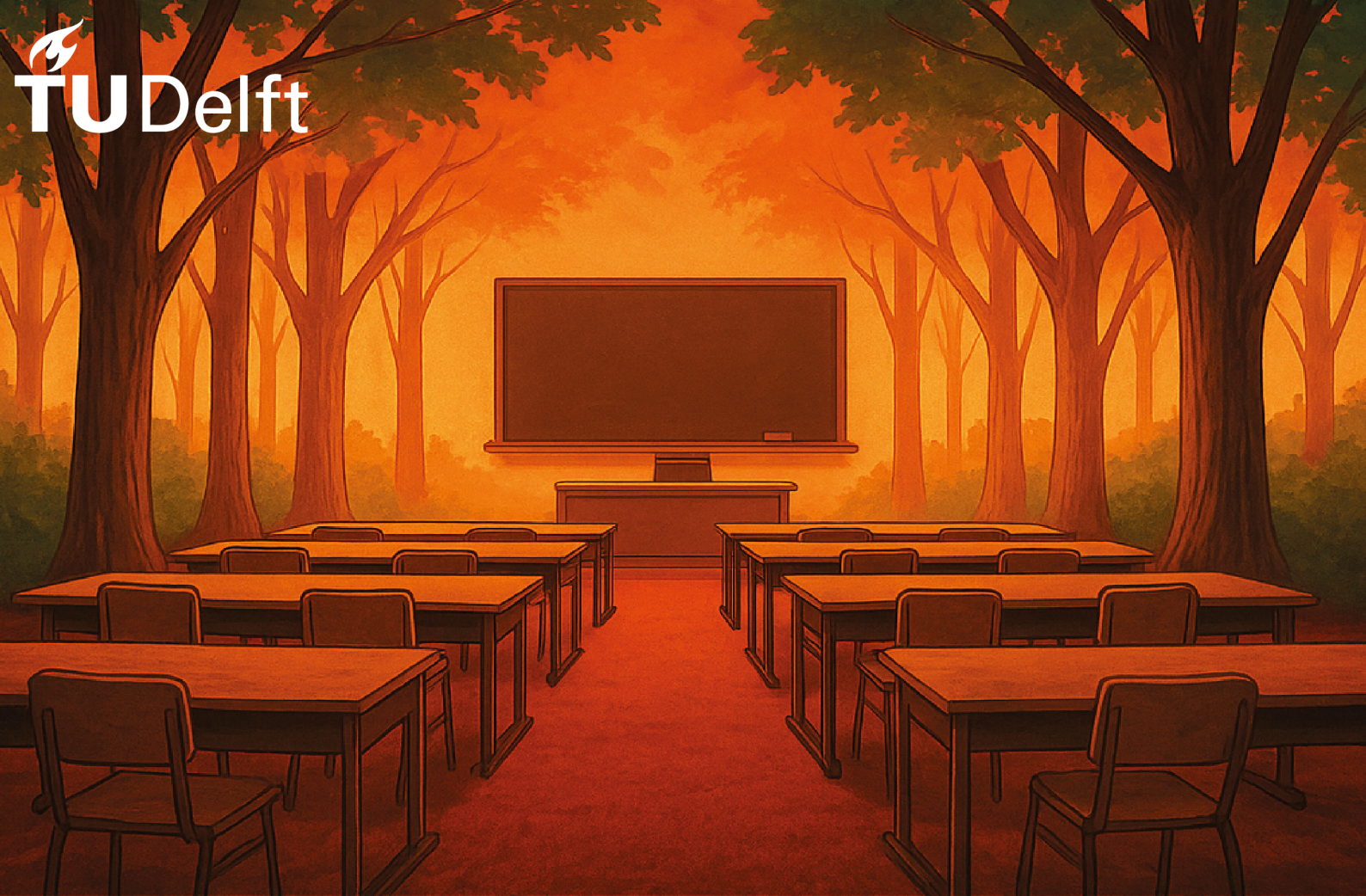




STRESS IN THE LEARNING ENVIRONMENT

Influencing stress and wellbeing of university students by identifying stressors in the physical learning environment

Master thesis

19 June 2025

Bauke Meijer
4722906



First mentor
Second mentor
Third mentor

Dr.ir. M.H. [Monique] Arkesteijn [TU Delft]
Dr.ir. V. [Vitalija] Danivska [TU Delft]
Ir. S. [Sophie] Schuller, PhD[c], [TU Eindhoven]

I COLOPHON



Student information

Name	Bauke Meijer
Student number	4722906

Educational institution

Institution	Delft University of Technology
Faculty	Architecture and the built environment

Graduation programme

Degree programme	Architecture, Urbanism and Building Sciences
Department	Management in the Built Environment
Studio	Value in Corporate and Public Real Estate
Document	Graduation Thesis
Title	Stress in the Learning Environment

Supervisors

First mentor	Dr.ir. M.H. [Monique] Arkesteijn [TU Delft]
Second mentor	Dr.ir. V. [Vitalija] Danivska [TU Delft]
Third mentor	Ir. S. [Sophie] Schuller, PhD[c], [TU Eindhoven]
Internship	Ir. S. [Saskia] Knoop [VKZ BV]
BoE delegate	Dr.ir. M.C. [Martijn] Lugten [TU Delft]

II PREFACE

In the past few weeks, as my thesis drafts began to resemble a complete document, it finally started to dawn on me how close I am to finishing my time in Delft. I'm now beginning to fully grasp the "af" (finished) in the Dutch word afstuderen. It's made me reflect on the many years I've spent here. The year was 2017 when I first walked through the main entrance of BK City, blissfully unaware of job markets, career paths, or architectural prestige, but simply excited to pour my creativity into something.

It took me five years to complete my bachelor's, with plenty of detours along the way: committees, boards, internships, anything I could find to stretch out my time in Delft. Those years gave me ample opportunity to explore design and architecture, both academically and personally. But they also gave me time to reflect. I came to see that, while many of my peers had the drive and talent to become the next big architects, I didn't share that same calling. What I discovered during my time on the board of SHS Delft was that the so-called "boring" side of the built environment, as many bachelor's students see it, wasn't boring at all. It was where things actually got done. That realisation led me to the Management in the Built Environment master's track, and to saying goodbye to designing buildings so I could focus on helping get them built. Over the past three years, I've found a true sense of belonging in this track. It's a close-knit group of teachers and students where everyone seems to know each other and studying happens in a healthy balance with social life. Joining a committee at BOSS in my first year made me feel even more at home. And even after being away from the faculty for more than half a year, pursuing less academic goals abroad, it felt incredibly welcoming to return to the hallways of BK City. After taking a few courses with the next generation of MBE students, I quickly found myself surrounded by new friends.

But all good things must come to an end. Like many before me, I embarked on the graduation lab journey, though hopefully not like too many others before me, I had a rough time finding a topic. After many hours of guidance, support, and feedback from my mentors at TU Delft, Monique Arkesteijn and Vitalija Danivska, and later on from TU Eindhoven's Sophie Schuller, I found myself exploring a subject I never expected to write a thesis about: stress in the learning environment. Without the three of you, I wouldn't have gotten anywhere. Being a complete layman in the field of psychology made for a rocky road, but also for many learning moments I'm grateful for. Later in the process, I joined VKZ BV for a graduation internship under the guidance of Saskia Knoop. I'd also like to express my deep appreciation for my unofficial mentor, Sake Zijlstra, for always offering a listening ear and helping me learn how to solve problems on my own, not just during this thesis, but throughout my many years at this faculty. To all my mentors: thank you. I know I haven't always been the easiest student, but your guidance helped steer me, finally, to my academic destination: graduating from Delft University of Technology.

III ABSTRACT

Stress among university students is a growing concern across the Netherlands, Europe, and the world, yet the influence of physical learning environments on stress remains underexplored. This thesis investigates how two contrasting university study environments influence students' stress responses, both physiologically and psychologically. The study compares two real-life university rooms at Delft University of Technology: a traditional, warm-toned space and a newer, cool-toned, modern environment. Stress was measured using salivary cortisol, custom-designed survey items, and thematic analysis of open-ended survey responses.

