on creating ideal home-offices environments

Section	Focus	Participant Insights	Quotes
Desired Enhancements & Improvements	Lighting Adjustments for Flexibility	Participants emphasized the importance of lighting control that support different tasks and moods.	- *"I could install adjustable blinds to filter the entry of light."* - *"A versatile lamp with both ambient and task lighting could create a soothing atmosphere or brighter lighting for focused work."* - *"The lighting should allow for both concentration and relaxation, making the space feel uniquely mine."*
	Temperature Control and Comfort	Some participants mentioned temperature control as essential for comfort, particularly in warmer climates.	- *"I need an air conditioner because warm weather in Vancouver is really warm inside the home and workplace."* - *"Maybe I'd come up with ways to keep the office refreshed and cool."*
	Need for Dedicated Workspace	Many participants expressed a desire for a separate or designated workspace to create boundaries between work and personal life.	- *"I would have preferred to have a completely separate work desk so that I don't have to arrange everything from the beginning every time I want to start work!"* - *"Separating workplace from other environments in the house."*
Impact of Lighting in Home Office	Natural Light for Energy and Mood	Participants value natural light for its energizing and calming effects, as well as the connection it provides to the outdoors.	- *"A large window lets in plenty of natural light, which feels great, especially in the mornings."* - *"Light gives me energy."* - *"Lighting in my room is more than it should be, makes me motivated to start my day."*
	Adjustable Artificial Lighting for Focus	Many participants find that yellow light is relaxing at night, while white or blue light helps them feel more alert.	- *"Yellow light gives me peace of mind, especially when working at night. White and blue light make my eyes feel more alert."* - *"If I add a white color to this lamp so I can have a neutral environment, not just yellow, I would be really happy."* - *"If I had a little balcony full of plants and I put strip lighting it would have doubled my energy."*
	Challenges with Lighting Control	Some participants reported challenges with current lighting setups, citing limited options and difficulty with ceiling lighting.	- *"I don't have any lighting despite that lighting is really important to me."* - *"I would have liked to have a separate room with better lighting, as the current lighting is really poor."*
Desired Workspace Feelings	Feeling of Motivation and Belonging	Participants desire a workspace that fosters focus, comfort, and a sense of belonging. They value an environment	- *"I want to feel energized, happy, and motivated."* - *"In my home-office space, I should feel comfortable, focused, and inspired."* - *"I want to feel the place belongs to me."*

		where they feel motivated, happy.	

Source: Parastoo Shahpari

Some participants expressed that their artificial lighting was insufficient, particularly when working at night, leading to discomfort and reduced productivity. Participants showed distinct preferences for lighting types and color temperatures. Warm light was favored for its calming and relaxing effect, making it suitable for evening work, while cooler light was appreciated for enhancing focus and productivity during the day. However, cooler light was also noted to cause discomfort if used for extended periods.

Many participants expressed a desire for adjustable lighting options that could transition between ambient and task lighting, allowing them to tailor their workspace to different needs and times of day. Despite recognizing the positive effects of lighting on their mood and productivity, the photos of their desk revealed that most participants lacked task or desk lighting in their home offices. In cases where task lighting was present, it often lacked advanced features such as adjustability in color temperature or brightness. (Figure 37)

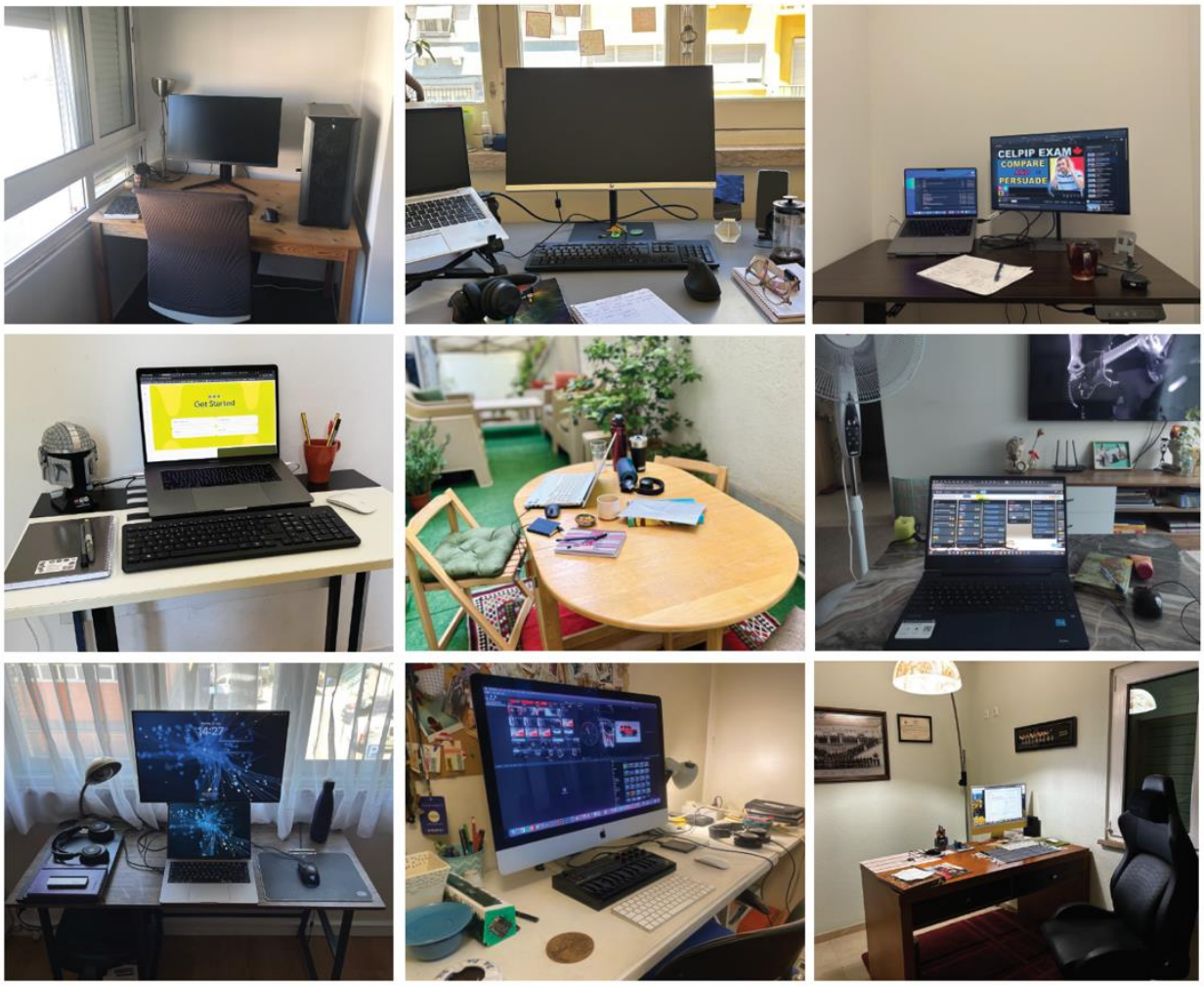

Figure 37: Participants desk arrangements

Source: Parastoo Shahpari

Additionally, the use of shutters to control the intensity of natural light was evident in several setups. While this allowed participants to minimize glare, it also had the potential to affect their mood, as it reduced the influx of natural light, which many participants found energizing and uplifting. These findings underscore the importance of customizable lighting solutions to enhance the comfort and functionality of home-office environments. (Figure 38)

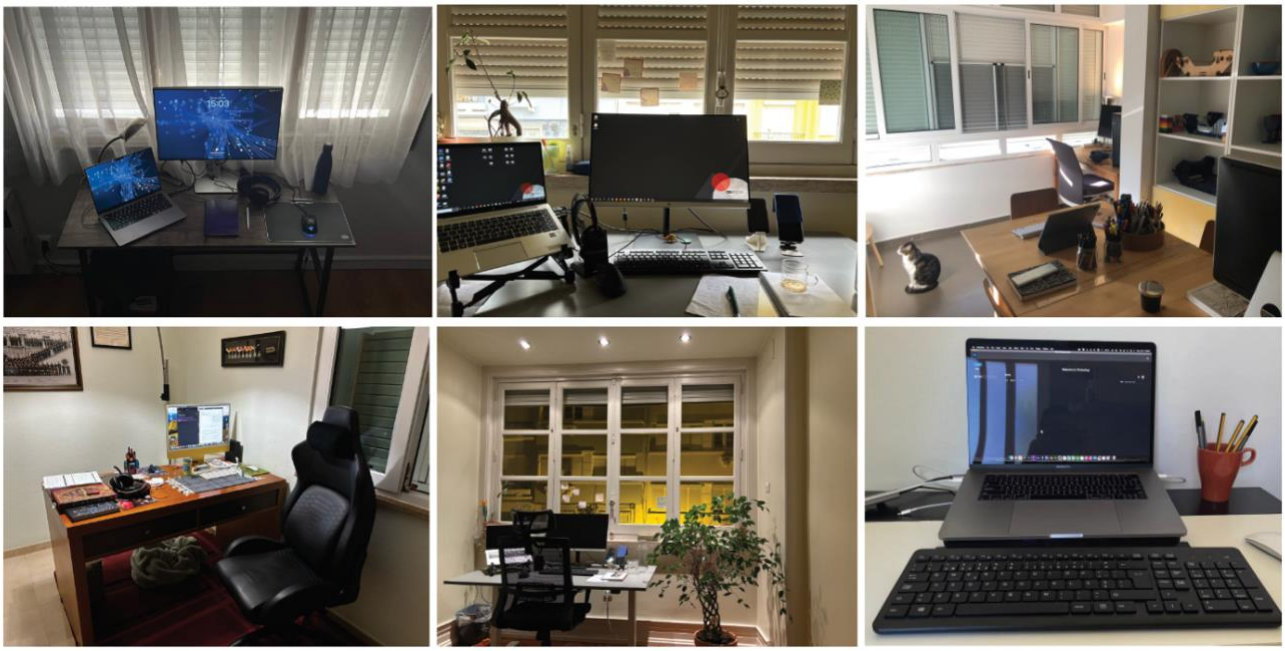

Figure 38:Use of shutters to minimize glare

Source: Parastoo Shahpari

By the final day, participants had developed greater awareness of IEQ factors in their workspaces that influence their mood and comfort. They gained valuable insights into their specific needs for creating a comfortable and productive environment, identifying key elements that contribute to a supportive workspace. Notably, lighting was not spontaneously identified by all participants until prompted, indicating that while it significantly impacts productivity, its importance may often go unrecognized without deliberate reflection.

- *"This process encouraged me to closely examine and critically think about the factors that influence my work performance and mood…This reflection not only helped me identify specific improvements to make but also allowed me to discover what I genuinely enjoy and need to feel comfortable and productive. It has been eye-opening to understand how these elements affect my overall well-being."*

- *"By making these tasks over the past week, l realized that there were somethings in my home office that needed to be changed or added, like a better cooling system, so I think these tasks have help me improve my home office environment."*
- *"This week I tried to focus on the details of my home-office. A place that I spend eight hours of my life daily."*
- *"The existence of a fixed workspace and the need to filter light."*
- *"When I wanted to take a picture in the middle of work, I noticed my surroundings more."*
- *"It made me to think more about my workspace and I understood how important it is to make changes and improvements…I should make a more serious decision about it."*
- *"I've realized how much ventilation impacts my mood!"*

4.1.2.4. Conclusive synthesis

The cultural probes provided a deeper understanding of the environmental and design factors that influence productivity and well-being in home-office setups. Key themes emerged from participants' reflections, emphasizing the significance of lighting, workspace organization, and environmental conditions.

Lighting was identified as a critical component of a supportive work environment. Natural light was widely valued for its positive impact on energy and mood, while artificial lighting was seen as essential for creating a functional and adaptable workspace. The need for adjustable lighting, both in intensity and color temperature, was frequently highlighted, yet many participants lacked these options. Challenges with managing natural light, such as glare, and the use of shutters to mitigate it, also revealed the complex relationship between lighting and mood.

Workspace Organization played a vital role in participant satisfaction, with ergonomic furniture and greenery enhancing comfort and focus. Participants expressed the importance of a well-structured environment that supports both productivity and relaxation. However, the overlap between work and personal spaces remained a significant challenge for many, emphasizing the need for dedicated work areas.

The cultural probes also heightened participants' awareness of IEQ factors, encouraging them to reflect on their workspace needs and preferences. While some aspects, such as lighting, were not initially prioritized, the tasks revealed their importance in creating a functional and enjoyable work environment.

Overall, the findings underline the importance of human-centered design in home-office setups, focusing on flexible lighting solutions, ergonomic furniture, and dedicated, well-organized spaces. These insights provide a foundation for improving remote work environments, fostering both productivity and well-being.

4.2. Generative

In the Generative Phase of this study, **empathy maps** and **user journey maps** were utilized to gain a comprehensive understanding of remote workers' interactions with their home-office lighting environments. Empathy maps served as a foundational tool in capturing users' emotional and cognitive states (what they say, think, feel, and do) providing valuable insights into their motivations and pain points. This approach fosters a user-centric design process by ensuring that solutions are tailored to actual user experiences. (Figure 39)

Building upon the insights gained from empathy map, user journey maps offer a visual representation of the user's experience, documenting their actions, thoughts, and emotions at each interaction point. Richardson (2010) emphasizes that user journey maps are effective tools for improving customer experience by providing insights into user interactions and highlighting areas for enhancement.

4.2.1. Empathy map

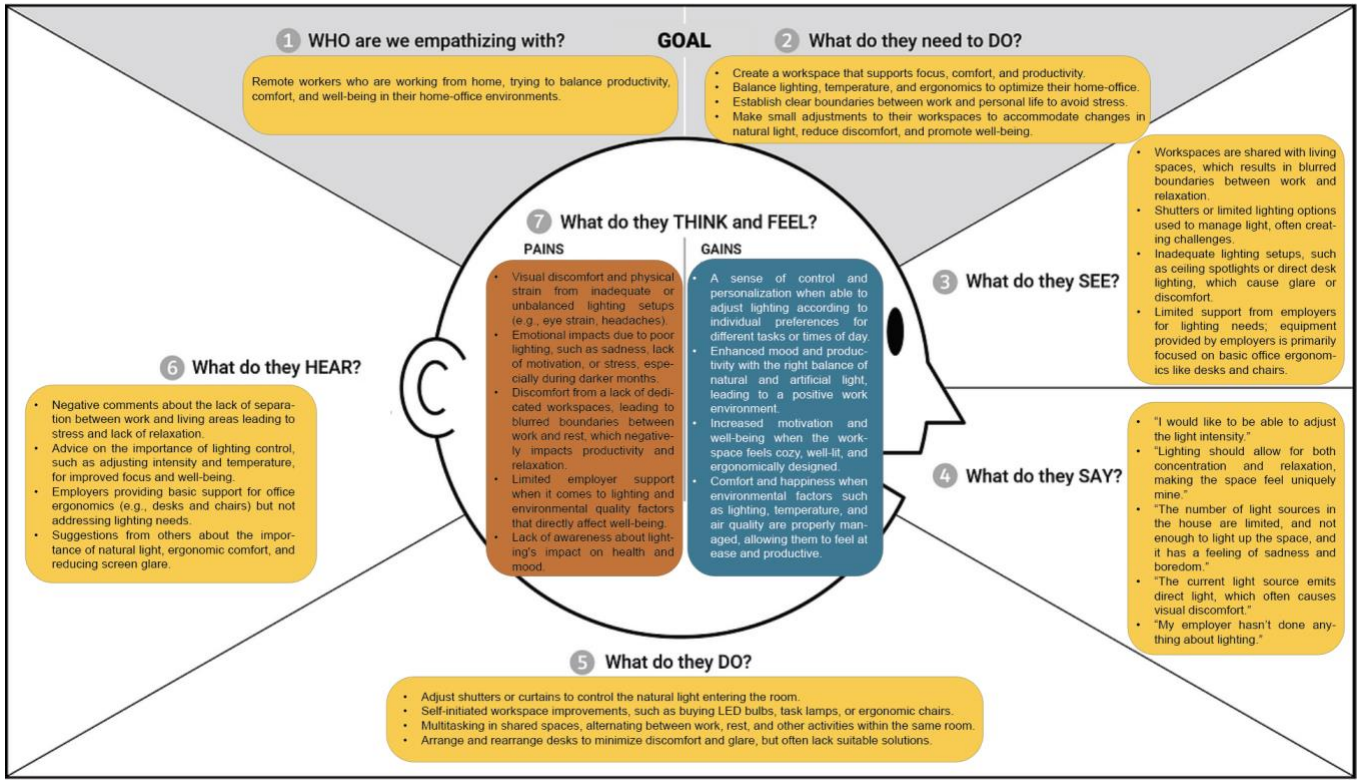

Figure 39: Empathy map

Source: Parastoo Shahpari

1. Who are we empathizing with?

We are empathizing with remote workers who are WFH, trying to balance productivity, comfort, and well-being in their home-offices

2. What do they need to do?

- Create a workspace that supports focus, comfort, and productivity.
- Balance lighting, temperature, and ergonomics to optimize their home-office.
- Establish clear boundaries between work and personal life to avoid stress
- Make small adjustments to their workspace to accommodate changes in natural light, reduce discomfort, and promote well-being.

3. What do they see?

- Workspaces are shared with living spaces, which results in blurred boundaries between work and relaxation.
- Shutters or limited lighting options used to manage light, often create challenges.
- Inadequate lighting setups, such as ceiling spotlights or direct desk lighting, which cause glare or discomfort.
- Limited support from employers for lighting needs; equipment provided by employers is primarily focused on basic office ergonomics like desks and chairs.