Results show that students in the newer room reported improved concentration and reduced self-perceived physiological stress. In contrast, cortisol levels slightly increased in this space, though not significantly. This rise may indicate focused arousal or "eustress" rather than distress, suggesting that environments supporting concentration might trigger physiological activation even when perceived stress is low. Qualitative responses supported this interpretation, with students describing task-dependent preferences and subconscious responses to room design.

These findings suggest that the physical learning environment can influence how students experience stress, while also highlighting a mismatch between psychological and physiological indicators. The divergence reinforces the importance of using multi-method approaches in environmental stress research, implementing multiple stress indicators both physiological and psychological. The study concludes that a diverse range of adaptable study environments is needed to accommodate students' varying emotional and cognitive needs. Physical design should be considered a meaningful factor in promoting student wellbeing and academic performance.

Keywords: Psychological stress, Physiological stress, University, learning environment, Student, Salivary cortisol

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1 INTRODUCTION

This first chapter introduces the background and motivation for the study. It outlines why stress among university students has become a topic of growing concern and presents the central research aim. The chapter concludes with a set of research questions and a simplified conceptual framework to guide the analysis.

1.1 PROBLEM STATEMENT

In recent years, stress among university students has emerged as a critical concern, reflecting broader societal challenges surrounding mental well-being in young people (American Psychological Association (APA), 2020). The World Health Organization (WHO, 2017) reports a significant increase in mental health disorders over recent decades, with the impact being particularly acute among younger populations. Research by Kessler (2007) underscores that mental health challenges often begin to manifest between the ages of 16 and 24, coinciding with the ages of university students. This developmental phase is marked by heightened vulnerability due to academic pressures, social transitions, and personal growth milestones, making university students a group at elevated risk for mental health challenges (APA, 2020). Stress, depression, anxiety, loneliness, and even burnout have become increasingly prevalent among this demographic (Auerbach et al., 2016). Across Europe, recent surveys reveal that mental health concerns and elevated stress levels are common among university students.

Across Europe, recent surveys indicate that mental health difficulties and high stress are common among university students. According to the Eurostudent study (Cuppen, 2022), over one-third of students report low emotional well-being, with rates approaching 60% in some countries. The European University Association (EUA) also notes that around 40% of higher-education students experience mental health challenges, and approximately 20% meet criteria for clinical disorders, of which numerous cases are stress-related (Hauschildt, 2022). In the Netherlands, data from the Trimbos Institute show that 56% of students report high to very high stress, while 44% experience symptoms of anxiety or depression (Dopmeijer, 2023).

Despite their susceptibility, students often underutilise available support services, potentially due to stigma, limited awareness, or insufficient accessibility (Gulliver et al., 2010). This gap in engagement underscores the importance of exploring alternative approaches to support student well-being. One area of interest is the role of the physical learning environment, where students spend a significant portion of their time (Fraser, 2001). Thoughtfully designed learning environments could help mitigate stress factors, providing a sustainable and proactive means of fostering mental well-being. By understanding how elements of physical design impact stress outcomes, institutions can identify strategies to improve students' experiences and reduce stressors within academic environments.

While the influence of environmental characteristics on mental health and stress has been widely studied in workplaces (Al Horr et al., 2016; Bergefurt et al., 2023), their role in university learning environments remains underexplored. The direct link between physical university learning environments and student stress has received limited attention in academic research, presenting both a gap and an opportunity for further research.

1.2 RESEARCH AIM

This thesis investigates how physical learning environments influence stress among university students. These two concepts, stress and the physical characteristics of study spaces, form the central focus of the research. Other elements, such as student background or types of stressors, are treated as contextual influences rather than as core variables. The goal is to better understand whether and how specific features of the built environment play a role in shaping students' stress experiences during academic activity. While previous research has shown that such factors can affect well-being in work environments, their role in university learning contexts remains underexplored. This study aims to address that gap by exploring the relationship between physical study environments and student stress, with the broader goal of identifying design insights that support mental well-being in higher education.

To explore how physical learning environments influence stress, this thesis is guided by a structured set of research questions. These address both theoretical dimensions (what stress is, how it is measured, and what we know about environmental effects) and practical applications (how different learning environments affect student stress in practice).

1.3 RESEARCH QUESTIONS

The central aim of this thesis is to explore the relationship between physical university learning environments and perceived stress among students, with a focus on Dutch universities. To achieve this, the following research questions have been formulated to guide the investigation. These questions are formulated to ensure a comprehensive understanding of the topic, combining theoretical insights with empirical analysis.

1.3.1 MAIN RESEARCH QUESTION

The main research question in this thesis is the following:

"What is the relationship between (new) physical learning environments and stress among students at a Dutch University?"

By addressing this main question, the study aims to provide evidence-based guidelines that inform future campus development, contributing to sustainable, stress-reducing learning environments that enhance students' well-being and academic performance.

1.3.2 SUB RESEARCH QUESTIONS

To address the main research question, the following sub-questions are proposed:

RQ1: *"What are the different types of stress and stressors relevant to university students in learning environments?"*

RQ2: *"How can different types of stress in university students be measured?"*

RQ3: *"What is a (new) university learning environment?"*

RQ4: *"What observable characteristics of (new) university learning environments influence stress among university students?"*

RQ5: *"How do newer university learning environments differ from traditional ones in their influence on student stress?"*

1.3.3 RELEVANCE OF RESEARCH QUESTIONS

These research questions collectively aim to provide a holistic understanding of how physical university learning environments influence stress. They encompass both theoretical exploration and empirical investigation, ensuring that the study addresses not only the broader relationship between learning environments and stress but also the specific mechanisms and characteristics at play. By answering these questions, the research will contribute to the development of student-centered campus designs that help foster (mental) well-being.

1.4 CONCEPTUAL FRAMEWORK

To clarify the scope and structure of this research, the diagram below presents a simplified conceptual framework. It visualises the relationship between student-specific stress(ors), the physical characteristics of newer and traditional learning environments, and students' stress. This framework serves as a foundation for the study, clarifying how each sub-question connects to key concepts.

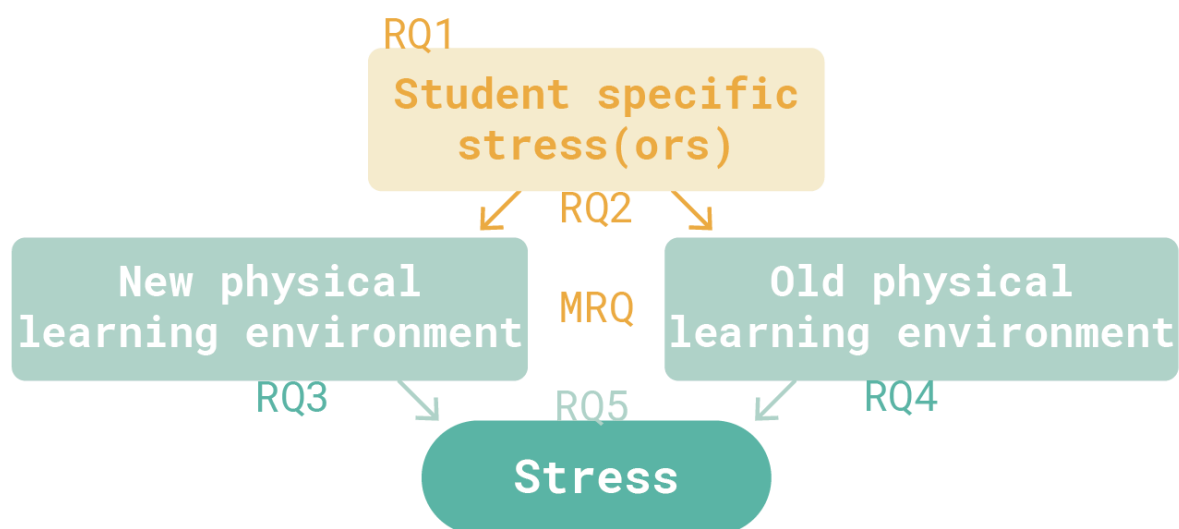


Figure 1: Initial conceptual framework showing assumed relationships between student stress(ors), physical learning environments, and stress, along with corresponding research questions (own ill.)

This simplified framework is used to structure the empirical study. It centres around two constructs: physical environment and stress (both perceived and physiological). RQ2 supports this framework by defining how stress is measured but is not itself a theoretical component.