4. What do they say?

- *"I would like to be able to adjust the light intensity."*
- *"Lighting should allow for both concentration and relaxation, making the space feel uniquely mine."*
- *"The number of light sources in the house are limited, and not enough to light up the space, and it has a feeling of sadness and boredom."*
- *"The current light source emits direct light, which often caused visual discomfort."*
- *"My employer hasn't done anything about lighting."*

5. what do they do?

- Adjust shutters or curtains to control the natural light entering the room.
- Self-initiated workspace improvement, such as buying LED bulbs, task lamps, or ergonomic chairs.
- Multitasking in shared spaces, alternating between work, rest and other activities within the same room.
- Arrange and rearrange desk to minimize discomfort and glare, but often lack suitable solutions.

6. What do they hear?

- Negative comments about the lack of separation between work and living areas leading to stress and lack of relaxation.
- Advice on the importance of lighting control, such as adjustment intensity and temperature, for improved focus and well-being.

- Employers providing basic support for office ergonomics like desks and chairs but not addressing lighting needs.
- Suggestions from others about the importance of natural light, ergonomics, comfort, and reducing screen glare.

7. What do they think and feel?

Pains

- Visual discomfort and physical strain from inadequate or unbalanced lighting setups like eye strain and headaches
- Emotional impacts due to poor lighting, such as sadness, lack of motivation, or stress, especially during darker months.
- Discomfort from lack of dedicated workspaces leading to blurred boundaries between work and rest, which negatively impacts productivity and relaxation.
- Limited employers support when it comes to lighting and environmental quality factors that directly affect well-being.
- Lack of awareness about lighting's impacts on health and moods.

Gains

- A sense of control and personalization when able to adjust lighting according to individual preferences for different tasks or times of day.
- Enhanced mood and productivity with the right balance of natural and artificial light, leading to positive work environment.
- Increased motivation and well-being when the workspace feel cozy, well-lit, and ergonomically designed.
- Comfort and happiness when environmental factors such as lighting and temperature are properly managed, allowing them feel at ease and productive.
-

4.2.2. User journey maps

Maria represents remote workers who struggle to balance their professional and personal lives in shared living spaces. Like many, she faces challenges with lighting that fails to adapt to different tasks and moods. Her journey highlights the need for customizable and seamless lighting solutions to support productivity and relaxation. (Figure 40)

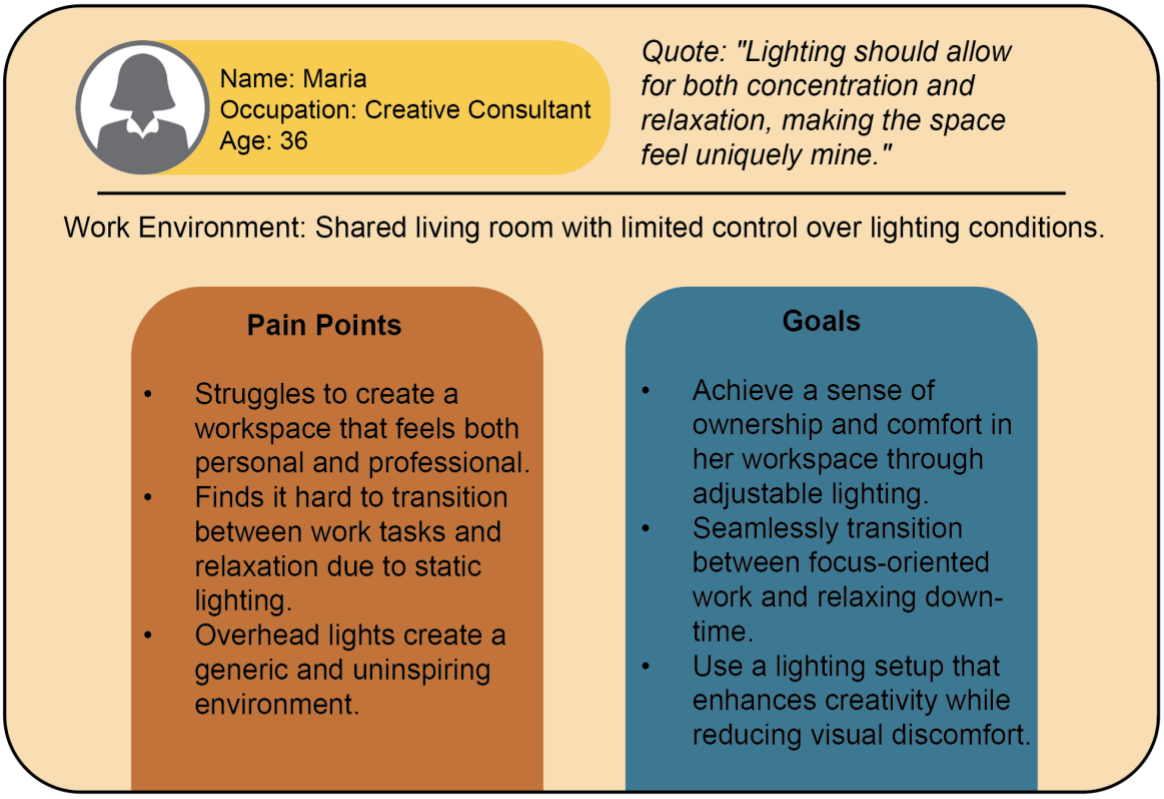

Figure 40: Maria's persona card

Source: Parastoo Shahpari

Persona 1: Maria

- Name: Maria
- Age: 36
- Occupation: Creative Consultant
- Work Environment: Shared living room with limited control over lighting conditions.

Details:

Maria lives in Belém, a picturesque neighborhood close to the Tagus River and the Centro Cultural de Belém (CCB). Her apartment benefits from large west-facing windows that allow ample natural light in the afternoon, creating a warm and inviting space. However, during peak sunlight hours, the light becomes too intense, causing glare and making it difficult to focus. To control the excess light, Maria often uses shutters, adjusting them throughout the day to balance natural light levels. While the shutters help manage brightness, they also darken the room, leaving it feeling dull and uninspiring.

Maria shares her home with her partner, a graphic designer, and their playful cat, Luna, who often lounges near her workspace. Her desk, positioned in the shared living room, doubles as a dining area in the evenings, meaning the space must serve multiple purposes. She enjoys taking breaks for inspiration at the nearby CCB museum or walking along the Tagus River. Despite her love for creativity, the static lighting in her workspace creates a challenge, as it fails to adapt to her dynamic tasks or provide a personalized ambiance.

Scenario:

Maria begins her day by partially opening the shutters to let in soft morning light while avoiding harsh glare. As the afternoon sunlight grows stronger, she closes the shutters halfway, leaving the room dim and uninspiring. During work hours, the static overhead lights feel too generic for her creative tasks, making it hard to concentrate or brainstorm. By the evening, Maria struggles to transition her shared workspace into a relaxing environment for dinner or leisure time, as the harsh lighting disrupts the cozy atmosphere she desires.

Maria needs a lighting solution that adapts to the natural light shifts in her apartment while supporting her creativity and providing a calming ambiance for the evenings. Adjustable lighting that complements her use of shutters would help her create a workspace that feels both professional and personal, inspiring her throughout the day.

Figure 41 represent user journey map for Maria

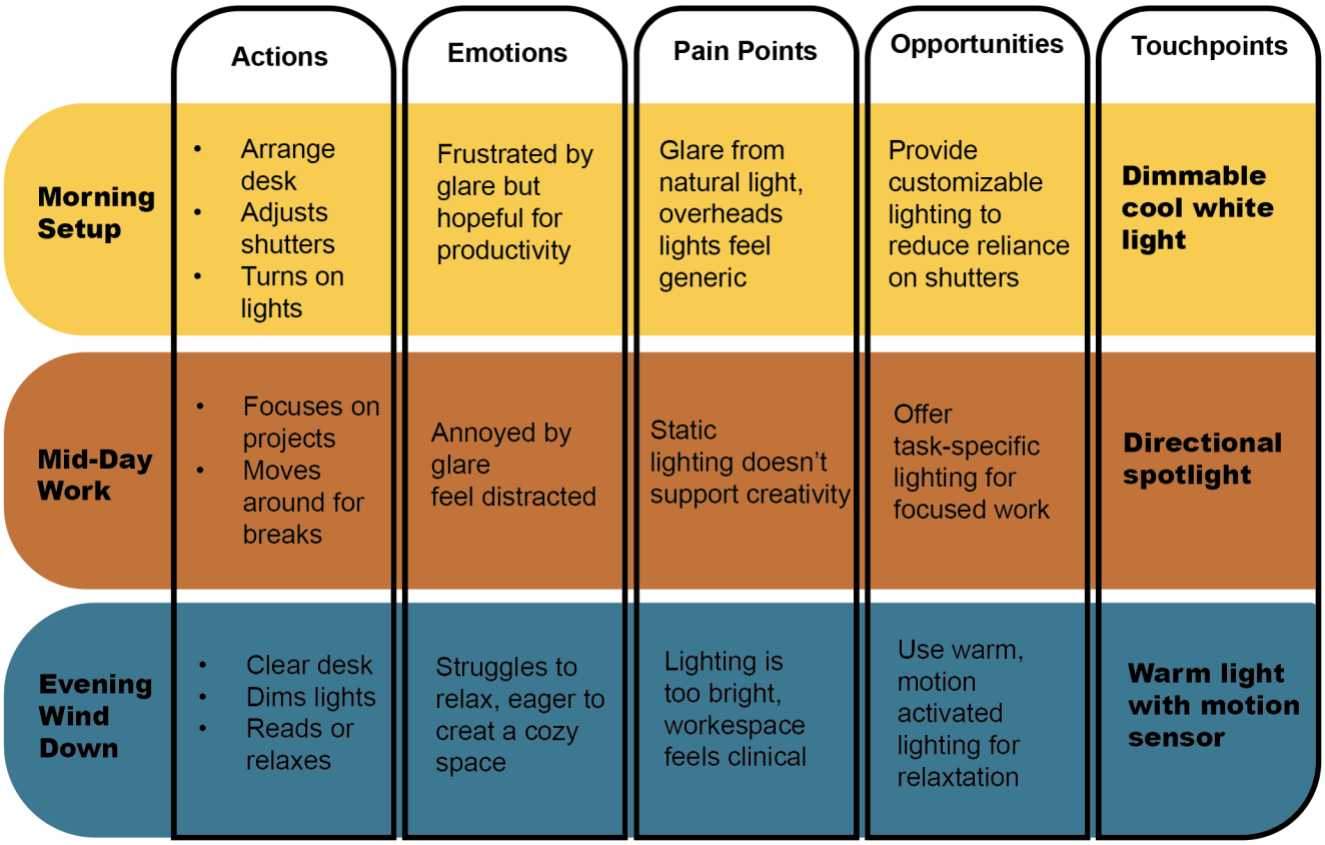

Figure 41: Maria's User journey map

Source: Parastoo Shahpari

David reflects remote workers juggling multiple roles in multi-purpose spaces. He faces discomfort from harsh lighting, uneven natural light, and the inability to transition his workspace into a relaxing environment. His journey underscores the importance of adaptive, visually comfortable lighting solutions that promote focus, reduce strain, and create a soothing ambiance for work-life balance. (Figure 42)

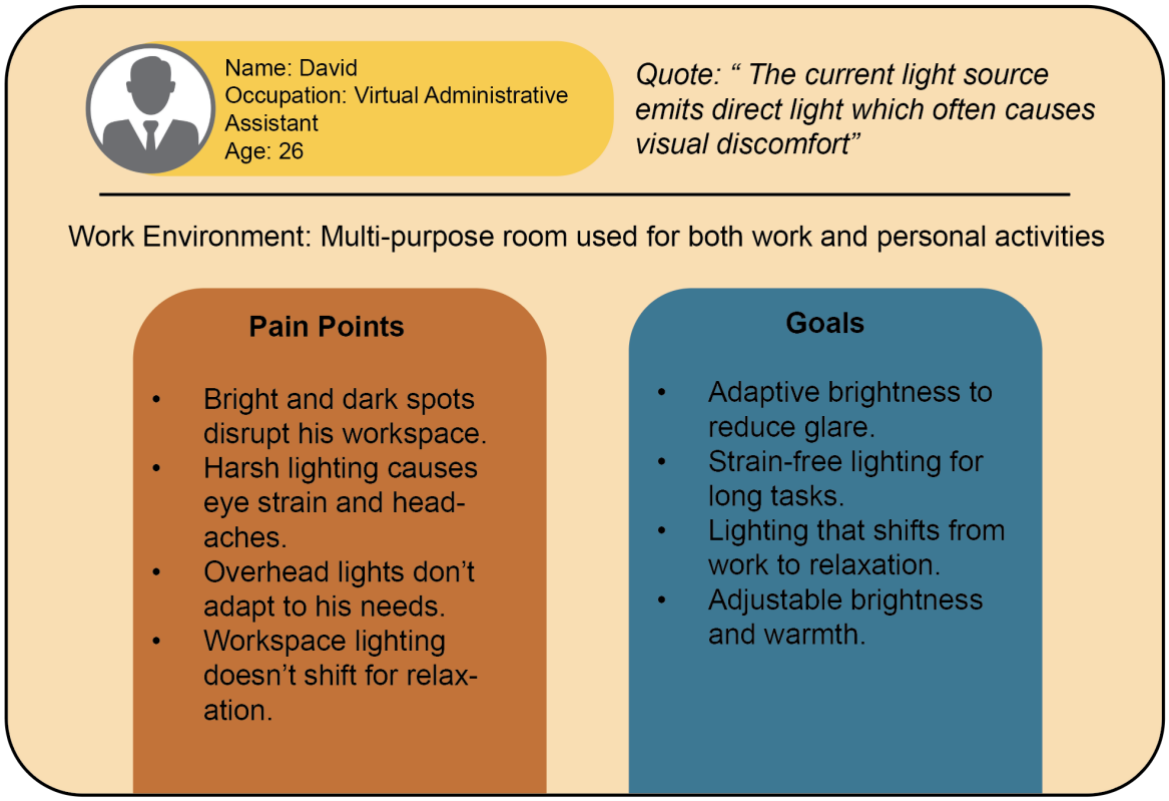

Figure 42: David's persona card

Source: Parastoo Shahpari

Persona 2: David

- Name: David
- Age: 26
- Occupation: Virtual Administrative Assistant
- Work Environment: Multi-purpose room used for both work and personal activities.

Details:

David lives in a two-bedroom apartment in Areeiro, a neighborhood known for its residential charm but with denser urban planning, which limits natural light during certain hours of the day. His apartment faces east, meaning morning sunlight floods his workspace but fades in the afternoon, often leaving his desk in shadow. He shares the apartment with a roommate and has no pets. David prefers to keep a tidy workspace and enjoys listening to instrumental music while working.

David is also culturally engaged and frequently visits nearby cafés or takes walks in Alameda Park, a green area close to his home. His workspace is in the living room near a window but lacks adaptable lighting, making it hard for him to transition between professional tasks and relaxation.

Scenario:

David starts his day by arranging his desk and adjusting the shutters to let in as much natural light as possible. However, as the day progresses, the lighting becomes uneven due to the limited exposure of his east-facing window. Overhead lights create harsh glare on his screen, causing frequent eye strain. By evening, his workspace feels clinical, and the lighting doesn't shift to a more relaxing tone, making it difficult for him to unwind after work. David desires a lighting setup that adapts to these changes, offering bright, glare-free light during work and warm, calming light in the evenings.

Figure 43 represent user journey map for David

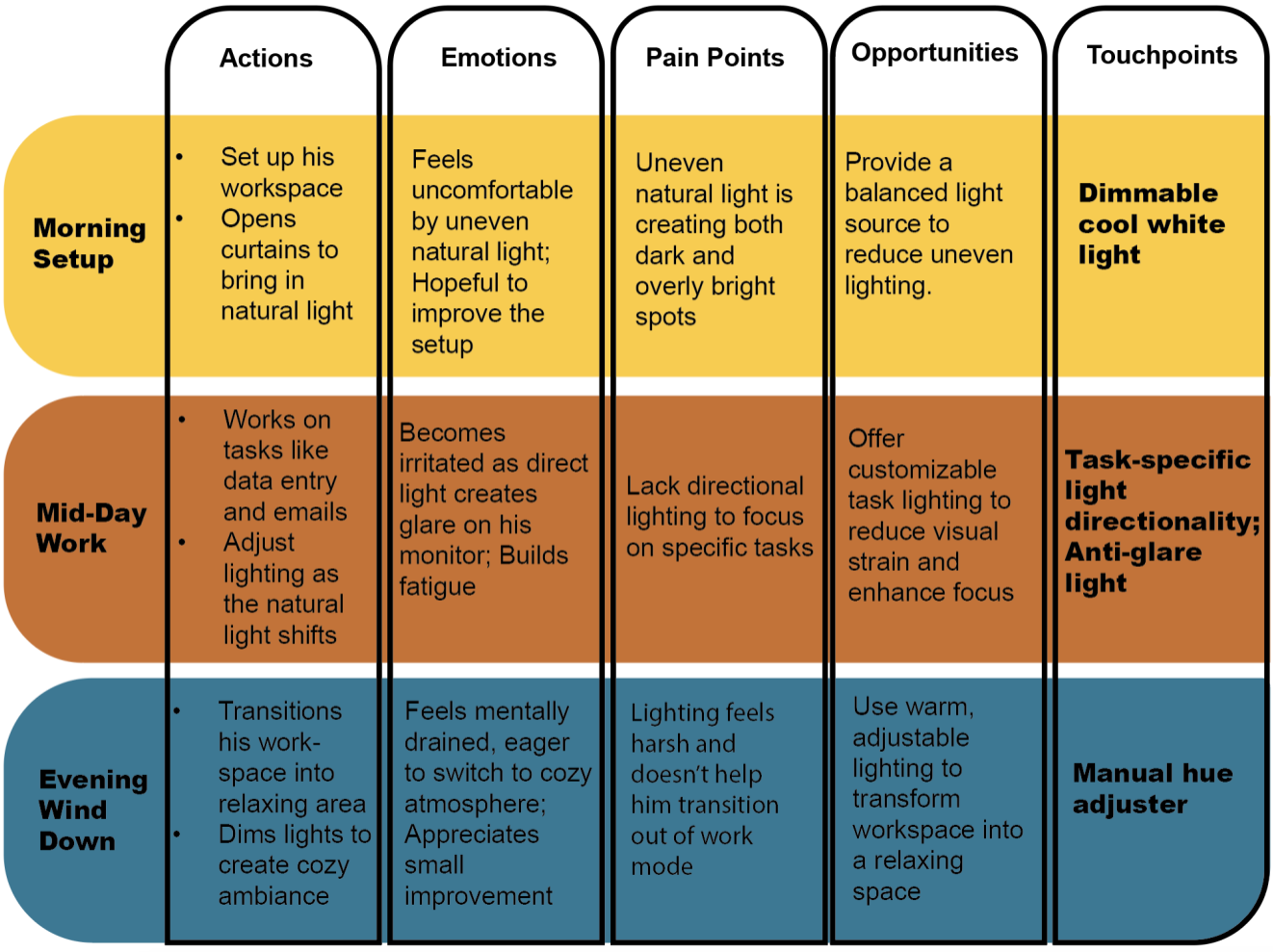

Figure 43: David's user journey map

Source: Parastoo Shahpari

4.2.3. Conclusion

The generative phase of this study provided valuable insights into the needs, behaviors, and challenges faced by remote workers in their home-office environments. By employing empathy maps and user journey maps, this phase highlighted key aspects that influence the design of effective, user-centric lighting solutions.

Through the empathy map, the study identified that remote workers face significant challenges in balancing productivity, comfort, and well-being due to inadequate and static lighting setups. Common pain points included visual discomfort, emotional impacts of poor lighting, and difficulties transitioning between professional and personal tasks in shared, multi-purpose spaces. These insights underscore the necessity of designing adaptable lighting systems that respond to the dynamic needs of remote workers.

The user journey maps, grounded in scenarios for personas like Maria and David, further emphasized the importance of personalized and adaptive lighting solutions. Both scenarios revealed how natural light patterns and static artificial lighting impact productivity, creativity, and relaxation. Maria's struggle with controlling intense afternoon sunlight and David's discomfort from uneven lighting throughout the day reflect the critical need for lighting systems that harmonize with natural light shifts, reduce glare, and create a comfortable ambiance.

This phase demonstrated that cultural factors, environmental conditions, and personal preferences all influence the effectiveness of workspace lighting. The findings suggest a strong demand for innovative, human-centric designs that prioritize flexibility, well-being, and user empowerment. By addressing these needs, future lighting solutions can foster an environment that supports productivity, comfort, and a healthier work-life balance for remote workers.

4.2.4. Mood Board

A mood board was developed to explore the visual and emotional tone of the lighting solutions, informed by user insights gathered during the exploratory phase. This step provided inspiration for the concept generation phase, ensuring the designs aligned with user needs. (Figure 44)

Figure 44: The mood board

4.2.5. Sketches

Following the mood board analysis, a series of sketches were created to visually explore and refine the conceptual framework. These sketches illustrate the initial ideas and structural organization of key elements, helping to establish the foundation for the theoretical contextualization. (Figures 45, 46, 47)

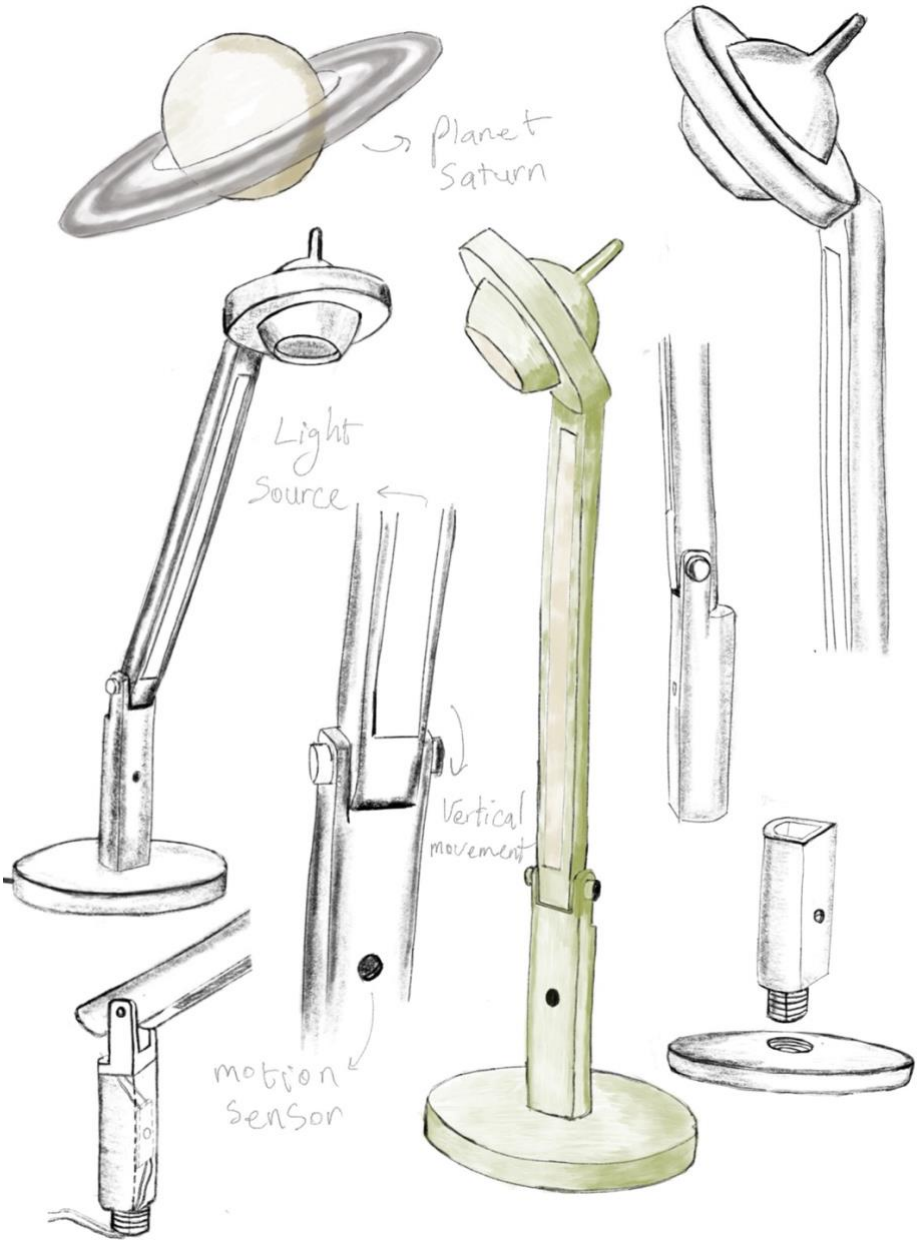

Figure 45: Initial sketch outlining key lighting components

Source: Parastoo Shahpari

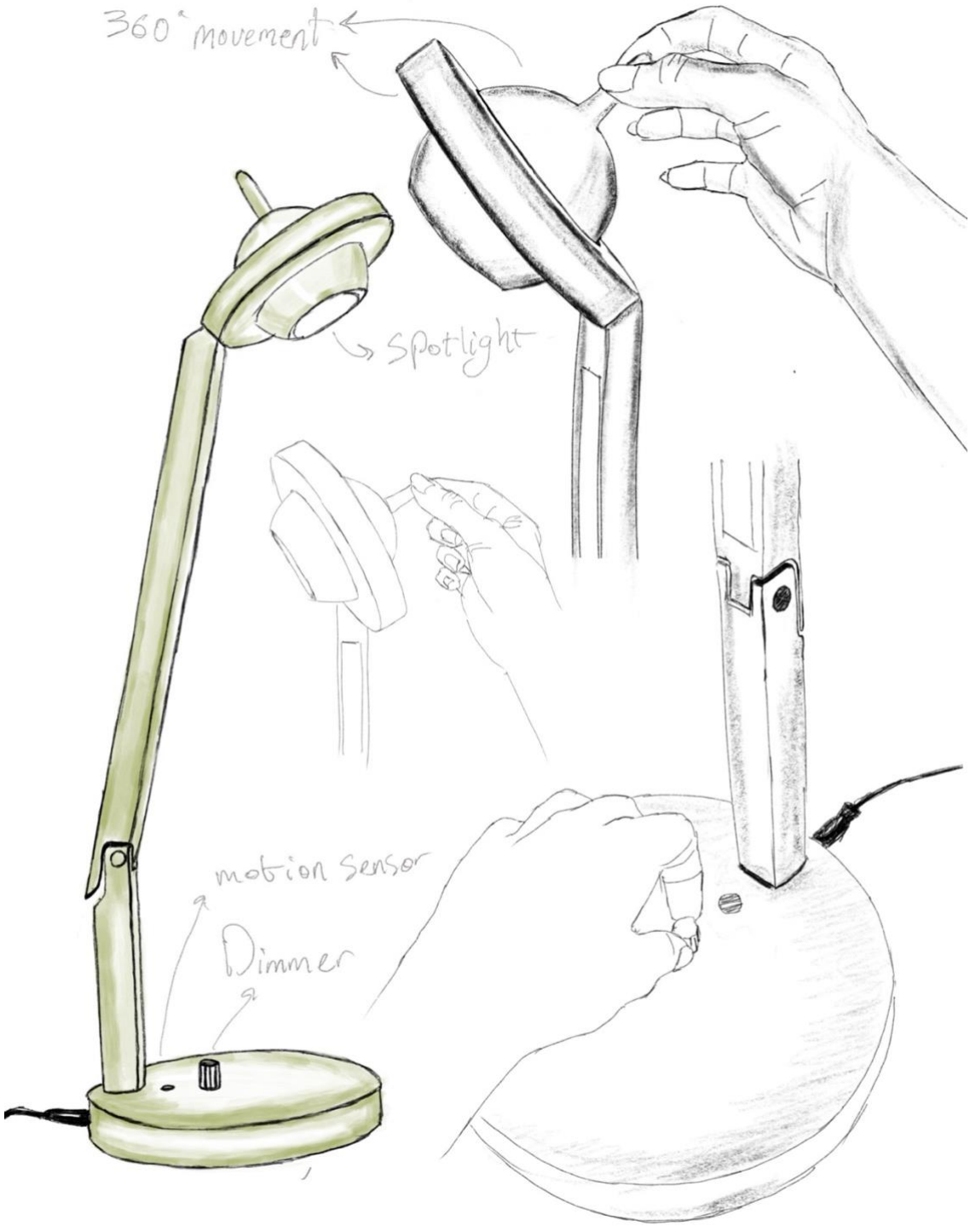

Figure 46: Sketches after the refinements

Source: Parastoo Shahpari

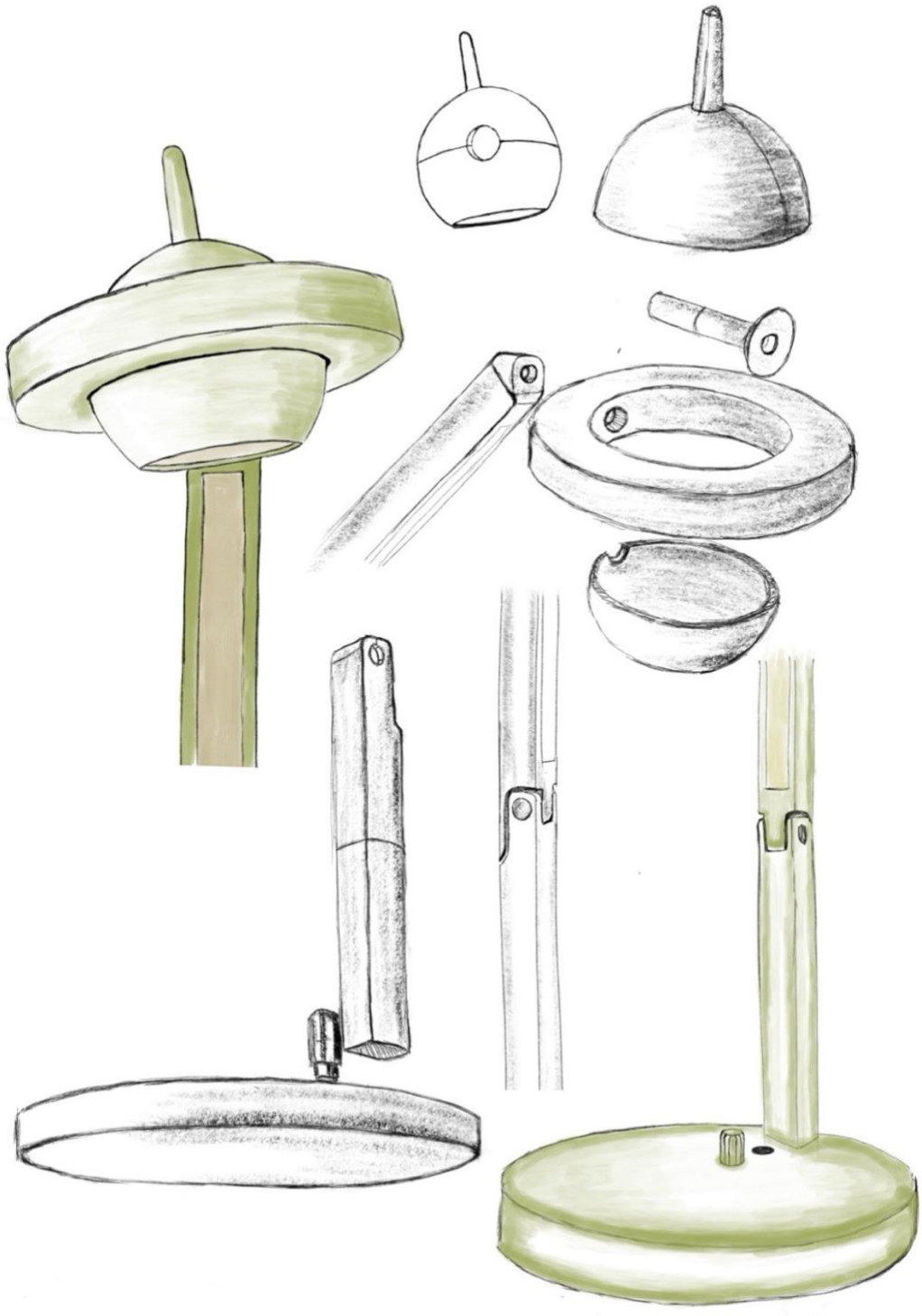

Figure 47: Sketches of the details

Source: Parastoo Shahpari

4.2.6. Concept Development

The generative phase of this project explores the intersection of functionality, symbolism, and emotional connection in designing intelligent lighting for home-office environments. Drawing inspiration from the cosmic connection between humans and the universe, the lamp design is centered on the symbolism of Saturn—a planet that embodies beauty, mystery, and interconnectedness. The ring-like form and soft, ambient glow evoke the feeling of holding a fragment of the universe, serving as both a functional tool and a poetic reminder of something greater.

This design is rooted in the philosophical tradition of Aristotle's Poetics, which highlights the importance of combining theory, praxis, and poíesis to create meaningful objects (Aristotle, 2007). Theory involves the search for knowledge grounded in current realities, praxis focuses on solving practical problems, and poíesis emphasizes the emotional and imaginative storytelling conveyed by the design. The Saturn lamp incorporates all three elements, offering a lighting solution that is functional, culturally resonant, and emotionally engaging.

At its core, the lamp is designed to nurture health and well-being while respecting sustainability, much like the planets that sustain life. It draws on Charles Sanders Peirce's theory of signs, which emphasizes the interpretive relationship between an object's form, its meaning, and the user's perception (Peirce, 1998). By considering these semiotic principles, the lamp's design fosters an intuitive and meaningful interaction between users and their environment.
The Saturn lamp uses its celestial-inspired design to create a deeper emotional connection, inviting users to feel connected to the larger cosmos. Similarly, Umberto Eco's A Theory of Semiotics informs the universal appeal of the design by demonstrating how cultural symbols, like the planet Saturn, can transcend individual contexts to evoke shared meaning (Eco, 1976). These semiotic principles ensure the lamp resonates with a diverse audience, blending practicality with profound symbolic value.

This concept also draws inspiration from art and design history, where lighting has often reflected cosmic and natural themes. Vico Magistretti's *Eclisse* lamp (1965) embodies the interplay of light and shadow through its eclipse-inspired form, while Michele De Lucchi and Giancarlo Fassina's *Tolomeo* lamp (1987) prioritizes adaptability and balance, qualities that metaphorically align with the dynamic movement of planetary systems (Magistretti, 1965; De Lucchi & Fassina, 1987). The Saturn lamp builds on this tradition, integrating poetic symbolism with advanced functionality to address the specific needs of remote workers.