2 THEORATICAL BACKGROUND

This chapter provides the theoretical foundation for exploring how physical university environments influence student stress. It begins with a conceptual overview of stress, distinguishing between its psychological and physiological dimensions, and outlining its relevance to student wellbeing. The chapter then reviews validated methods for measuring stress, including both subjective self-report tools and objective physiological biomarkers. Building on this, the final section examines how specific physical characteristics of learning environments can influence stress responses. Together, these perspectives inform the hypotheses and conceptual framework that guide the empirical part of this research.

2.1 UNDERSTANDING STRESS

Stress is a multifaceted response encompassing both psychological and physiological dimensions, triggered by internal or external demands that challenge an individual's capacity to adapt (Selye, 1956; Lazarus & Folkman, 1984; Persiani, 2021). Stress is adaptive and needed, and can be categorised as either distress (negative stress) or eustress (positive stress), depending on whether the individual perceives themselves as capable of coping with the stressor (Selye, 1956; Leidy et al., 1990). It is recognised as a factor linked to numerous chronic disease risk factors, affecting both physical and mental health (Juster et al., 2010; Shah, 2024). Stress is induced by various internal and external stressors that disrupt an individual's balance (Selye, 1956). According to the Job Demands-Resources (JD-R) model, which is widely used in workplace stress research, stress arises when the demands placed on an individual exceed their available resources (Demerouti et al., 2010; Bakker & Demerouti, 2007). While this study does not directly apply the JD-R model, it is relevant as a conceptual foundation, especially because it informs the student-specific framework by Slimmen et al. (2022) used later in this chapter. The perception of stress is influenced by individual differences and coping mechanisms, with some stressors acting as motivators while others lead to detrimental effects (Persiani, 2021).

2.1.1 PSYCHOLOGICAL AND PHYSIOLOGICAL STRESS

Psychological stress arises from cognitive and emotional processes in response to perceived challenges, often influenced by an individual's subjective evaluation of events (Persiani, 2021; Giannakakis et al., 2019). Stressors can be physical, task-related, interpersonal, or environmental (Quick et al., 2003), and their impact on psychological well-being depends on individual factors such as personality, gender, and available resources (Leidy et al., 1990). Psychological stress can impair cognitive performance, memory, and emotional well-being (McEwen, 2006). Empirical studies have shown that psychological stress can lead to cognitive impairments, including difficulties in attention, working memory, and decision-making. For instance, high stress levels have been associated with reduced performance in tasks requiring executive functions (Shields et al., 2016). Moreover, chronic psychological stress has been linked to structural and functional changes in brain regions such as the hippocampus and prefrontal cortex, which are critical for memory and cognitive control (McEwen & Morrison, 2013).

Individual and personal differences also modulate the impact of psychological stress. Individuals with high resilience or effective coping strategies may experience less detrimental effects on cognitive functions compared to those with maladaptive coping mechanisms (Connor & Davidson, 2003).

Physiological stress is an involuntary response mediated by the autonomic nervous system (ANS), involving a series of biochemical and neuroendocrine processes (Giannakakis et al., 2019; Persiani, 2021). Upon encountering a stressor, the body activates two primary systems: the hypothalamic pituitary adrenal (HPA) axis and the sympathetic adrenal medullary (SAM) axis (Shah, 2024; Juster et al., 2010). The HPA axis governs the body's prolonged stress response. Activation begins when the hypothalamus releases corticotropin releasing hormone (CRH), stimulating the adrenocorticotrophic hormone (ACTH), which then prompts the adrenal cortex to produce glucocorticoids, notably cortisol, which modulate physiological functions (Juster et al., 2010; McEwen & Wingfield, 2003). On the other hand, the SAM axis manages the immediate "fight or flight" response (Tonello et al., 2014). Stress triggers the sympathetic nervous system, leading to the activation of the adrenal medulla and the release of adrenaline (epinephrine) and noradrenaline (norepinephrine), which prepare the body for action by increasing heart rate, blood pressure, and energy availability (Godoy et al., 2018; Shah, 2024). Both axes play integral roles in enabling the body to cope with stressors by regulating cardiovascular, metabolic, and immune functions.

The relationship between psychological and physiological stress responses is often varied, with individual differences playing a significant role (Hilger et al., 2024). Factors such as personality traits, cognitive ability, and interoceptive awareness can moderate the correspondence between these stress responses (Mordkoff et al., 1964; Koksai, 2022). While psychological stress is typically assessed through self-reports, physiological stress is often measured using biomarkers (e.g. cortisol levels and heart rate). The exact measurement methods will be discussed further on in this chapter. Studies have shown that these measured results do not always correlate, suggesting the need for comprehensive stress assessments that include both psychological and physiological indicators (Becker et al., 2022; Sommerfeldt et al., 2019).

2.1.2 ACUTE AND CHRONIC STRESS

Stress is commonly categorised as acute or chronic, depending on its duration and impact. While other classifications exist, this study focuses specifically on acute and chronic stress, as these are the most widely examined in psychological and health-related research. Acute stress is short-term and arises in response to immediate challenges, often enhancing alertness and motivation if managed effectively (Lazarus & Folkman, 1984). Acute stress triggers the "fight or flight" response, characterised by increased heart rate, blood pressure, and cortisol levels (Tonello et al., 2014). Excessive acute stress can lead to anxiety and diminished cognitive performance (APA, 2024). While short-term activation of these systems can be adaptive, prolonged exposure can disrupt homeostasis and lead to long-term health issues (Shah, 2024).

Chronic stress, on the other hand, persists over extended periods due to ongoing challenges. Prolonged activation of the stress response can result in sustained elevated levels of biomarkers such as cortisol, adrenaline, and inflammatory cytokines (McEwen, 2008; Schuller, 2024; Shah, 2024). Chronic elevations in these markers increase the risk of cardiovascular disease, metabolic disorders, and mental health challenges such as burnout and depression (Schuller, 2024; APA, 2024). Additionally, chronic stress can contribute to allostatic load, a state characterised by cumulative physiological wear and tear resulting from continuous or recurrent exposure to stressors without adequate recovery (McEwen, 2008). Allostatic load itself is not inherently negative; rather, it becomes harmful when sustained at high levels or when the body's adaptive capacities are exceeded, subsequently impairing functions of the brain, immune system, and cardiovascular system (McEwen, 2008; Juster et al., 2010; Shah, 2024).

2.1.3 UNIVERSITY STUDENTS AND STRESS

The effects of stress on university students' health and academic performance are profound (Saleh et al., 2017; Talib et al., 2012). A relevant framework for understanding student stress is presented by Slimmen et al. (2022), who investigated how different categories of stressors affect university students' mental wellbeing. Their study identified four key stress domains: academic pressure, financial pressure, family circumstances, and side-activity pressure. These categories were derived from previous empirical research and structured using two theoretical models: the JD-R model (Bakker & Demerouti, 2007) and the Student Wellbeing Model (Gubbels & Kappe, 2019), which inform this study indirectly but are not applied independently.

Importantly, Slimmen et al. (2022) found that all four stressors significantly contributed to higher perceived stress levels, which in turn were associated with lower mental wellbeing. Notably, academic and family pressures also exerted a direct negative influence on mental wellbeing, meaning that they affected wellbeing even when students did not report feeling more stressed. This suggests that certain stressors may bypass conscious perception and still impact mental health outcomes.

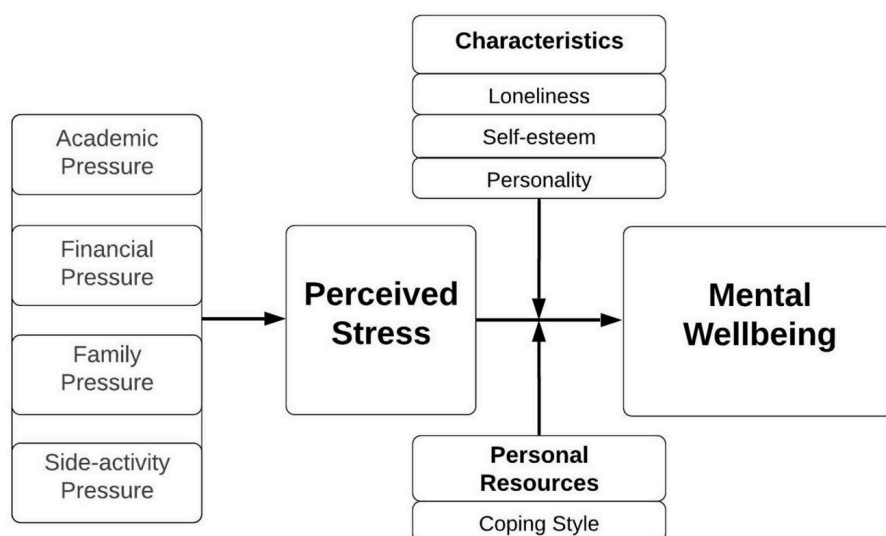


Figure 2: The relationship between underlying stressors, perceived stress, characteristics, personal resources and mental wellbeing. (Slimmen et al., 2022)

A complementary perspective is offered by Hamaideh (2010), who applied the Student-Life Stress Inventory (SSI) to classify stressors among university students into five psychological categories: self-imposed stressors (e.g., perfectionism, competitiveness), pressures (e.g., overload, time constraints), conflicts (e.g., interpersonal tensions), changes (e.g., life transitions), and frustrations (e.g., blocked goals). While Hamaideh's model is more psychological and typological, there is clear conceptual overlap with Slimmen et al.'s (2022) domain-based approach. For example, academic and side-activity pressures can be linked to perceived overload and self-imposed expectations, while family-related stress may manifest in interpersonal conflicts or frustrations. Together, these studies underscore the multifaceted nature of student stress, combining both structural demands and personal experiences. In this research, Slimmen et al.'s (2022) framework of four student stressors, academic, financial, family-related, and side-activity pressure, is adopted as the basis for examining stress in university learning environments.

Recent surveys across Europe indicate that high stress levels and mental health challenges are widespread among university students. For example, a 2022 report by EUA found that about 40% of higher-education students in EU countries experience mental health or wellbeing difficulties, with nearly 20% facing diagnosable disorders (Hauschildt, 2022). Nationally, a Trimbos-Institut survey reports that 56% of Dutch students experience high or very high stress, while 44% report anxiety or depression symptoms (Dopmeijer, 2023). These figures far exceed those of the general population and highlight stress among students as a significant and systemic concern. Given that students spend many hours in classrooms, libraries, and study environments, it is crucial to examine how the physical design of these spaces may exacerbate or alleviate stress. By exploring the interplay between environmental conditions and student well-being, this study contributes to a more comprehensive understanding of academic stress as a spatial phenomenon.

While stress is often framed negatively, it can also have beneficial effects, particularly when experienced as eustress, or positive stress. Eustress refers to manageable, motivating forms of stress that can enhance energy, focus, and performance, especially when students feel capable of meeting academic demands (Ganesan et al., 2018). Moderate levels of stress, when well-regulated, can foster growth, learning, and adaptation. Individual traits strongly influence whether stress is experienced as eustress or distress: for example, high self-efficacy enables students to benefit from challenge, while conscientiousness is positively associated with eustress. In contrast, introversion and low emotional stability increase the likelihood of distress responses (Mateo et al., 2016). Recognising the distinction between eustress and distress is crucial when evaluating student well-being, as it highlights that stress is not inherently harmful, its effects depend on context, coping capacity, and the design of the environment in which it occurs.

2.2 MEASURING STRESS

Building on the conceptual distinctions introduced in the previous section, this part of the literature review focuses on how psychological and physiological stress can be measured. This section reviews validated tools and biomarkers used to measure psychological and physiological stress, with particular attention to their applicability in university student contexts.

2.2.1 MEASURING PSYCHOLOGICAL STRESS

The Perceived Stress Scale (PSS) is one of the most widely used and validated tools for assessing psychological stress across diverse populations and languages. It is available in three versions: the PSS-4, PSS-10, and PSS-14. The PSS-4, while suitable for time-limited contexts, shows lower reliability and validity due to its brevity and limited item base (Huang et al., 2020). In contrast, both the PSS-10 and PSS-14 offer stronger psychometric properties. Notably, the PSS-10 has been found to match or even exceed the PSS-14 in terms of internal consistency and structural validity across various populations (Roberti et al., 2006). The PSS-10 is currently the most widely accepted version. It demonstrates robust internal consistency and construct validity in multiple studies (Klein et al., 2016; Huang et al., 2020). The scale generally reflects a two-factor structure, capturing both perceived distress and coping ability (Nielsen et al., 2016; Kožar & Kožar, 2023). Moreover, it has shown measurement invariance across gender and demographic groups, reinforcing its value for comparative research (Reis et al., 2019). Its validity across age groups and clinical contexts further supports its broad applicability (Kožar & Kožar, 2023). Because of its reliability, brevity, and cross-context applicability, the PSS-10 is widely used in both academic and clinical settings to assess perceived psychological stress and its potential impacts on mental and physical health (Nielsen et al., 2016).

2.2.2 MEASURING PHYSIOLOGICAL STRESS

As described in the previous subchapter, physiological stress is mediated by the HPA and SAM axes. In this subchapter the specific methods of measuring this type of stress will be outlined. Below is a review of the most widely used and validated biomarkers in physiological stress research. The following sections outline key physiological biomarkers, grouped by cardiovascular, electrodermal, and endocrine indicators.

2.2.2.1 CARDIOVASCULAR BIOMARKERS

Heart Rate (HR) measures the number of heartbeats per minute. It increases acutely in response to stress due to sympathetic nervous system activation (Shaffer & Ginsberg, 2017). Heart Rate Variability (HRV) measures fluctuations in the time intervals between heartbeats (R-R or N-N intervals) and reflects parasympathetic nervous system activity (Acharya et al., 2006; McCraty & Shaffer, 2015). A lower HRV is typically associated with higher stress and poorer autonomic regulation (Shaffer & Ginsberg, 2017). However, it is important to note that HR and HRV are not specific to stress alone. These measures can also reflect general arousal, cognitive workload, physical activity, and emotional engagement, depending on the context (Shaffer & Ginsberg, 2017). Therefore, careful interpretation is required when using them as stress indicators in dynamic real-world environments. Because the SAM axis directly affects cardiovascular function, both HR and HRV serve as real-time indicators of acute stress reactivity, especially during emotionally or cognitively demanding situations (Faurholt-Jepsen et al., 2017; Kim et al., 2018).

To build confidence in this method, it is important to recognise that HRV has been successfully used in academic stress research. A recent systematic review spanning 48 educational studies confirms HRV as a valid non-invasive biomarker for emotional stress and focused attention in university settings (Kim et al., 2024)

2.2.2.2 ELECTRODERMAL ACTIVITY

Electrodermal Activity (EDA), also known as Galvanic Skin Response (GSR), measures changes in the skin's electrical conductance due to sweat gland activity. These glands are exclusively innervated by the sympathetic nervous system, making EDA a direct marker of SAM activation (Critchley, 2002). EDA increases rapidly during psychological arousal, emotional stress, or anticipation of a challenge. It has been validated for real-time stress detection, particularly in naturalistic settings using wearable technology (Zangróniz et al., 2017; Bakker et al., 2011). EDA has also been widely used in educational research to capture moment-to-moment physiological arousal. For example, studies have used EDA to monitor student engagement and stress during programming tasks and classroom activities, showing strong correlations with emotional arousal and attention shifts (Harley et al., 2015; Papamitsiou & Economides, 2014).

2.2.2.3 ENDOCRINE BIOMARKERS

Cortisol is a widely used biomarker for assessing chronic stress, but it can also reflect acute stress reactivity depending on the timing and context of sampling (Hellhammer et al., 2009). Cortisol can be measured via saliva, blood, urine, or hair, each reflecting different time scales, saliva for momentary changes, hair for long-term exposure (Stalder et al., 2016). Salivary alpha-amylase is another biomarker increasingly used in stress research. Although not a hormone, its secretion is influenced by sympathetic activation, making it a useful indirect indicator of SAM system activity (Nater & Rohleder, 2009). Joon Park et al. (2023) recently conducted a naturalistic study measuring cortisol in students before and after a major exam, highlighting the usefulness of cortisol research in educational settings.