The lamp incorporates two distinct light sources tailored to the requirements of home-office environments:

1. **A Vertical Light**: Provides bright, focused illumination to enhance concentration and productivity during work tasks. This feature aligns with research by Boyce (2014), which underscores the importance of task lighting in improving performance and reducing eye strain.
2. **A Warm, Adjustable Spotlight**: Provides 360-degree flexibility for relaxation, aligning with Human-Centric Lighting (HCL) principles that emphasize personalized lighting

control for well-being. While often overlooked, the directionality of light can influence visual comfort and ambiance. Research by Figueiro et al. (2018) underscores the importance of lighting conditions—including intensity, spectrum, and positioning—in supporting circadian rhythms and enhancing overall comfort. To further enhance its emotional connection, the lamp's calming green finish draws inspiration from Kaplan and Kaplan's (1989) Attention Restoration Theory, which highlights the restorative psychological benefits of natural environments. Although this theory does not specifically address color, research by Küller et al. (2009) supports the idea that green environments contribute to reduced stress and enhanced well-being. By incorporating nature-inspired elements into its design, the lamp fosters a sense of tranquility and balance in the home office, bridging practicality and poetic beauty.

The generative phase thus seeks to create a design that seamlessly integrates health-conscious lighting principles, universal symbolism, and user-centered functionality. Inspired by the celestial themes of light in art, such as James Turrell's use of immersive light to evoke cosmic wonder (Turrell, 2013), the Saturn lamp offers remote workers a meaningful and transformative lighting experience that connects them to something greater than themselves while promoting well-being in the home office.

4.3. Evaluative

For the evaluative phase, prototyping was employed to explore and refine the design of a suitable desk lamp that addresses the needs of remote workers. This process involved creating iterations of the intelligent task lamp to test its functionality, adaptability, and technical feasibility. Expert evaluations were conducted to assess the ergonomic considerations, lighting quality, and overall practicality of the design. These evaluations provided critical insights, enabling refinements to the product and ensuring it meets industry standards while addressing the specific challenges identified in the research.

4.3.1. Prototyping

Based on the data gathered during the exploratory and generative phases of the research, participants expressed a preference for customizable lighting conditions in terms of color temperature and intensity. To meet these preferences, the desk lamp prototype incorporates two distinct light sources, each designed to address specific needs.

The first light source is a vertically adjustable COB LED with a color temperature of 6000K. This cool white light is intended for use in the morning and throughout the day to enhance focus and productivity. The choice of COB LED technology was influenced by participants' concerns about glare; COB LEDs minimize glare, making them ideal for prolonged work sessions. (Figure 48)

Figure 48: Vertical light of the prototyped desk lamp

Source: Parastoo Shahpari

Participants also emphasized the importance of creating a warm, relaxing atmosphere in the evening. To cater to this need, the second light source is a spotlight with a warm light at 2700K. This light is specifically designed to foster a cozy environment, suitable for nighttime relaxation or tasks requiring localized lighting. (Figure 49)

Figure 49: Warm spotlight of the prototyped desk lamp

Source: Parastoo Shahpari

Another critical need highlighted by participants was the ability to adjust the intensity of the light to avoid fatigue and headaches. The vertical light's brightness can be smoothly adjusted to suit varying tasks and preferences. The spotlight, equipped with a motion sensor for ease of use, can be turned on and off with a simple touch, allowing users to effortlessly shift between work and relaxation settings.

Additionally, remote workers expressed the need for adjustable light direction to accommodate task-specific requirements. The spotlight's direction can be manually adjusted by hand, ensuring precise illumination where needed. Both lights can be used independently or simultaneously, offering flexibility. (Figure 50)

Figure 50: Manual adjustment of the spotlight direction

Source: Parastoo Shahpari

Finally, participants noted that greenery in their living environment positively impacts mood. Drawing inspiration from this feedback, the desk lamp is designed in a calming green color to subtly evoke this sense of natural connection.

The proposed intelligent task light, with its dimmable cool white vertical light, motion-sensor warm spotlight, and manual directional adjustment, aims to address these identified needs. By aligning functionality with user preferences, this solution has the potential to enhance focus, improve comfort, and seamlessly integrate with users' lifestyles.

4.3.2. Expert evaluations

The expert evaluation of the prototype was conducted with Professors Rui Marcelino and Rui Pedro Fernandes Tomás, who shared their detailed insights on various aspects of the design, including aesthetics, usability, feasibility, and physics. Their initial impressions of the final prototype were positive, with both experts commending the effort put into creating a near-final product.

Here are the protocol questions for expert evaluation

General Opinion on Final Work

1. What are your overall impressions of the final prototype?
2. Do you think the prototype conveys the intended functionality and design effectively?

Aesthetics

3. How would you evaluate the aesthetic design of the prototype?
4. Are there any elements you think could be improved to make the design more visually appealing?
5. Does the prototype effectively balance form and functionality?

Usability

6. How user-friendly do you find the prototype?
7. Are the controls and functionality intuitive for a first-time user?
8. Do you have any suggestions to enhance the usability or maintenance aspects of the design?

Feasibility

9. From a production perspective, do you think the prototype is feasible to manufacture?
10. Do you have recommendations on materials or manufacturing methods that could improve feasibility or reduce costs?

Physics

11. Are there any physical aspects, such as stability or balance, that you think should be improved?
12. Do you believe the current design optimizes the use of materials and structural integrity?

General Opinion on Final Work

Professor Rui Marcelino highlighted the effort involved in assembling a cohesive prototype and noted its resemblance to a finalized product. Professor Rui Pedro Fernandes Tomás shared similar observations, emphasizing the potential for refining the design to achieve a polished final version.

Aesthetic

Professor Rui Marcelino appreciated the poetic and romantic sense of the spotlight, which he described as "planet-like," resembling Saturn, with light emanating as if from a planet. (Figure 51) He suggested that the vertical component should be slimmer and less prominent to enhance the effect of the floating spotlight. Similarly, Professor Rui Pedro Fernandes Tomás emphasized that the vertical part and the profile connecting it to the base should have the same size and also be slimmer, ensuring a cohesive and harmonious design. Both experts agreed that refining these elements would contribute to a sleeker and more visually appealing appearance.

Figure 51: planet-like spotlight

Source: Parastoo Shahpari

Usability

Professor Rui Marcelino admired the versatility of the lamp, noting its potential for various activities such as work, leisure, and ambient lighting and the lamp could be useful for him, However, he pointed out that the on/off controls could be more intuitive for a first-time user, as it is not immediately obvious how to operate the lamp at first glance. He emphasized that while the usability is modern and interesting, it could be made clearer.
Professor Rui Pedro Fernandes Tomás suggested integrating all controls internally to simplify the user experience and improve usability. He highlighted the importance of modular components for easier maintenance and repair. Additionally, he suggested incorporating the ability to change colors, which would add an extra layer of functionality to the design. Both professors agreed that refining these aspects would significantly enhance the usability of the lamp.

Feasibility

Professor Rui Marcelino affirmed the feasibility of the design, highlighting that it could be effectively manufactured using injection molding or a combination of injection-molded and metal parts. He noted that the production process appears viable without any significant issues. However,

he recommended incorporating a more discreet hinge mechanism to enhance both the visual and functional aspects of the lamp, ensuring a more seamless and elegant design.

Professor Rui Pedro Fernandes Tomás echoed the feasibility of the design, suggesting that casting aluminum for structural components would be an efficient and durable manufacturing approach. He emphasized the need to avoid external controls, as integrating them internally would not only improve the lamp's aesthetics but also streamline the production process for greater efficiency. Both experts agreed that these adjustments would contribute to the design's practicality and production readiness.

Physics

Professor Rui Marcelino highlighted a slight imbalance due to the attachment point of the lamp and suggested uncentering it to improve stability. Professor Rui Pedro Fernandes Tomás recommended removing the caps and replace it with threaded connections for better durability and assembly. (Figure 52)

Figure 52:component of the desk lamp

Source: Parastoo Shahpari

The evaluation highlighted the strengths and areas for improvement in the prototype, with both professors commending the effort and thoughtfulness behind the design. They agreed on its potential for refinement to achieve a polished final version. In terms of aesthetics, usability, feasibility, and physics, their feedback provided actionable suggestions, emphasizing the importance of creating a more cohesive, user-friendly, and production-ready product. By addressing the proposed refinements, the prototype can evolve into a functional and visually appealing final design.

4.3.3. Final Prototype

The figures 53 and 54 represent the final prototype after undergoing refinements, reflecting the completed design process.

Figure 53: The Saturn lamp, different light sources

Source: Parastoo Shahpari

Figure 54: The Saturn lamp- Details

Source: Parastoo Shahpari

4.3.4. Technical Drawings

As part of the evaluative phase, a series of technical drawings were created to detail the final prototype's design and construction (Figures 55, 56 and 57). These drawings provide precise measurements and structural components, ensuring a clear representation of the prototype’s functionality and assembly.