2.2.2.4 BIOMARKERS FOR THIS RESEARCH

Due to time constraints inherent in a graduation project, chronic stress measures like hair cortisol analysis are not feasible. Additionally, invasive biomarkers that could cause participant discomfort, such as blood or urine samples, are excluded from this study. This research therefore focuses on acute physiological stress, emphasising real-time, non-invasive biomarkers. Among these, HRV, HR, and EDA are included in the selection due to their strong empirical validation, accessibility through wearable sensors, and direct linkage to SAM system activity, which is especially relevant for stress triggered by psychological appraisal in short-term scenarios (McEwen, 2008; Gianaros et al., 2018). Salivary cortisol will also be included in the selection, as it provides a non-invasive measure of HPA axis activity. However, its delayed response must be considered when interpreting short-term stress exposure effects (Hellhammer et al., 2009). Levels begin to rise shortly after stress exposure, peak around 25 minutes, and then gradually return to baseline as cortisol is cleared from circulation, with a half-life of approximately 60-70 minutes (Gunnar & Quevedo, 2007). All of these biomarkers are deemed suitable within the scope of this research and will be further discussed in the methodology section.

2.3 ENVIRONMENTAL CHARACTERISTICS AND STRESS

Beyond understanding stress itself, it is equally important to examine how the physical characteristics of learning environments contribute to or mitigate student stress. This section reviews literature from both educational and workplace settings, with a focus on physical characteristics. Given the limited research specifically targeting university settings, studies from office and school environments are also included to build a broader understanding. The goal is to identify which physical factors are most relevant for stress reduction in academic spaces, and to justify their inclusion in the conceptual framework and empirical study.

2.3.1 UNIVERSITY STUDENTS AND STRESS

Students spend a significant amount of time indoors at their educational institutions (Fraser, 2001), and the quality of these physical environments can impact both their well-being and academic performance (van den Bogerd, 2021). By the time they graduate, students spend approximately 20,000 hours in classrooms (Fraser, 2001), further highlighting the significant time spent in learning environments. Enhancing indoor environmental conditions may serve as a buffer against stress (van den Bogerd, 2021). In the literature, green spaces and biophilic design principles are the main elements in influencing stress in physical learning environments. Exposure to natural environments, such as campus forests and green spaces, has been shown to improve students' psychological health by reducing stress and depression, and enhancing their life satisfaction (Ulrich et al., 1991, Bang et al., 2017, Payne et al., 2020, Ning et al., 2023). Huang et al. (2020) emphasise that plant landscapes not only beautify campuses but also support diverse student needs, from shaded leisure areas to visually calming pathways. Green spaces also contribute to inclusivity, offering accessible environments that foster interaction and belonging (Campos, 2021). Sustainable landscaping approaches, like "sponge cities" for rainwater recycling, provide functional, stress-reducing environments (Huang et al., 2020).

Biophilic design integrates natural elements, like plants, water features, and natural materials, into built environments to reduce stress and enhance well-being. Abdelaal and Soebarto (2018) demonstrate how biophilic principles can foster relaxation in educational spaces. The literature suggests that biophilic environments improve cognitive function, emotional resilience, and creativity, making them suitable in stress-reducing campus designs (Abdelaal & Soebarto, 2018). In another study, stressors in classrooms were identified that increased anxiety among college students at Zhejiang University in China (Wen et al., 2024). Influencing factors were ventilation, lighting, thermal comfort and noise conditions. The paper suggests that enhancing these classrooms can lower the likelihood of student anxiety.

2.3.2 WORKPLACE AND STRESS

During the literature screening, limited literature was found specifically dedicated to the relation between physical learning environments of university and stress. However, much research has been done on physical workplaces and their relation to users' wellbeing and stress. Al Horr et al. (2016) mention 8 characteristics that affect occupant satisfaction and productivity, namely indoor air quality and ventilation, thermal comfort, lighting and daylighting, noise and acoustics, office layout, biophilia and views, look and feel, and location and amenities. Of these 8 characteristics, 7 characteristics were identified by Kropman et al. (2022) that were relevant to the effect of the physical office space on mental health. The characteristic 'Location and amenities' was eliminated as this characteristic is not bound to the physical work environment itself. In their research Kropman et al. (2022) and Bergefurt et al. (2023) related the following 7 characteristics to office work environments: noise, acoustics and privacy, light and daylight, thermal comfort and temperature, indoor air quality and ventilation, layout and design, biophilia and views, look and feel.

Frequency of relationships studied between physical workspace and mental health											
	Concentration	Sleep quality	Mood	Stress	Productivity	Depression	Well- being	Fatigue	Engagement	Burnout	Nr. of papers
Noise, acoustics, and privacy	8	8	7	9	11	5	6	5	5	3	20
Light and daylight	6	7	6	6	8	4	3	4	4	2	14
Thermal comfort and temperature	6	6	6	6	10	5	4	5	5	3	13
Indoor air quality and ventilation	6	5	5	5	8	4	3	4	4	2	12
Layout and design	3	1	2	2	4	1	2	2	2	2	10
Biophilia and views	2	2	3	2	3	3	1	1	1	1	6
Look and feel	1	1	1	1	2	1	1	1	1	1	2
Nr. of papers	10	10	9	10	12	7	6	5	6	4	

Table 1: relationships between physical workspace and mental health, from Bergefurt et al. (2023)

In their literature review, Bergefurt et al. (2023) reviewed the frequency of relationships between physical workspace characteristics and mental health aspects, linking the 7 characteristics to stress, an important aspect of mental health, as well. Interestingly, there seems to be a lack of research on the combination of the characteristic 'look and feel' and stress, making it a potential topic for further research.

2.3.2.1 NOISE, ACOUSTICS AND PRIVACY

Workplace acoustics significantly affect concentration, fatigue, and stress. Background noise exceeding 48dB reduces productivity and increases fatigue (Haapakangas et al., 2018; Lou & Ou, 2019). High background noise levels have been linked to reduced well-being and increased stress (Colenberg et al., 2020). Similarly, high speech intelligibility, where background conversations are clearly understood, can become a major source of distraction, leading to cognitive stress and task disruption (Colenberg et al., 2020). Speech privacy is particularly problematic in open-plan offices, where high speech intelligibility causes distractions and cognitive strain (Liebl et al., 2012; Haynes et al., 2017). Enclosed offices or partitions improve focus and reduce stress, though excessively high partitions can lead to unpredictability in sound (Kim & Dear, 2013). Providing quiet zones and acoustic treatments improves employee satisfaction and task performance (Candido et al., 2019).

2.3.2.2 LIGHT AND DAYLIGHT

Lighting plays a crucial role in regulating circadian rhythms, influencing sleep quality, stress levels, and cognitive performance. Artificial lighting that lacks variation can disrupt melatonin and cortisol levels, leading to fatigue and reduced well-being (Van Bommel, 2006; Vetter et al., 2022). Dynamic and integrative lighting systems can mitigate these effects by adjusting intensity and colour temperature to align with natural rhythms (Ghaeili Ardabili et al., 2023). Exposure to natural daylight improves mood and productivity, though excessive light can cause glare and stress (Moscoso et al., 2021; Mork et al., 2020). Optimal daylight access depends on the window-to-wall ratio (WWR), which should be between 15% and 60% for balanced lighting (Hong et al., 2019).

2.3.2.3 THERMAL COMFORT AND TEMPERATURE

Thermal comfort varies between individuals but significantly affects productivity, stress, and cognitive function. The ideal office temperature typically ranges between 20-24°C, with women generally preferring slightly warmer temperatures than men (Mahdavi & Unzeitig, 2005;). Deviations from optimal temperatures increase stress and fatigue (Kim et al., 2018). Individual control over thermal conditions improves satisfaction and enhances workplace performance (D'Oca et al., 2018).

2.3.2.4 INDOOR AIR QUALITY AND VENTILATION

Poor indoor air quality (IAQ) negatively impacts cognitive function, respiratory health, and productivity. Ventilation rates should be at least 8L/s/person to maintain good air quality (ASHRAE, 2022). High levels of CO₂ (above 1000ppm) and volatile organic compounds (VOCs) increase fatigue and stress, while low air exchange rates are linked to reduced concentration and mental well-being (Gupta et al., 2020). Implementing HVAC systems, real-time air quality monitoring, and using plants for air purification can improve IAQ (Asif & Zeeshan, 2023).

2.3.2.5 LAYOUT AND DESIGN

Office layouts significantly impact employee well-being, stress, and productivity. Private offices provide the highest levels of concentration, productivity, and reduced stress (Bodin Danielsson et al., 2008; Di Blasio et al., 2019). Group offices offer moderate benefits, while open-plan offices (especially with more than 20 employees) have the most negative effects, including increased stress and reduced concentration (Di Blasio et al., 2019; Seddigh et al., 2014). Flexible workspaces with designated quiet zones and breakout rooms enhance productivity and well-being (Haapakangas et al., 2018). Additionally, the availability of storage space, ergonomic furniture, and personal control over workspaces improves perceived productivity (Lou & Ou, 2019; Haynes et al., 2017). High workplace density, both in terms of people and objects, has been shown to contribute to elevated stress levels (Schuller, 2022). Traditional workstation designs that rely on static desks and chairs can contribute to sedentary behavior and poor posture, which negatively affect physiological stress markers such as muscle tension and cardiometabolic health (Schuller et al., 2024). On the other hand, ergonomic and active workstations have been linked to improved HRV and lower levels of salivary alpha-amylase, indicating a reduction in physiological stress (Schuller et al., 2024).

2.3.2.6 BIOPHILIA AND VIEWS

Biophilic design, which integrates natural elements into the workspace, reduces stress, improves mood, and enhances productivity (Aristizabal et al., 2021; Lei et al., 2021; Yin et al., 2020). Exposure to natural views and indoor plants contributes to cognitive restoration and mental well-being (Smith et al., 2011; Ayuso Sanchez et al., 2018). Outdoor view elements, such as large windows providing views of natural elements, are noted for their role in reducing anxiety levels after exposure to stress (Yin et al., 2020). A limited number of plants is most effective, as excessive greenery can create visual clutter and reduce comfort (Hähn et al., 2020). Employees without natural views may compensate by bringing in plants, underscoring the importance of direct exposure to nature (Bringslimark et al., 2011). A recent study by Terblanche and Khumalo (2024) confirms that students prefer to study in biophilic areas, as these environments evoke positive emotions and help them feel rejuvenated and energised. However, the authors also note that some students still opt for non-biophilic areas, often due to practical factors such as noise levels or lack of monitoring in the preferred spaces.

2.3.2.7 LOOK AND FEEL

Küller et al. (2006) suggest that effective office colour design can have a positive impact on employees' mood. Generally, cool colours are linked to enhanced concentration and attentiveness, whereas warm colours tend to evoke arousal (Küller et al., 2006). Some research indicates that warm colours, such as red, may contribute to higher anxiety and stress levels, while cool colours, like blue, are potentially associated with increased depressive symptoms (Kwallek et al., 1988). According to Kwallek et al. (1997), white and neutral tones are perceived as the most suitable and spacious for office spaces, whereas orange and purple are among the least favored colours. The widespread preference for white office environments may be attributed to employees' familiarity with such settings (van der Voordt et al., 2017). Additionally, Mahnke (1996) proposes that soft shades, including pale gold, orange, green, and sandstone, can also be well-suited for office environments. Focussing on learning environments, research indicates that colour focusses academic experience as well as stress in students. Warm colours, such as reds and yellows, are associated with creating a pleasant and relaxed atmosphere, which can help reduce anxiety and depression among students (Llinares et al., 2021). These colours are more effective in promoting relaxation compared to cold and neutral colours (Toa et al., 2022). Cold colours, like blue, are found to enhance attention and concentration. Blue, in particular, is noted for increasing feelings of relaxation and calmness, which can be beneficial in reducing stress (Al-Ayash et al., 2016, Tiwari et al., 2024).

2.3.3 CONCLUSION

Given the overlap in environmental demands, such as concentration, comfort, and well-being, it is reasonable to explore whether these same physical characteristics also influence stress levels in university learning environments. While students' stress responses may differ from working adults due to developmental and contextual factors (e.g., age-related brain maturation), the literature suggests that core environmental influences remain relevant across settings. This justifies investigating their effects within a higher education context.

Therefore, this research aims to investigate whether (some of) these physical characteristics, including noise, acoustics and privacy, lighting and daylight, layout and design, biophilia and views, and look and feel, similarly affect perceived stress within the context of higher education learning environments. The theoretical foundations that have been delved into in this chapter guide the empirical component of the study, which is described in the following methodology chapter.

2.4 HYPOTHESES AND CONCEPTUAL FRAMEWORK

Building on the theoretical insights presented in this chapter, this study formulates two hypotheses to guide the empirical investigation into the relationship between physical learning environments and student stress:

- H1: There is a statistically significant relationship between physical learning environment and students' perceived stress, as measured through survey responses.
- H2: Students will report lower levels of perceived and physiological stress after studying in the newer learning environment (Room B), compared to the traditional environment (Room A).

These hypotheses reflect findings from both literature on stress and environmental research. The hypotheses are also grounded in the distinction between different types of stress and recognise the need to assess stress using both subjective self-reports and objective physiological measures. Chapter 3 presents the methodology used to operationalise and test these hypotheses, including the participant sample, data collection instruments, and analytical strategy.

Based on the literature reviewed in this chapter, an updated conceptual framework has been developed. This framework synthesises theoretical and visualises how both student-specific stressors and the physical characteristics of university learning environments influence students' stress responses through the mediating process of perception and appraisal. The model integrates Slimmen et al.'s (2022) framework of four key student stress domains, reflecting the underlying personal context of participants. It also incorporates physical environmental characteristics derived from workplace and educational research, including five of the seven core design aspects described by Kropman et al. (2022) and Bergefurt et al. (2023). Importantly, the framework distinguishes between psychological stress and physiological stress, as recommended in research utilising multidimensional stress assessment (Becker et al., 2022; Sommerfeldt et al., 2019).

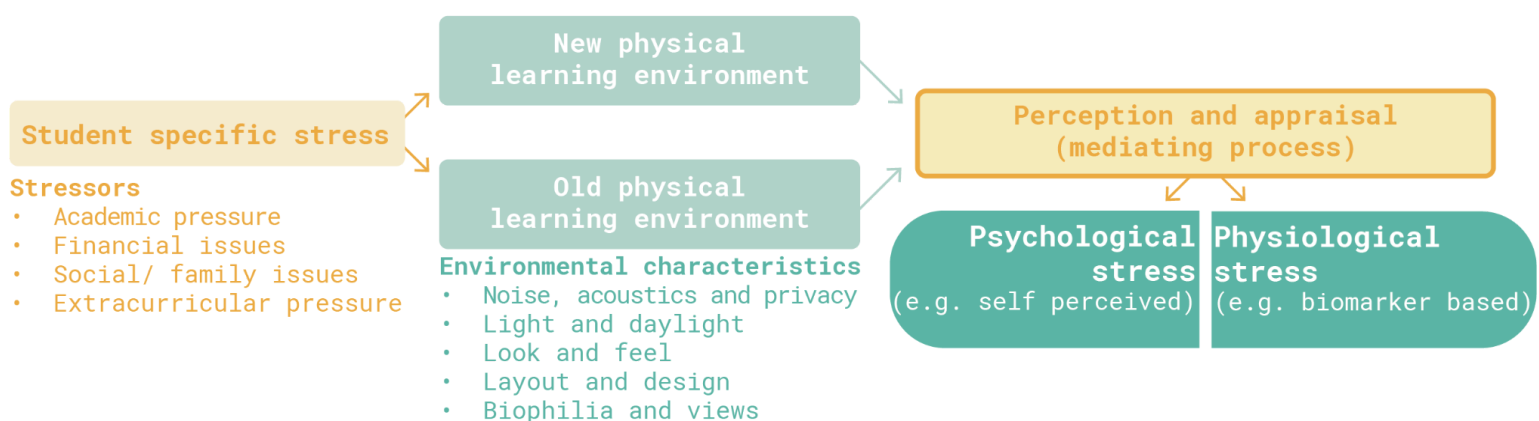


Figure 3: Updated conceptual framework based on the literature (own ill.)

3 METHODOLOGY

This chapter outlines the methodological approach used to investigate the relationship between physical learning environments and stress among university students. The study was designed to compare two distinct university study rooms that differ in spatial characteristics, allowing for an examination of how environmental features influence both perceived and physiological stress.