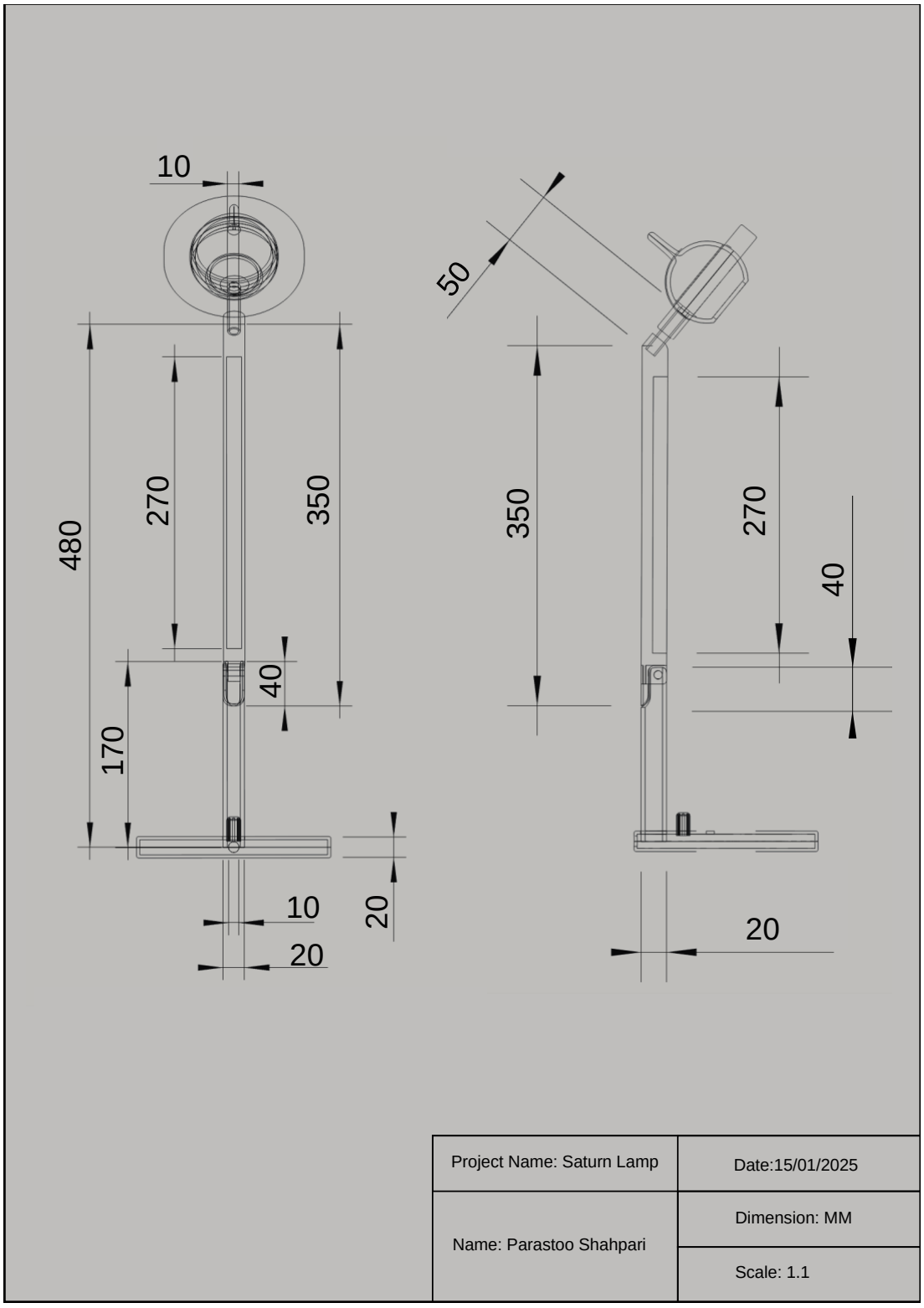

Figure 55: Front and right views of the final prototype, technical drawings

Source: Parastoo Shahpari

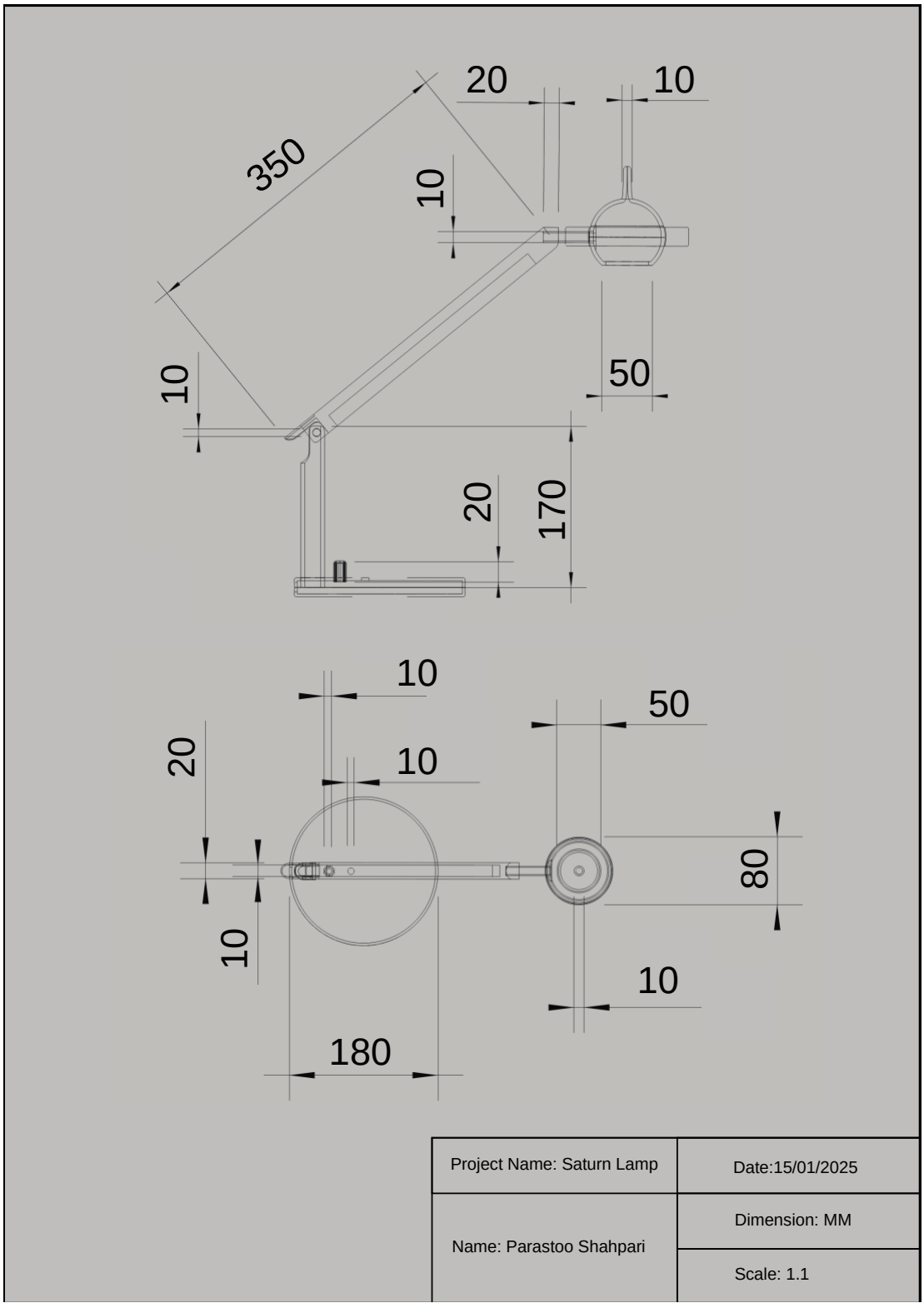

Figure 56: Right and Top views of the final prototype, technical drawings

Source: Parastoo Shahpari

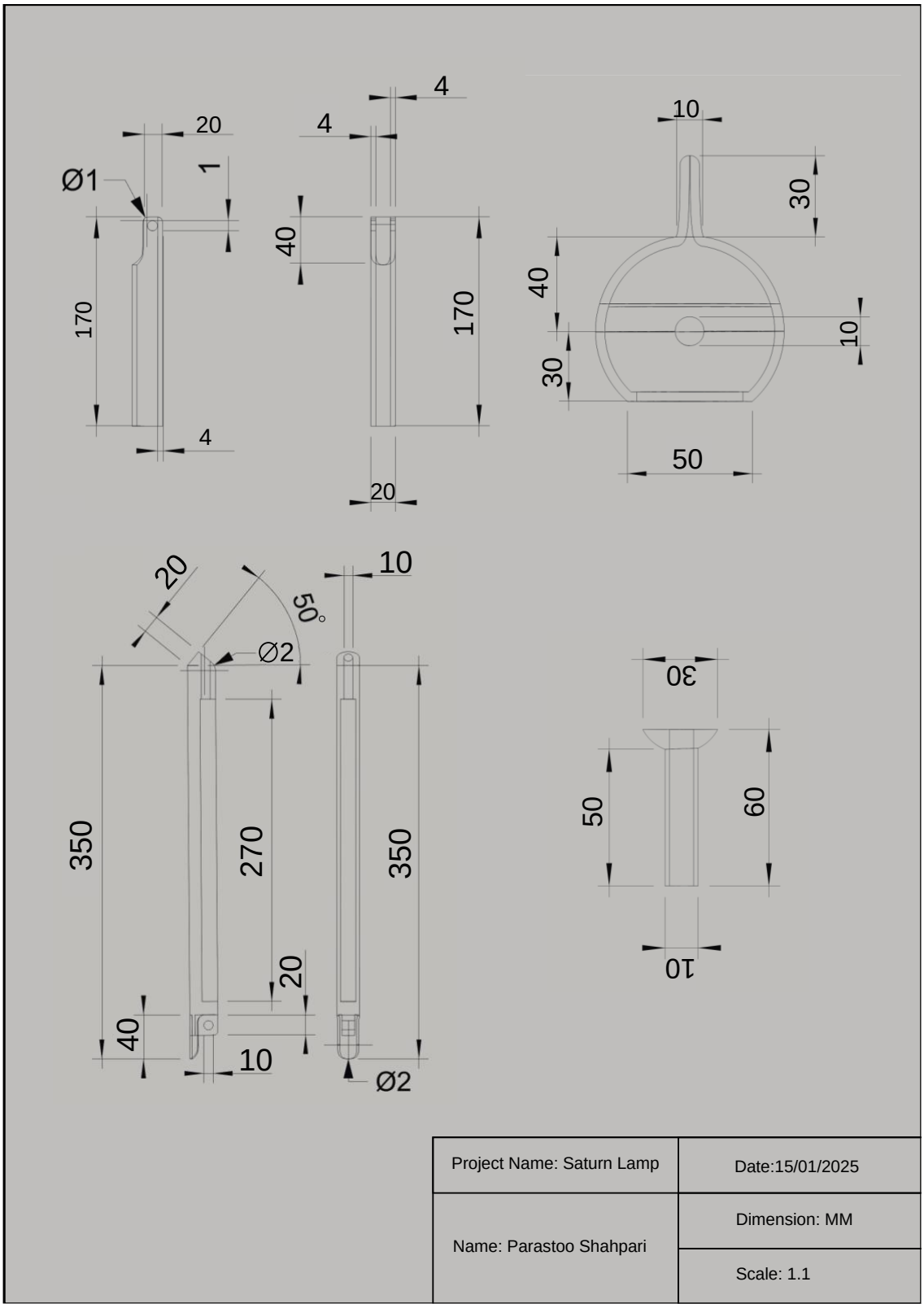

Figure 57: Detailed technical drawings of the final prototype

Source: Parastoo Shahpari

5. Conclusions

5.1. Conclusion

The research underscores the transformative impact of intelligent lighting design on enhancing productivity, comfort, and well-being among remote workers in home-office settings. With the rapid rise of remote work and the multifunctional nature of home environments, there is a pressing need for innovative solutions that address the interplay between lighting and other indoor environmental quality (IEQ) factors. This study emphasizes the critical role lighting plays not only in illuminating spaces but also in shaping human health, mood, and performance.

Indoor lighting profoundly affects biological processes and psychological states, with its influence extending to circadian rhythms, cognitive focus, and emotional well-being. The study highlights that effective lighting solutions must strike a balance between functional utility and emotional resonance, addressing the diverse needs of remote workers. Factors such as light intensity, color temperature, and spectral composition emerged as pivotal in regulating sleep-wake cycles, maintaining sustained attention, and fostering an overall sense of comfort. Advanced human-centric lighting (HCL) systems, powered by LED technology, exemplify how adaptive, personalized lighting can transform home offices into dynamic spaces that respond to individual preferences and daily routines.

A key finding of the research is the inadequacy of current lighting systems for remote workers. Many home-office setups suffer from limited adjustability, outdated technologies, and insufficient integration of natural light. These limitations negatively impact productivity and well-being, underscoring the importance of designing lighting solutions that transition seamlessly between task-focused and ambient modes. Task lighting, in particular, is identified as a cornerstone of effective workspace design, ensuring adequate illumination for specific activities while minimizing physical strain and visual discomfort.

Moreover, the study advocates for a holistic approach to intelligent lighting design, integrating it with other IEQ factors such as ventilation, acoustics, and thermal comfort. This integration is crucial as people spend more time in their homes, blurring the boundaries between work and leisure. By aligning advanced lighting technology with IEQ, it is possible to create environments that not only enhance productivity but also promote long-term health and sustainability.

The findings also reflect the broader potential of intelligent lighting to support energy efficiency and environmental consciousness. As technology continues to advance, the adoption of adaptive and energy-saving lighting solutions becomes increasingly vital. This study establishes that personalized and ergonomic lighting strategies can foster healthier, more efficient, and comfortable home-office environments, which are essential to meet the demands of modern remote work culture.

Equally important is the need to raise awareness among remote workers and organizations about the significance of intelligent lighting and its broader implications for well-being and productivity. Remote workers must be educated on the benefits of appropriate lighting setups, while

organizations should prioritize investing in user-centric, adaptive lighting solutions to support their employees in achieving optimal performance. This awareness and proactive approach will ensure that both individuals and organizations are better equipped to adapt to the evolving demands of remote work.

As a tangible outcome of this research, a fully developed intelligent lighting system was created to enhance the well-being and productivity of remote workers. This system prioritizes personalization by offering adaptable lighting solutions tailored to various tasks and individual preferences. By incorporating multiple lighting modes, it seamlessly transitions between functional, ambient, and task-specific settings, ensuring a dynamic and responsive environment. Designed to support both professional and personal activities, the system exemplifies how intelligent lighting can enhance home-office spaces, addressing the evolving needs of remote workers while fostering comfort, efficiency, and overall well-being.

In conclusion, this research highlights the need for user-centric, dynamic, and health-conscious lighting designs that respond to the evolving lifestyles of remote workers. Intelligent lighting, when integrated with broader IEQ considerations, emerges as a key enabler of well-being and productivity in home offices. By advocating for the convergence of innovative lighting design, advanced technology, and awareness among stakeholders, this study lays the groundwork for a future where indoor environments are not only functional but also deeply supportive of human health and happiness.

5.2. Recommendation for future researches

Based on the findings and conclusions of this study, several avenues for future research are recommended to further advance knowledge and innovation in enhancing productivity and well-being in home-office environments:

1. **Exploration of IEQ Factors and Integration with Intelligent Design**:

   Future research should delve deeper into the integration of indoor environmental quality (IEQ) factors—such as air quality, thermal comfort, acoustics, and lighting—with intelligent design. Studies should focus on how these elements can work synergistically to create holistic, adaptive environments that optimize health and productivity in home offices. Exploring the technological and architectural frameworks necessary for seamless integration will be particularly valuable.

2. **Advancements in Human-Centric Lighting Design**:

   As HCL is a relatively new concept in home-office contexts, more research is needed to understand its long-term impacts on circadian rhythms, cognitive performance, and emotional well-being. Investigations could explore how HCL can be customized to meet individual needs, considering factors such as age, work patterns, and personal preferences. Additionally, studies should assess the scalability of HCL technologies and their energy efficiency in residential settings.

3. **The Role of Awareness in Driving Adoption**:

   Further research should explore the role of awareness campaigns in increasing the demand for and willingness to adopt intelligent and energy-efficient lighting solutions. This includes examining the effectiveness of education programs targeted at remote workers and organizations, as well as the impact of marketing strategies on consumer behavior. Understanding how awareness influences decision-making can inform strategies to bridge the gap between technological advancements and market adoption.

4. **Energy Efficiency and Sustainability Metrics**:

   Future studies could focus on developing measurable metrics for evaluating the energy efficiency and sustainability of intelligent lighting systems. Research might also assess the environmental impact of widespread adoption of such systems in residential spaces, considering their lifecycle from production to disposal.

5. **User Experience and Behavioral Studies**:

To ensure intelligent lighting systems are user-friendly and widely adopted, future research should explore user experiences, including potential barriers to adoption such as cost, complexity, and lack of knowledge. Behavioral studies could investigate how different demographic groups interact with intelligent lighting and IEQ systems, providing insights into designing solutions that cater to diverse populations.

6. **The Economic Impact of Intelligent Lighting Solutions**:

   Research on the cost-benefit analysis of implementing intelligent lighting systems in home offices could provide a stronger case for their adoption. This includes examining how productivity gains, health improvements, and energy savings offset initial investments, particularly for remote workers and organizations supporting their teams.

7. **Longitudinal Studies on Health Impacts**:

   Long-term studies are necessary to comprehensively assess the impact of intelligent lighting and integrated IEQ systems on physical and mental health. These studies could provide robust evidence to support policy changes and incentivize organizations to invest in employee-friendly home-office setups.

By addressing these areas, future research can contribute to a deeper understanding of how to design and implement innovative, user-centric solutions that enhance productivity, health, and overall quality of life for remote workers.

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7. Appendix

7.1. Appendix A: Questionnaire

7.1.1. Survey Questions

Section 1

Which language do you prefer?

English
Portuguese
Persian

Section 2

Introduction:

Suitable Lighting Products for Remote Workers

Thank you for participating in my questionnaire. I am Parastoo Shahpari, a master's student in product design at the Lisbon School of Architecture. I'm conducting this survey as part of my thesis, aimed at designing lighting products tailored to the needs of remote workers in homes. Your insights are invaluable in shaping innovative products that enhance remote workers' well-being and productivity in home-office environments.

This questionnaire should take approximately 10 minutes to complete.

1. What is your gender identity?

Female
Male
Prefer not to say

2. Which age group do you belong to?

18-25 years old
26-40 years old
41-60 years old
+61 years old

3. What best describe your professional current status?

Remote worker (Fully working from home)
Remote worker, working hybrid (partly from home, partly from office)

Working full time from office and also doing work related tasks from home.
Working from the office full time (Thank you for your time. Your participation in the survey is not required.)
Unemployed (Thank you for your time. Your participation in the survey is not required.)

Section 3

Your workspace in your home

Consider your home-office environment and answer these questions.

4. Which description best fits for your workspace?

I work in the same room where I sleep and relax.
I have a workspace separate from where I sleep and relax.
I utilize various areas within my home for work purposes.

5. Is natural light accessible in your workspace?

Yes, my room receives enough natural light.
There is some natural light, but it's limited.
No, my workspace lacks access to natural light entirely.

6. What is the arrangement of your desk in your workspace, in relation to the window and natural light?

It is positioned near a natural light source.
It is situated away from the natural light source.
There is no natural light available in the room.

7. Which description best matches the artificial lighting in your workspace?

The light intensity is adjustable.
The light color is adjustable.
Both the light intensity and color can be adjusted.
Neither the light intensity nor color is adjustable.

8. How satisfied are you with the lighting in your workspace, on a scale of 1 to 10? (1 being very dissatisfied, 5 being neutral, and 10 being very satisfied)

9. When envisioning the lighting in your workspace, what atmosphere would you prefer?

Warm (a cozy and intimate atmosphere with visible light sources)
Cold (a modern and contemporary feel with hidden source lighting)
Dynamic (versatile and adjustable lighting for various activities and moods)

10. Do you use a desk lamp in your workspace, in addition to ambient lighting?

Yes
No

11. If yes, can you adjust the direction of the lamp manually?

Yes
No

12. Which method would you prefer for controlling your lighting in your workspace?

Mobile Apps
Motion sensors
Remote controls
Physical switches
Combination of methods

Section 4

Awareness

13. What time of the day do you feel most alert and energetic to work? (preferred time to work)

Early morning
Morning and evenings
Late at night

14. Does your working routine at the moment match your preference? (Considering time zone and...)

Yes
No

15. How significantly do the transitions from spring/summer to autumn/winter impact your mood and performance on a scale of 1 to 10? (1 being no effect, 5 being moderate effect and 10 being significant effect)

16. Would you be willing to invest in energy-efficient advanced lighting solutions for your home-office environments, even if it may be more expensive?

(Advanced lighting control solutions involve sophisticated systems that regulate and manage the intensity, color, and timing of artificial light sources in various environments. These systems often incorporate sensors, smart controls, and automation technology to optimize energy efficiency, enhance user comfort, and create dynamic lighting experiences.)

Yes, I believe the long-term energy savings justify the investment.
Maybe, it would depend on the benefits, and potential energy savings offered.
No, I prefer to stick with conventional lighting solutions.

17. How much do you know about the influence of indoor lighting on residents' well-being and productivity?

I have a good understanding of its impact.
I have some knowledge about it.
I'm not familiar with this topic at all.

18. Do you experience any discomfort in specific areas of your home-office environment because of lighting? If yes, could you describe how?

19. Did your employer improve your home-office environment for better health and productivity as a remote worker? If so, what actions have been taken? As an employer who works remotely from home, have you taken any steps to improve the health and well-being of your remote workers? If yes, what actions have you taken?

20. Do you have any additional feedback or suggestions regarding lighting products for home office environments? (Please write it down)

Thank you for participating in my questionnaire

Your valuable input will help me to design lighting products to enhance remote workers' well-being and productivity while contributing to a greener, more sustainable future.

The questionnaire was available in three languages; however, to keep the appendix concise, only the English version is included.

7.2. Appendix B: Figures Related to Questionnaire Responses

7.2.1. Demographic Information

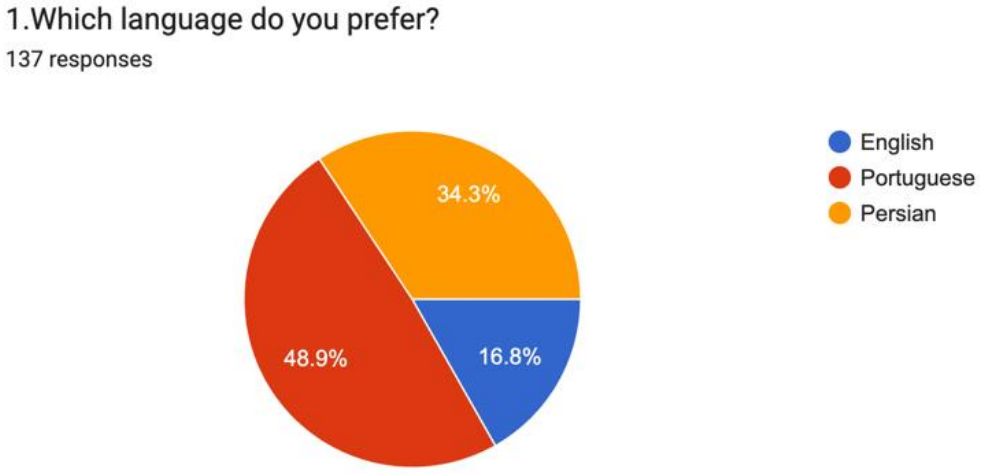
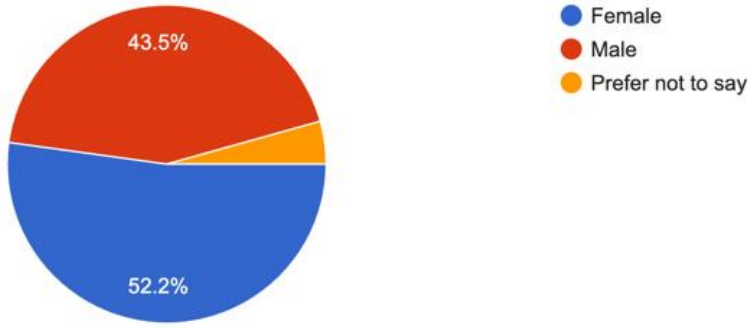


Figure 58: Language preferences

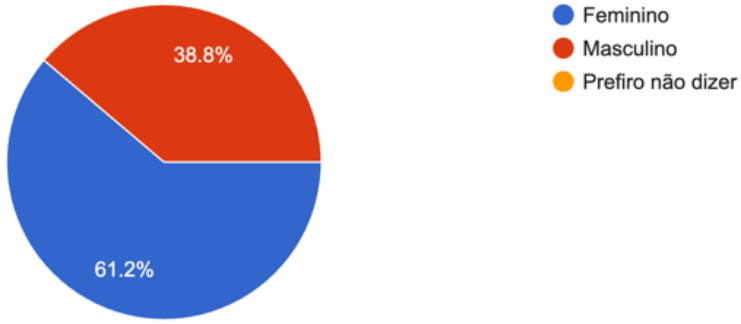
1. What is your gender identity?

23 responses



1. Indique o seu género?

67 responses



۱. جنسیت شما چیست؟

47 responses

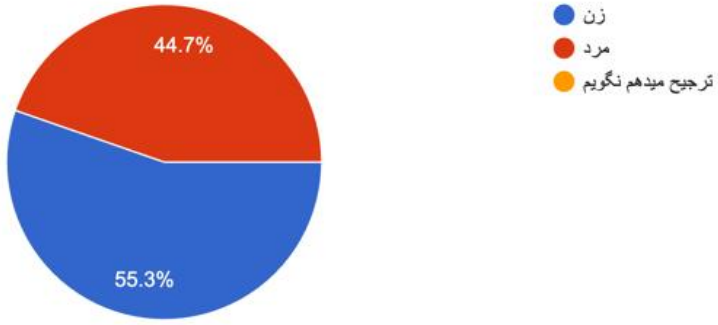


Figure 59: Gender Identity

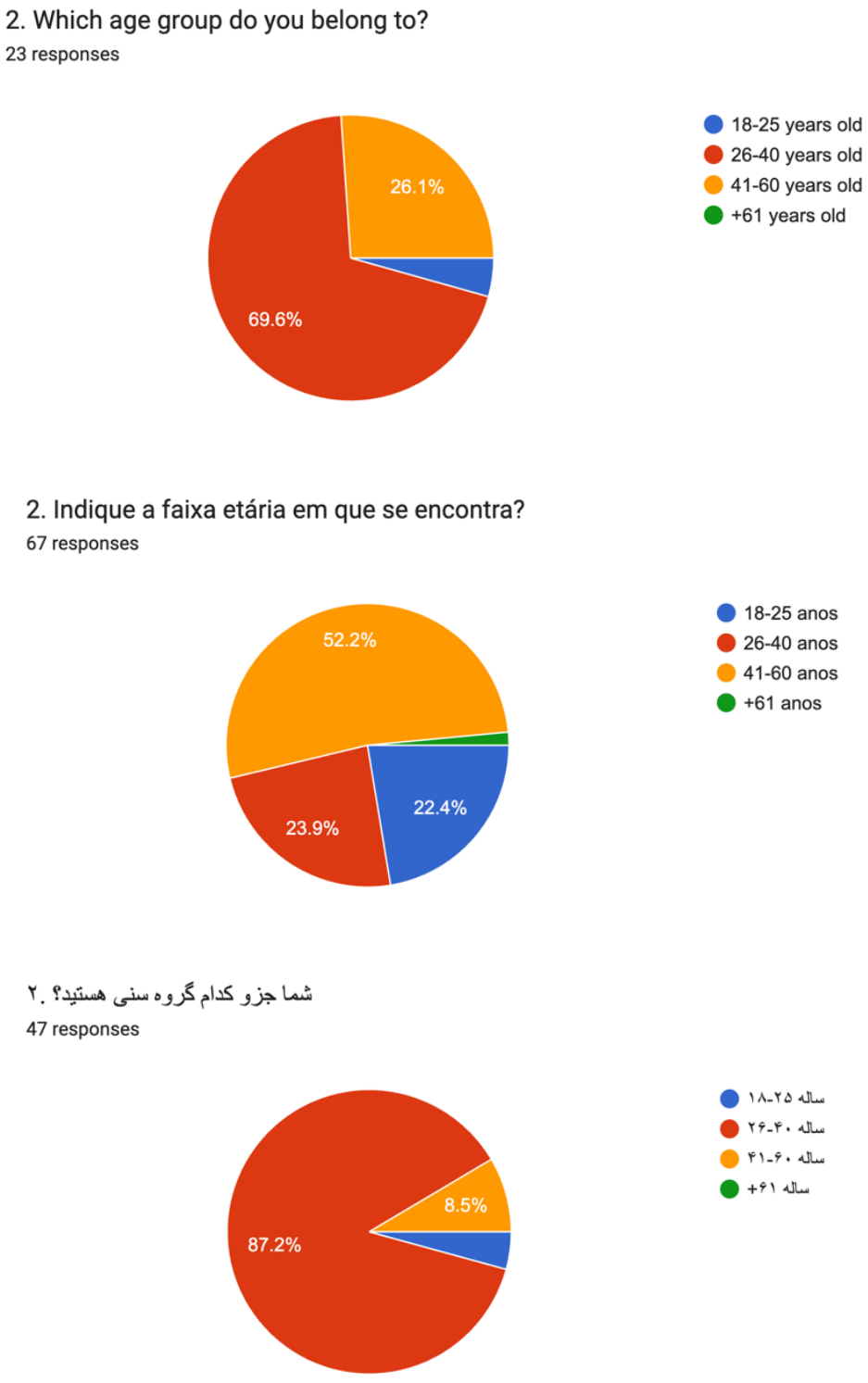


Figure 60: Age group

7.2.2. Workspace Characteristics

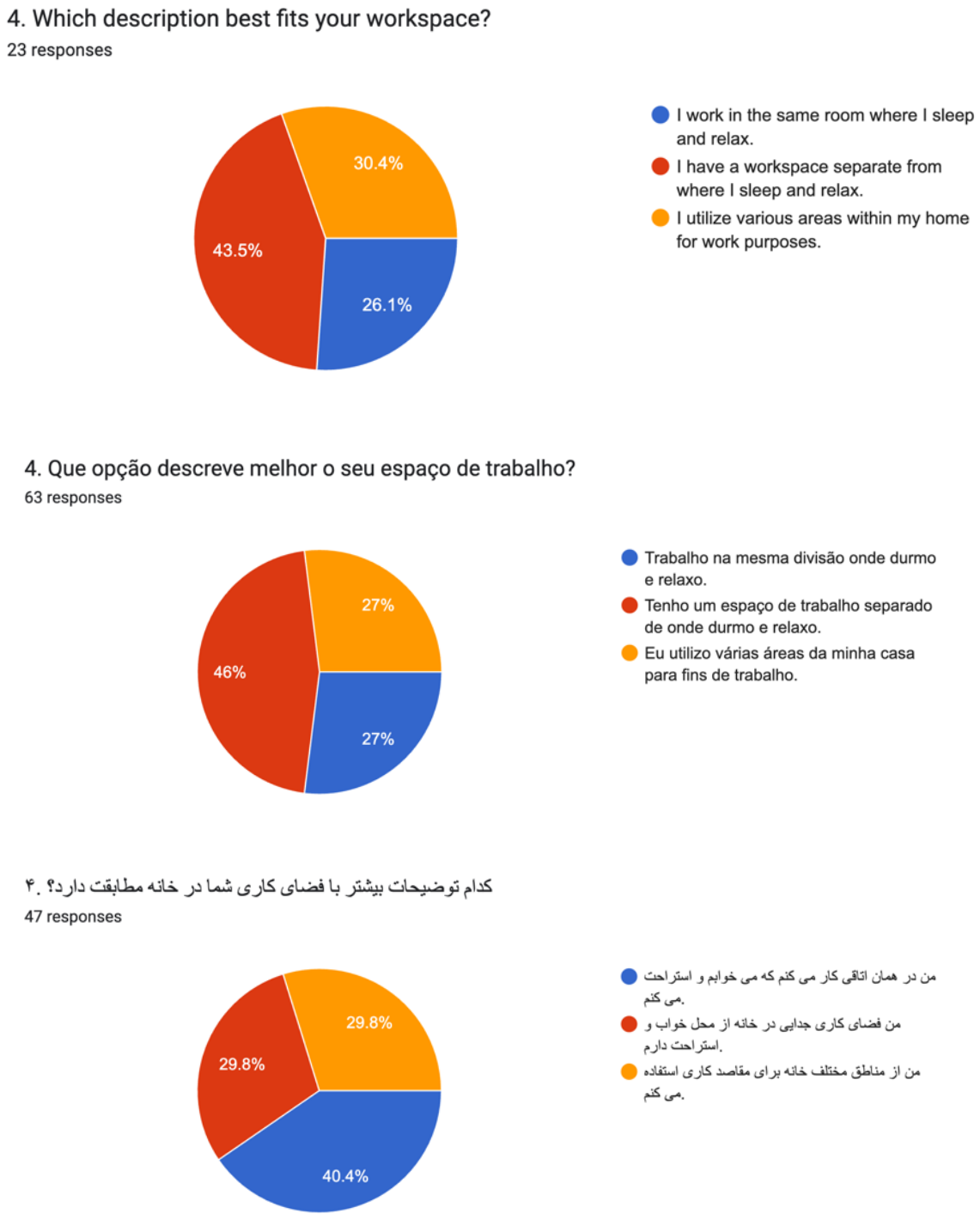
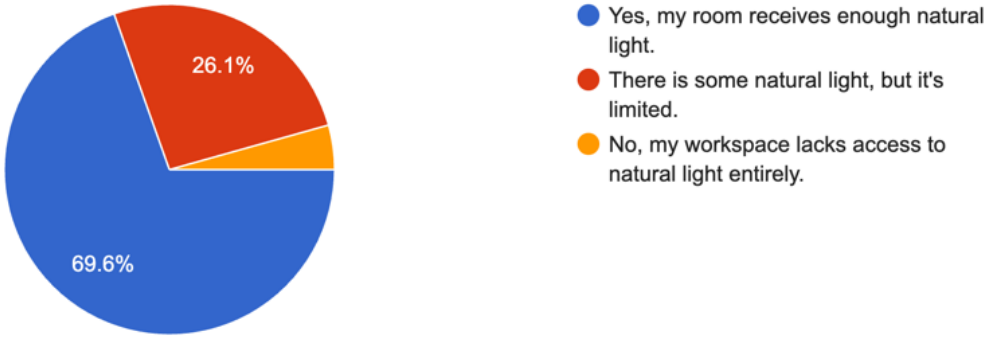


Figure 61:Workspace description

5. Is natural light accessible in your workspace?

23 responses



5. A luz natural está acessível no seu espaço de trabalho?

63 responses

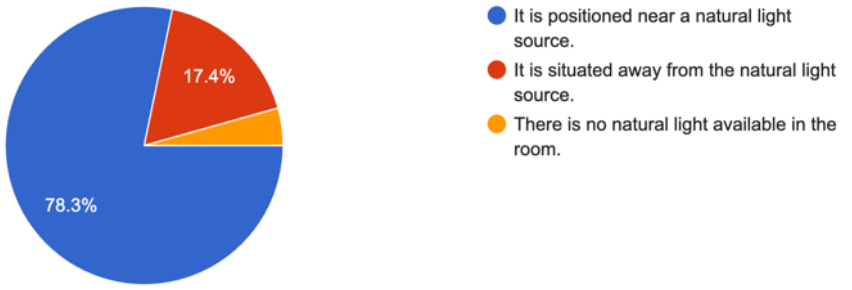
۵. آیا نور طبیعی در فضای کاری شما در خانه قابل دسترسی است؟

47 responses

Figure 62: Accessibility of natural light

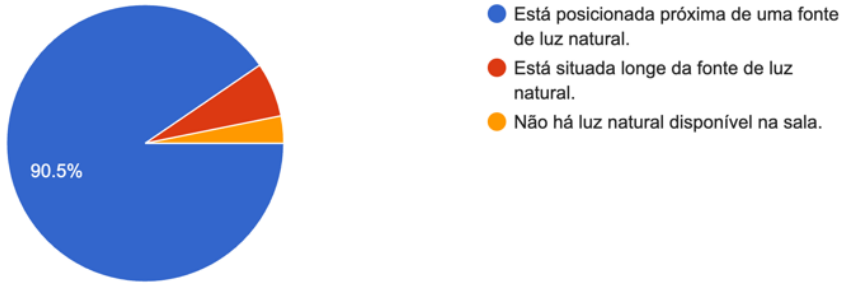
6. What is the arrangement of your desk in your workspace, in relation to the window and natural light?

23 responses



6. Qual a disposição da sua mesa no espaço de trabalho, em relação à janela e à luz natural?

63 responses



۶. چیدمان میز شما در فضای کارتان، نسبت به پنجره و نور طبیعی چگونه است؟

47 responses

Figure 63:Desk arrangement relative to natural light

7.2.3. Lighting preferences and adjustability

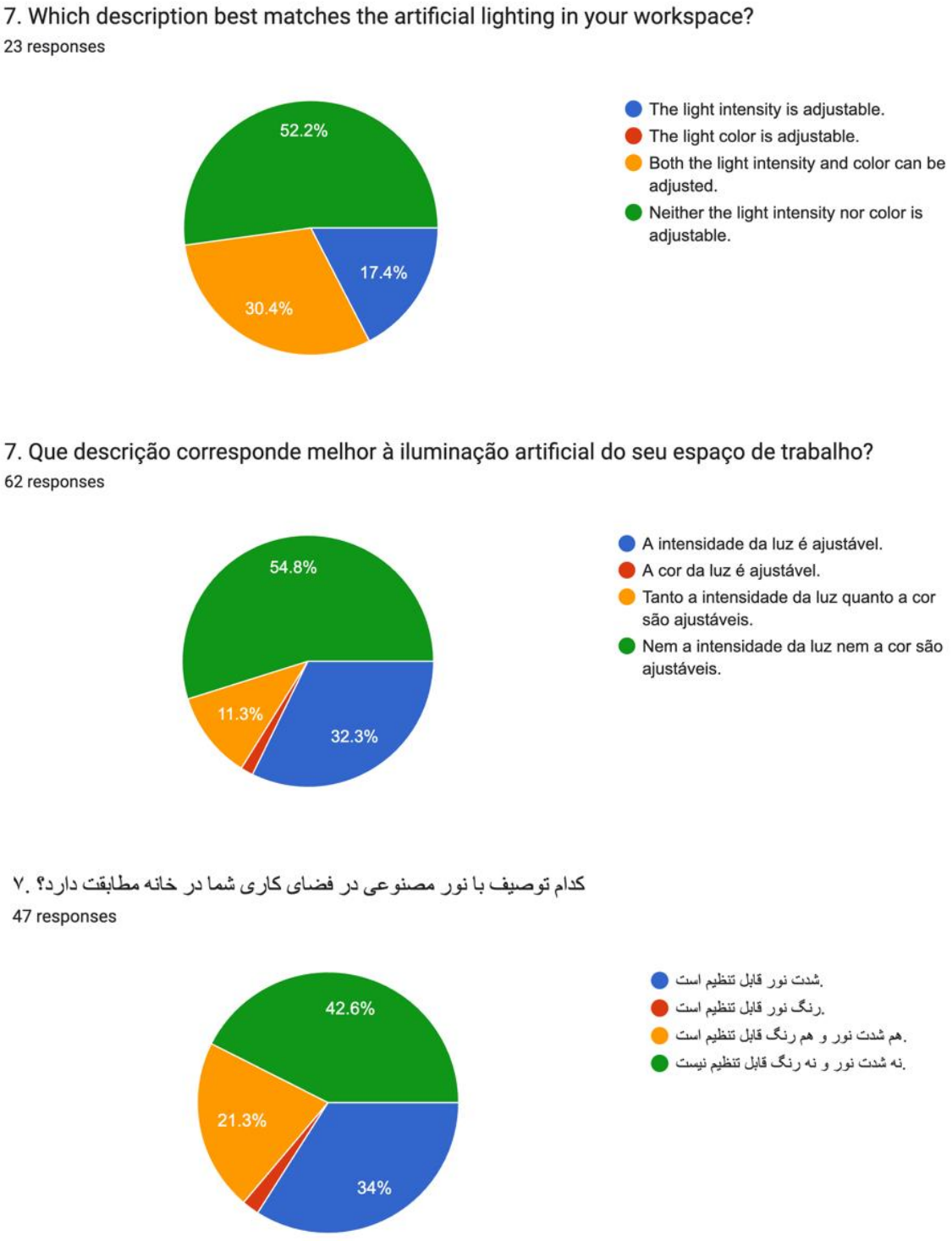
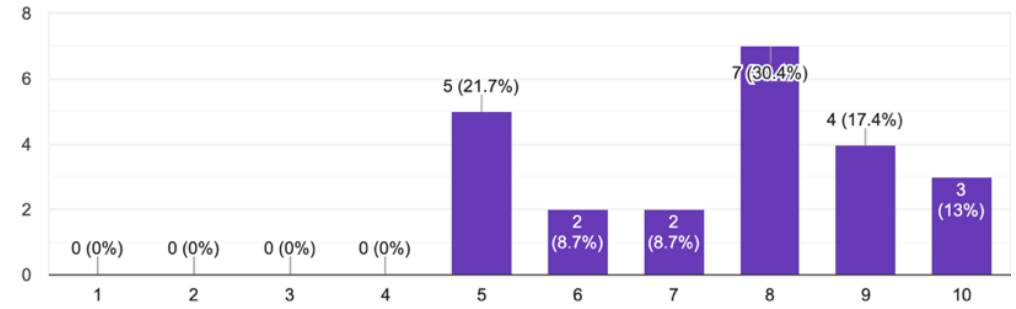


Figure 64: Artificial lighting types in the workspace

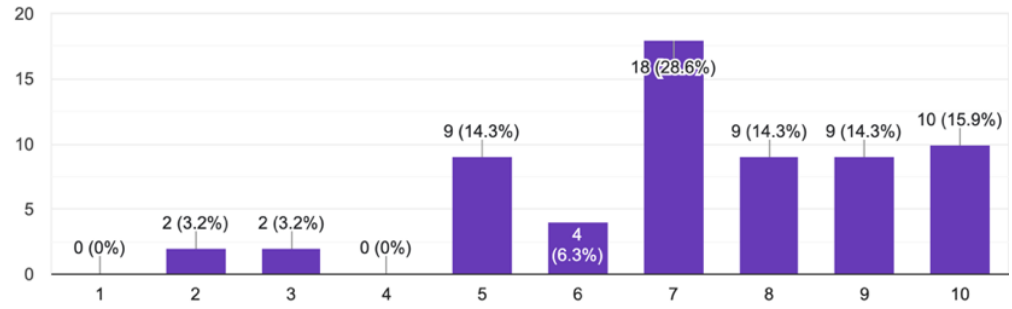
8. How satisfied are you with the lighting in your workspace, on a scale of 1 to 10? (1 being very dissatisfied, 5 being neutral, and 10 being very satisfied)