3.1 RESEARCH DESIGN OVERVIEW

This research adopts an experimental within-subject AB design to investigate how physical university learning environments influence perceived stress among students. Rather than a purely observational or correlational approach, the study applies an empirical experiment: participants engage in self-study sessions in two contrasting environments (Room A and Room B), after which their psychological and physiological stress responses are measured and compared. This design was chosen because it allows for direct comparison between environmental conditions, while controlling for individual differences by exposing each participant to both environments.

Given the limited scope and timeframe of this master's thesis (20 weeks), a controlled, small-scale experimental setup was the most feasible and effective way to isolate environmental effects on student stress. The research builds on theoretical foundations. Firstly, using the student stress domains defined by Slimmen et al. (2022), academic, financial, family, and extracurricular pressures, comparing them to the PSS-10 as a framework for interpreting stress levels and individual differences. Secondly, it incorporates five of the seven core environmental characteristics identified by Bergefurt et al. (2023) and Kropman et al. (2022) as relevant to mental health in indoor work environments: noise, acoustics and privacy, lighting and daylight, layout and design, biophilia and views, and look and feel.

These characteristics are adapted here to evaluate university study environments. The experiment is designed to test the study's main hypotheses, set up in the previous chapter, by comparing stress responses across two settings. The independent variable is the physical learning environment, while the dependent variables are students' perceived and physiological stress levels. Stress is assessed through a combination of quantitative instruments and self-reported experiences, which are further contextualised using environmental observations. The following sections describe the experimental setup in detail, including room characteristics, participant sampling, measurement procedures, and analysis strategy.

Research Question	Data source	Method/Tool	Analysis	Location
RQ1	Literature	Theoretical review	Building conceptual framework	2.1
RQ2	Literature	Review of tools	Justification of tool selection	2.2
RQ3	Literature/ observational data	Environmental & stress studies/ room documentation	Conceptual grounding	2.3/ 3.6
RQ4	Observational data	Room documentation	Qualitative comparison	3.6/ 4.5
RQ5	Experiment	Before/ after surveys and cortisol	Paired t-tests, ANOVA, lab work, coding	4/ 5/ 7

Table 2: Overview of research questions, data sources and methods

3.2 EXPERIMENTAL SETUP: LEARNING ENVIRONMENTS

To investigate how physical characteristics of university study spaces influence student stress, this research compares two contrasting learning environments located at Delft University of Technology. These spaces, referred to as Room A and Room B, were selected based on their differences in age, layout, design, and environmental qualities. In the context of the within subject AB study, AB refers to two environmental conditions: Room A and Room B, which differ in their physical characteristics, as a comparative research method to determine their effects on an outcome of interest (Quin et al., 2023). Within-subjects means that each participant experiences both environments, allowing for direct comparison of their stress responses across conditions (Greenwald, 1976). A practical factor in their selection was that both rooms could be reserved for exclusive use during the experiment, reducing the risk of distraction from other students.

While both spaces are normally used for lectures and group work, they were temporarily repurposed as self-study rooms for the duration of the experiment. This was done because actual self-study rooms can not be booked or reserved, as they are needed for students. Self-study was chosen as the activity context because it represents a common academic task for university students (Chen & Hong, 2023). Prior research shows that students prefer quiet, private settings for individual study, and that such environments are often in short supply on university campuses (Beckers et al., 2016; Goodnight & Jeitner, 2016). Self-study enables relatively consistent engagement because students can work at their own pace, using familiar materials, without needing additional instructions or coordination, reducing variability in behaviour between participants (Lim et al., 2024). The rooms were assessed using five of the seven physical environmental characteristics identified in prior literature as relevant to stress and mental well-being (Bergefurt et al., 2023; Kropman et al., 2022):

- Noise, acoustics and privacy
- Lighting and daylight
- Layout and design
- Biophilia and views
- Look and feel

These five were selected based on their relevance to learning environments and the feasibility of collecting accurate data. Two additional characteristics, thermal comfort and indoor air quality, were excluded due to the lack of appropriate measurement equipment and limited control over building-wide systems. Each room's characteristics were documented through a combination of methods:

- Noise levels were measured in decibels (dB) with a db meter (phone application).
- Lighting levels were measured in lux using a lux meter (phone application).
- Layout and design were recorded via photographs and annotated floor plans.
- Biophilia and views were described qualitatively based on views on greenery, plants, or natural elements.
- Look and feel was assessed based on color palette, furniture design, atmosphere

3.3 PARTICIPANTS

The experiment was conducted with a group of full-time university students enrolled in relevant academic programmes. Originally the targeted participant group was students partaking in the same discipline and study year, taking the same courses, in order to reduce the difference in academic pressure. Due to logistical constraints this criterion was eventually dropped. Rather than holding on to targeting a specific discipline or study year, the aim became to involve students who regularly engage in self-study activities and are familiar with campus learning environments. This broader inclusion approach increases the relevance of findings across the wider student population, while remaining feasible within the scope of a master's thesis. According to Johanson and Brooks (2009), sample sizes between 10 and 30 participants are often adequate for pilot or exploratory research, enabling meaningful data collection while accounting for practical constraints. The intended sample size was 20 participants, to be in the middle of this estimate. In total, 13 students participated in both study sessions, and 10 contributed complete salivary cortisol samples. Although this sample size limits statistical power, the within-subject design helped reduce variability by allowing direct comparison of each participant's responses across two conditions (Greenwald, 1976). To control for order effects, participants were randomly assigned to one of two session sequences:

- Half began in Room A (the traditional learning environment), followed by Room B (the newer environment);
- The other half experienced the rooms in reverse order.

	27-03-25	Room A 28-03-25	- -	31-03-2025	Room B 01-04-25	02-04-25	03-04-25	Room A 04-04-25
	Thursday	Friday	- -	Monday	Tuesday	Wednesday	Thursday	Friday
11:00-12:00	Baseline PSS-10	Group 1/ Room A	- -	-	Group 1/ Room B	-	-	-
Break	-	-	- -	-	-	-	-	-
13:00-14:00				Baseline PSS-10	Group 2/ Room B			Group 2/ Room A

Table 3: Participant distribution across sessions and rooms (own ill.)

Each participant took part in two self-study sessions, one in each room, on different days. During each session, psychological and physiological stress levels were measured before and after one hour of self-directed study. The day before their first session, participants were asked to fill in the PSS-10, assessing their self-perceived psychological stress levels over the past month. While the detailed procedure and timing are discussed in the following section, this structure ensured that each participant served as their own control, enabling clearer detection of differences between environments. All participants received an informed consent form explaining the purpose of the study, data privacy protocols, and their right to withdraw at any time. Participation was voluntary, and lunch was provided as a small incentive.

3.4 MEASURING STRESS

To evaluate the impact of physical learning environments on student stress, this research combines both psychological and physiological stress measures. This dual approach enables a more complete picture of participants' stress responses, reflecting both subjective perceptions and objective biological processes. The following sections outline the selected instruments, their theoretical basis, and the rationale for including or excluding alternative options.

3.4.1 PSYCHOLOGICAL STRESS: PSS-10 AND SURVEY

Psychological stress is assessed using the Perceived Stress Scale PSS-10 and a custom self-report survey developed for this study. The PSS-10 is a widely validated instrument for measuring perceived stress over the past month (Cohen et al., 1983; Roberti et al., 2006). It captures two dimensions: perceived helplessness and perceived self-efficacy. The PSS-10 was distributed among all participants a day in advance of their first experimental session to establish a baseline of psychological stress. Its inclusion allows for comparisons between participants and serves as a reference point for interpreting stress fluctuations. To assess stress before and after each study session, a custom self-report survey was developed. In contrast to the PSS-10 this survey has not been validated. This included four 10 point likert-scale items targeting immediate stress perception:

- Overall stress
- Difficulty focusing
- Self reported physiological stress
- Environment influence

This assessment was necessary because the PSS-10 is not designed to capture immediate stress responses to short-term environmental exposure, but rather give context to the perceived stress over the last month. These four items were designed to be intuitive and quick to complete, minimising disruption to the study sessions while targeting the specific dimensions most relevant to the experiment. The survey also included several open-ended questions, allowing participants to describe their experiences in their own words. This qualitative input was important for two reasons. Firstly, it enabled a richer understanding of how students perceive specific environmental characteristics (e.g., noise, light, layout). Secondly, it allowed the discovery of unanticipated factors or emotional responses that may not have been captured by structured items. These open responses were later coded and thematically analysed using ATLAS.ti (see Section 3.7).