23 responses



8. Como classificaria de 1-10 a sua satisfação com a sua iluminação atual no espaço de trabalho? (1 sendo muito insatisfeito, 5 sendo neutro e 10 sendo muito satisfeito)

63 responses



۸. چقدر از نورپردازی فضای کاری خود در خانه در مقیاس 1 تا 10 رضایت دارید؟ (1 بسیار ناراضی، 5 خنثی و 10 بسیار راضی)

47 responses

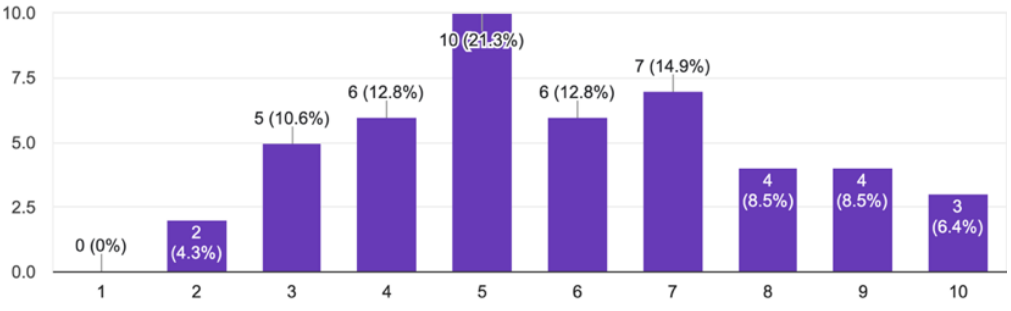


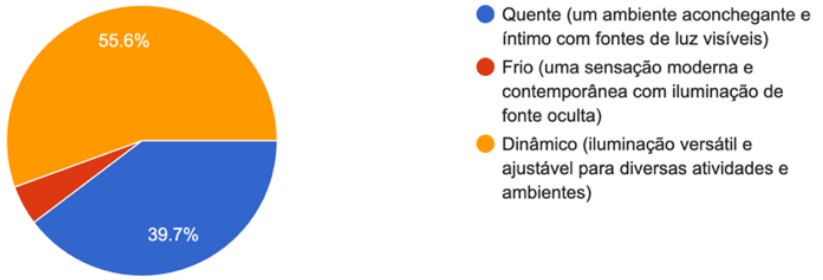
Figure 65: Satisfaction levels with workspace lighting

9. When envisioning the lighting in your workspace, what atmosphere would you prefer?

23 responses

9. Ao imaginar a iluminação do seu espaço de trabalho, que ambiente prefere?

63 responses



۹. هنگام تصور نور در فضای کاری خود در خانه، چه فضایی را ترجیح می دهید؟

47 responses

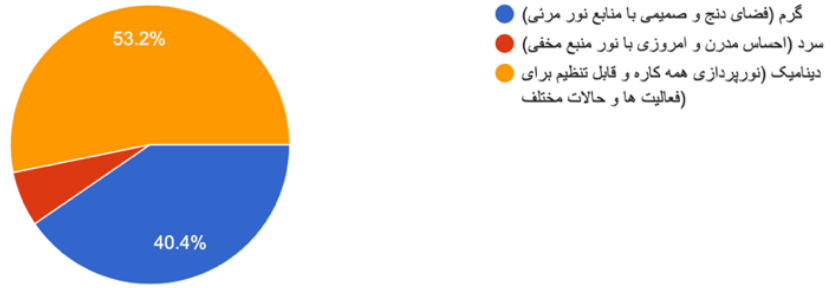
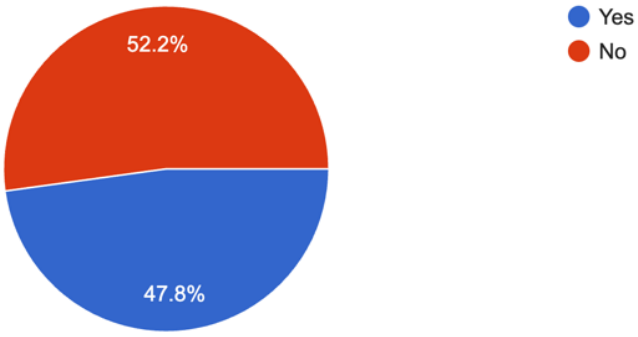


Figure 66: preferred atmosphere for workspace lighting

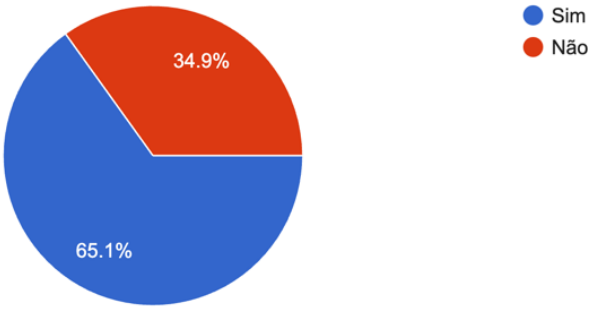
10. Do you utilize a desk lamp in your workspace, in addition to ambient lighting?

23 responses



10. Para além da iluminação ambiente, possui algum tipo de iluminação para secretária?

63 responses



۱۰. آیا در محیط کار خود در خانه علاوه بر نور محیط از چراغ رومیزی استفاده می کنید؟

47 responses

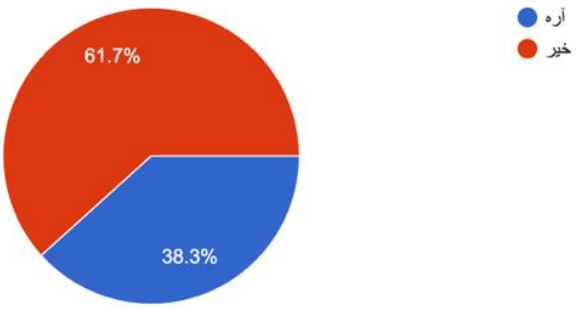
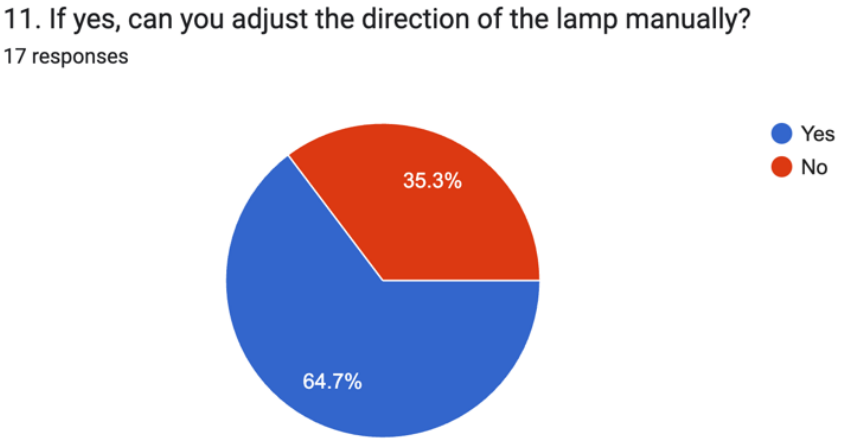
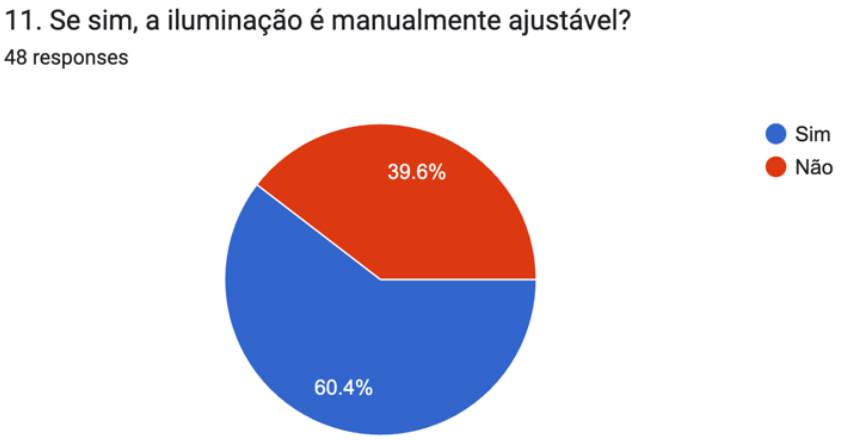


Figure 67:Use of desk lamp in the workspace





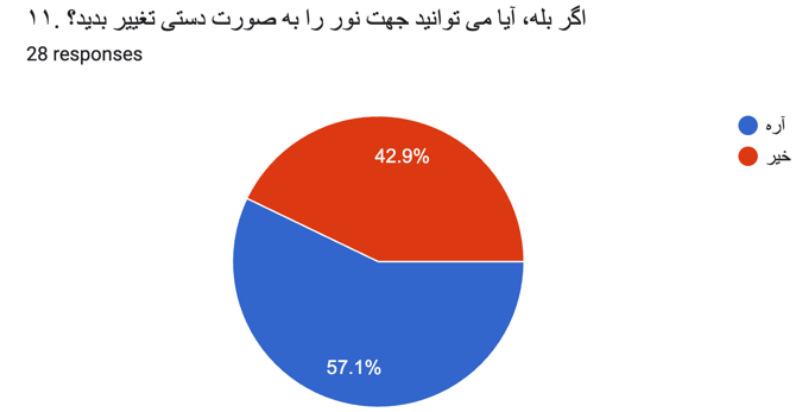
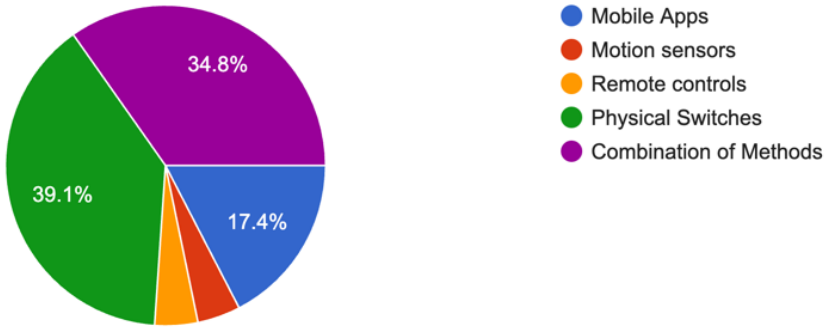


Figure 68: manual direction adjustability of desk lamp

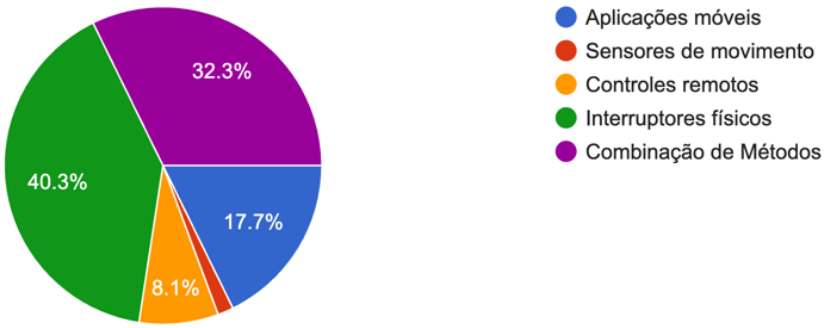
12. Which method would you prefer for controlling your lighting in your workspace?

23 responses



12. Que método prefere para controlar a iluminação do espaço de trabalho?

62 responses



۱۲. کدام روش را برای کنترل روشنایی در فضای کاری خود در خانه ترجیح می دهید؟

46 responses

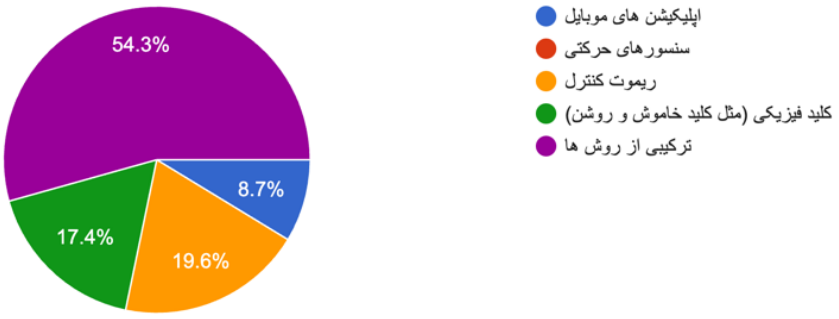
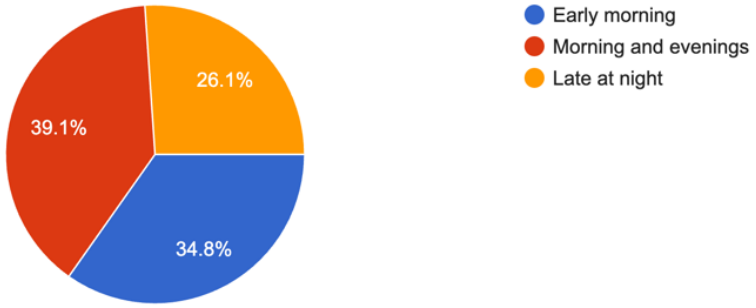


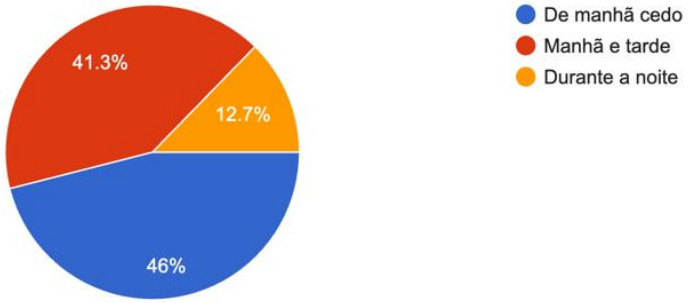
Figure 69: Preferred methods for lighting control in the workspace

7.2.4. Work routine and chronotypes

13 . What time of the day do you feel most alert and energetic to work?(preferred time to work)
23 responses



13. Em que altura do dia se sente com energia ou prefere trabalhar?
63 responses



۱۳. چه زمانی از روز برای کار انجام دادن بیشتر احساس هوشیاری و انرژی می کنید؟ (زمان ترجیحی برای کار)
47 responses

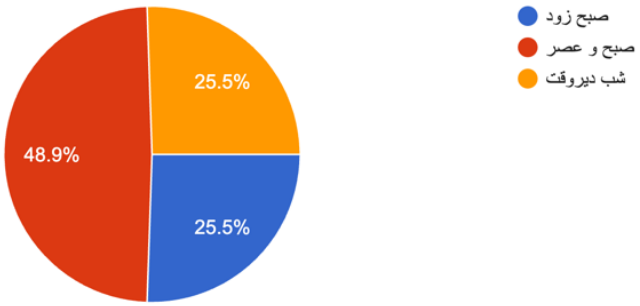
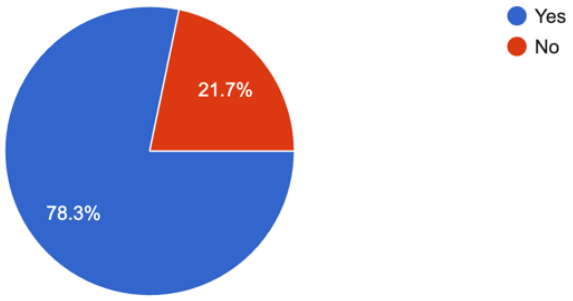


Figure 70: Time of day when respondents feel most alert and energetic

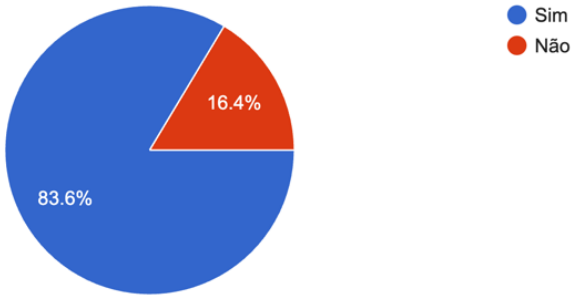
14. Does your working routine at the moment match your preference? (considering time zone and ...)

23 responses



14. A sua rotina de trabalho atual à sua preferência pelo horário de trabalho? (considerando fuso horário e ...)

61 responses



۱۴. آیا روال کاری شما در حال حاضر با ترجیح شما مطابقت دارد؟ (با در نظر گرفتن منطقه زمانی و تفاوت ساعت و ...)

47 responses

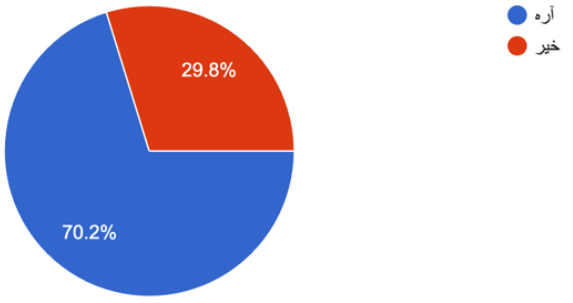
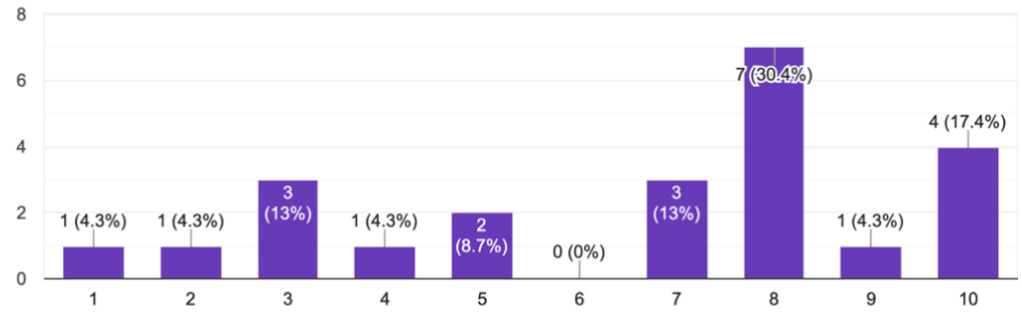


Figure 71:Alignment of current work routines with preferences

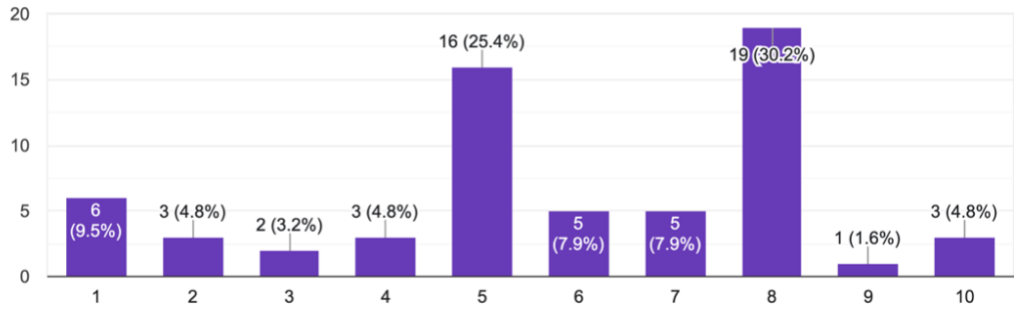
15. How significantly do the transitions from spring/summer to autumn/winter impact your mood and performance on a scale of 1 to 10?(1 being no e... moderate effect and 10 being significant effect)

23 responses



15. Classifique de 1-10 o impacto da mudança de fuso horário (primavera/verão para outono/inverno) no seu desempenho enquanto trabalh... 5 - efeito moderado e 10 - efeito significativo)

63 responses



۱۵. تغییر فصل از بهار/تابستان به پاییز/زمستان چقدر بر روحیه و عملکرد شما در مقیاس 1 تا 10 تأثیر می گذارد؟ (1 بدون تأثیر، 5 اثر متوسط و 10 تأثیر قابل توجه است)

47 responses

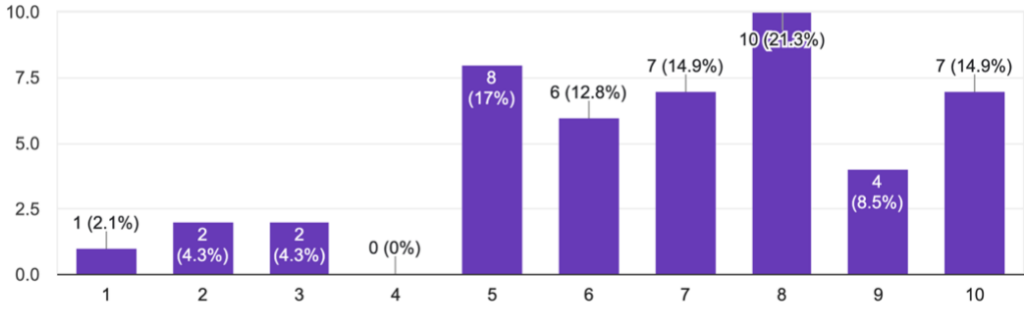


Figure 72:Mood impact of seasonal transitions

7.2.5. Investment in advanced lighting solution

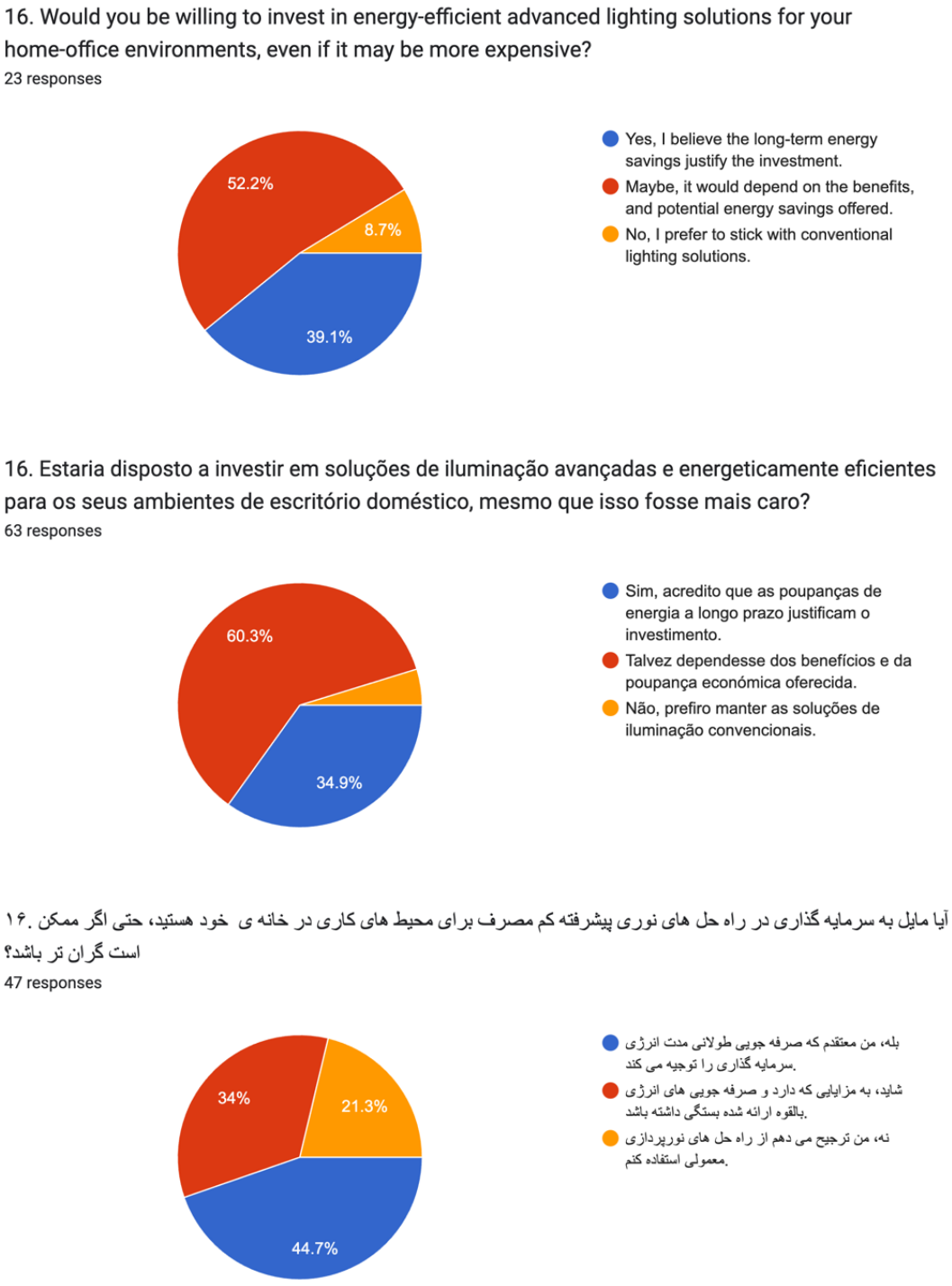
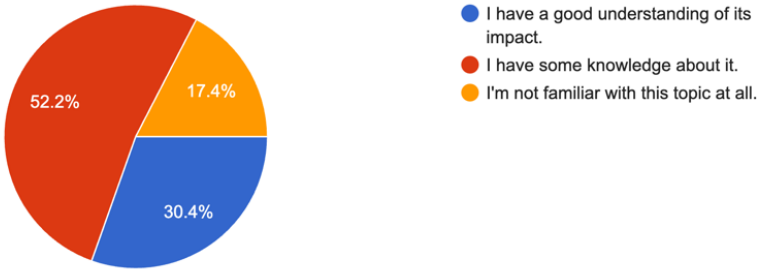


Figure 73:Willingness to invest in energy-efficient advanced lighting solutions

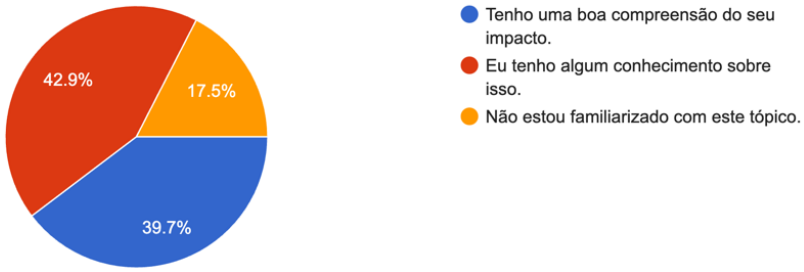
17. How much do you know about the influence of indoor lighting on residents' well-being and productivity?

23 responses



17. Qual o seu nível de compreensão acerca da influência da iluminação interna no bem-estar e na produtividade dos residentes?

63 responses



۱۷. در مورد تأثیر نورپردازی داخل ساختمان بر سلامت و خلاقیت ساکنان چقدر می دانید؟

47 responses

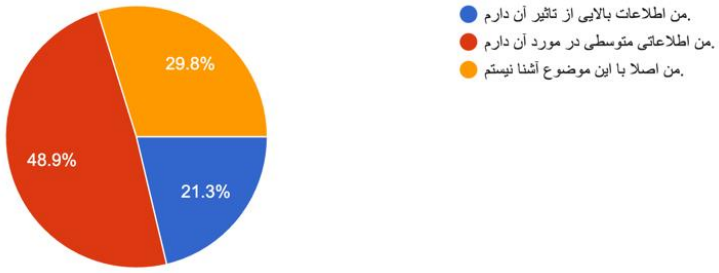
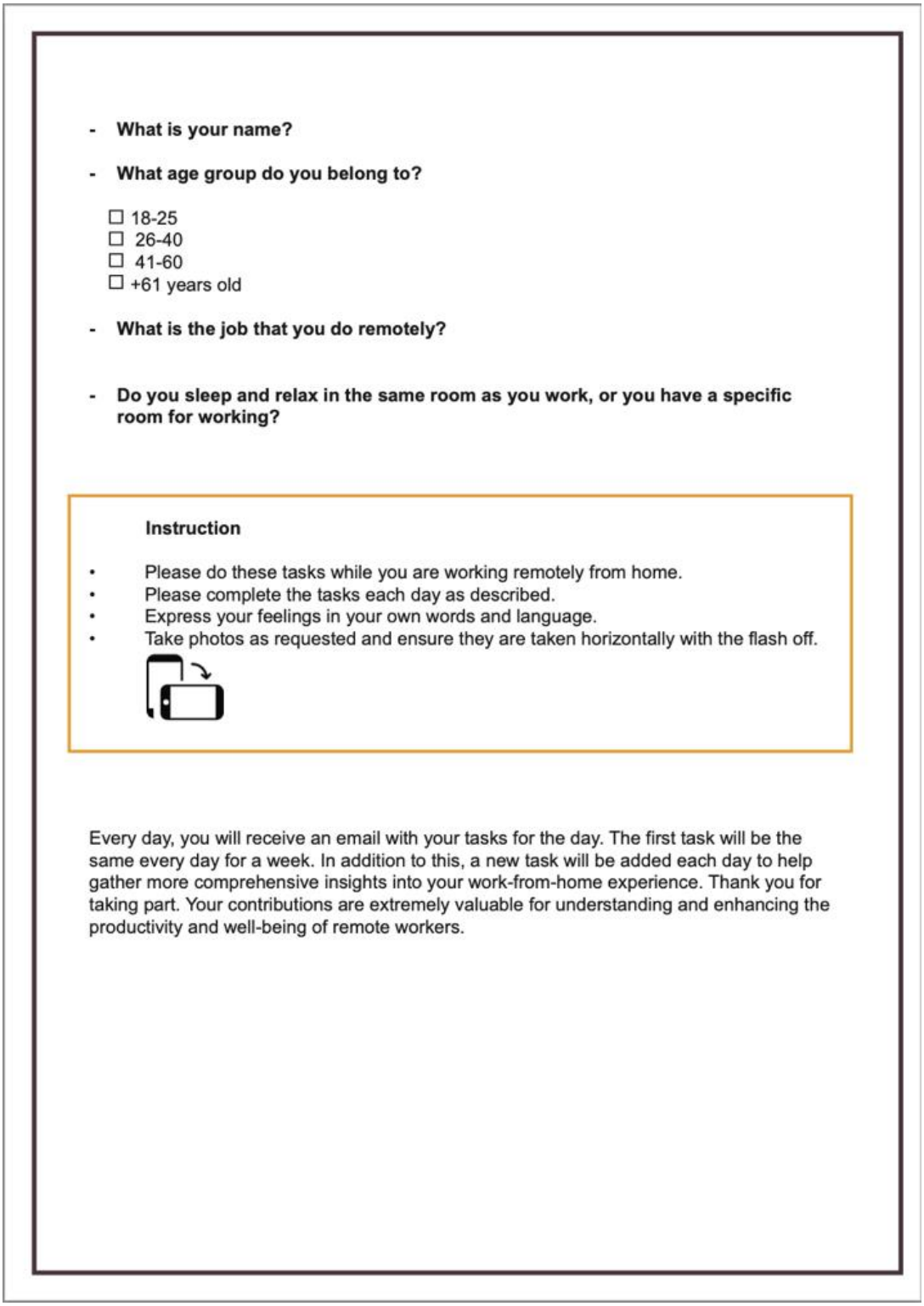


Figure 74: Awareness of the influence of indoor lighting on well-being and productivity

7.3. Digital Kit of Cultural Probes



- **What is your name?**

- **What age group do you belong to?**

☐ 18-25
☐ 26-40
☐ 41-60
☐ +61 years old

- **What is the job that you do remotely?**

- **Do you sleep and relax in the same room as you work, or you have a specific room for working?**

Instruction

- Please do these tasks while you are working remotely from home.
- Please complete the tasks each day as described.
- Express your feelings in your own words and language.
- Take photos as requested and ensure they are taken horizontally with the flash off.

Every day, you will receive an email with your tasks for the day. The first task will be the same every day for a week. In addition to this, a new task will be added each day to help gather more comprehensive insights into your work-from-home experience. Thank you for taking part. Your contributions are extremely valuable for understanding and enhancing the productivity and well-being of remote workers.

Figure 75: Digital kit of cultural probes

DAY 1

Stop working for a moment.

Please take a picture of your home-office environment with your desk. Write how you feel.

I feel … _____

_____

Because … _____

_____

_____

_____

_____

_____

_____

If there's something specific in your room that triggers these feelings, please mention it.

_____

Which one represents you the most today?

Continue to work

(Repeat this every day for a week)

DAY 2

Stop working for a moment.

Please take a picture of your home-office environment with your desk. Write how you feel.

I feel ... _____

_____

Because ... _____

_____

_____

_____

_____

_____

_____

If there's something specific in your room that triggers these feelings, please mention it.

_____

Go closer and take a picture of your table with its arrangement and write how you feel.

I feel ... _____

_____

_____

_____

_____

_____

_____

_____

Apart from your laptop, computer, and mobile phone, what must be on your desk.

_____

Which one represents you the most today?

Continue to work

DAY 3

Stop working for a moment.

Please take a picture of your home-office environment with your desk. Write how you feel.

I feel ...

Because ...

If there's something specific in your room that triggers these feelings, please mention it.

Which of the following photos is the closest to your ideal home office environment?

1 2 3 4

Write the reason, explaining what makes this environment closer to your ideal.

I like this home-office environment because...

Which one represents you the most today?

Continue to work

DAY 4

Stop working for a moment.

Please take a picture of your home-office environment with your desk. Write how you feel.

I feel ... _____

_____

Because ... _____

_____

_____

_____

_____

_____

If there's something specific in your room that triggers these feelings, please mention it.

_____

Show me the home-office environment that makes you feel refreshed and focused
(It can be a photo from the internet, Pinterest, a collage with photos or using AI.
Show it in any way you like)

Which one represents you the most today?

Continue to work

DAY 5

Stop working for a moment.

Please take a picture of your home-office environment with your desk. Write how you feel.

I feel ...

Because ...

If there's something specific in your room that triggers these feelings, please mention it.

Take a picture of the most comfortable and uncomfortable part of your home-office and explain why you feel this way:

It makes me feel comfortable because...

It makes me uncomfortable because...

Which one represents you the most today?

Continue to work

DAY 6

Stop working for a moment.

Please take a picture of your home-office environment with your desk. Write how you feel.

I feel ...

Because ...

If there's something specific in your room that triggers these feelings, please mention it.

I want to feel...

What changes or additions could make your home-office a better place to work?

How does the lighting of your home-office make you feel and what effect does it have on you?

It makes me feel ...

Which one represents you the most today?

Continue to work

DAY 7

Stop working for a moment.

Please take a picture of your home-office environment with your desk. Write how you feel.

I feel ... _____

_____

Because ... _____

_____

_____

_____

_____

_____

_____

If there's something specific in your room that triggers these feelings, please mention it.

_____

Write about any insights or changes you experienced from completing these tasks.

_____

_____

_____

Which one represents you the most today?

Thank you for taking part. Your contributions are extremely valuable for understanding and enhancing the productivity and well-being of remote workers.