3.4.2 PHYSIOLOGICAL STRESS: SALIVARY CORTISOL

To assess physiological stress, salivary cortisol was chosen as the primary biomarker. Cortisol is a hormone released by the HPA axis in response to stress and is commonly used to assess stress in naturalistic settings (Hellhammer et al., 2009). Saliva sampling is non-invasive and relatively simple to administer, making it well-suited for use in educational settings without clinical supervision. Participants provided one saliva sample before and one after each session, allowing for comparison of hormonal stress responses across Room A and Room B. While cortisol has a delayed response curve, typically peaking 25 minutes after stress onset (Gunnar & Quevedo, 2007), its inclusion offers a physiological complement to self-report data.

To minimise variation due to behavioral or dietary factors, participants received advance instructions based on the official Demeditec Cortisol Free in Saliva ELISA protocol (version 12-08-2023). They were asked to:

- Avoid eating a major meal within 60 minutes prior to sampling
- Avoid alcohol for 12 hours before the session
- Avoid brushing teeth for 60 minutes before collection
- Refrain from strenuous physical activity the night before and on the day of the session
- Rinse their mouth with water 10 minutes before sampling
- Avoid chewing gum or other substances during the sampling period
- Avoid pressure on the teeth, which could lead to contamination from gingival fluid.

Saliva was collected using the passive drool method, which is non-invasive and well suited to field research settings. Samples were stored in a freezer until further analysis.

3.4.2.1 EXCLUDED OPTIONS: EDA AND HRV

EDA and HRV were both considered as additional physiological indicators. Both are widely used in stress research. However, these methods were excluded for practical reasons. The EDA rings previously used in similar research were no longer functional, and replacement devices were not available within the project's budget or timeline. HRV monitoring requires wearable devices with consistent sampling quality and considerable post-processing. These were not available, and manual collection via sensors was not feasible. Although both methods offer real-time physiological stress data, salivary cortisol was ultimately selected for its non-invasiveness, established reliability, and compatibility with the experiment's time structure.

Method	Type	Pros	Cons	Included?
PSS-10	Psychological	Validated, reliable, easy to administer; baseline measure	Retrospective (not momentary), not task-specific	Yes
Custom survey (4 items)	Psychological	Immediate, session-specific feedback; simple and scalable	Limited depth; not standardized	Yes
Open-ended questions	Psychological	Adds nuance and captures personal perceptions	Subjective; requires manual coding	Yes
Salivary cortisol	Physiological	Non-invasive; reflects HPA axis activation	Delayed response curve; requires lab access; individual variation	Yes
EDA	Physiological	Real-time response; reflects SAM activation	Devices unavailable; requires calibration and filtering	No
HRV	Physiological	High sensitivity to acute stress; rich dataset	Equipment not available; data quality issues without controlled setting	No

Table 4. Summary of Stress Measurement Options

3.5 DATA COLLECTION PROCEDURE

The data collection took place over two experimental sessions held on separate days. Each participant engaged in self-study in both Room A and Room B, with the order of room exposure counterbalanced across participants to control for potential order effects. Sessions were scheduled between 11:00 and 15:00, which aligns with research suggesting this time period supports optimal cognitive performance in university students (Evans et al., 2017). Student preferences for study session duration vary, typically ranging from 30-60 minutes to 1-2 hours (Wright et al., 2019). For this study, a one-hour session was selected to allow participants enough time to acclimate to the room, while keeping the overall session duration manageable.



Figure 4: Explaining the experiment set up (own image)

Before each session, participants received a short introduction and signed an informed consent form outlining the study's purpose, procedures, data handling, and voluntary nature. They then completed a baseline self-report stress survey, and participants in the physiological condition provided a salivary cortisol sample. During the session, participants were instructed to work independently on academic materials of their own choosing, such as reading, note-taking, or assignment preparation. No specific task was assigned, to maintain ecological validity and mirror authentic self-study behavior. After one hour of study, participants completed a second survey and, where applicable, a second saliva sample. To reduce variability in cortisol data, participants received prior instructions regarding food, caffeine, and physical activity. The full sampling protocol is detailed in the subsection above.

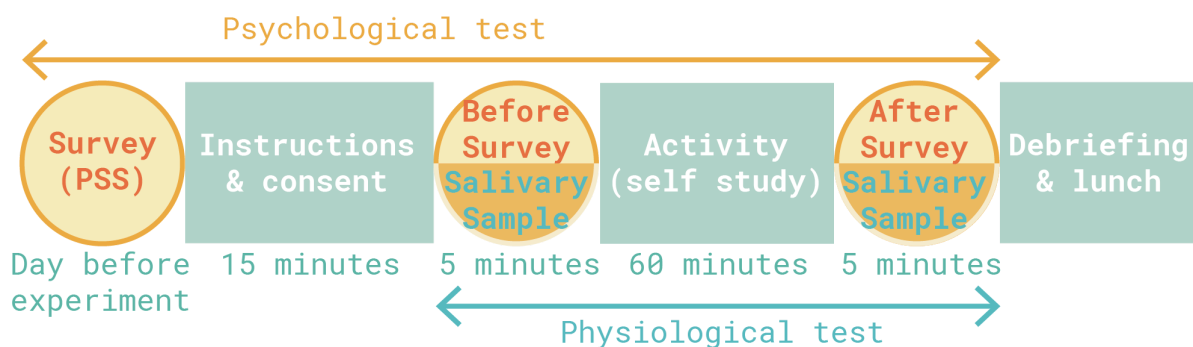


Figure 5: Experiment procedure (own ill.)

Each session lasted approximately 90 minutes, including briefing, measurement, study time and debriefing. The consistent structure across both rooms ensures that any observed differences in stress can be attributed to the physical environment rather than procedural variation.

3.6 ENVIRONMENTAL DOCUMENTATION

3.6.1 OVERVIEW OF MEASUREMENT METHODS

To contextualise differences in stress responses, the physical characteristics of both rooms were documented based on five key environmental dimensions drawn from workplace well-being literature: noise, acoustics and privacy; lighting and daylight; layout and design; biophilia and views; and look and feel (Bergefurt et al., 2023; Kropman et al., 2022). Each characteristic was assessed using a combination of objective tools, visual records, and qualitative observations. The table below summarises how each environmental aspect was evaluated.

Characteristic Measurement Method	
Noise, acoustics and privacy	1-minute sound level using dB meter (smartphone app); qualitative notes on disturbances
Lighting and daylight	Lux meter measurements at front, middle, and back; total window area and orientation
Layout and design	Annotated floor plan sketches; seating capacity; flexibility of furniture
Biophilia and views	Visual observations of greenery, window views, natural elements
Look and feel	Description of colors, textures, materials, design cues, and atmosphere

Table 5: Overview of environmental characteristics and measurement methods

The next sections describe Room A and Room B in detail, structured around these five dimensions. All observations were collected by the researcher during setup and confirmed during the experimental sessions.

3.6.2 ROOM A: HALL C IN BK CITY

Room A in this experiment is Hall C of the BK City building at Delft University of Technology. Originally constructed in 1923 and renovated for educational purposes in 2009, this space represents a more traditional university learning environment in terms of both architectural style and interior design. To provide environmental context for the stress measurements, the room is described using the five physical characteristics identified in the literature.



Figures 6 & 7: Room A, Hall C at BK City (own images)

3.6.2.1 NOISE, ACOUSTICS AND PRIVACY

Room A maintains relatively low background noise levels. A one-minute average sound level recorded in the empty room was 40 dB, corresponding to a relatively quiet indoor environment, with the ventilation system softly humming. This measurement was done with the 'decibelx:db sound level meter' application, downloadable for smartphones. This was also done per suggestion of one of the mentors. This app gives solid sound measurements fit for the scope of this research. The space is acoustically open but not reverberant, and ambient noise from adjacent interior spaces is minimal. However, noise from outside the building is audible due to the older window frames with renovated double-glazed glass, which offer limited sound insulation. This could affect the sense of acoustic privacy if loud activity is happening outside (e.g., construction, protests, police sirens).

3.6.2.2 LIGHT AND DAYLIGHT

Room A benefits from substantial daylight due to its large windows (approx. 40 m²), which span the outer walls. The windows face northwest and southwest, offering both indirect and angled afternoon sunlight. Light intensity measured during a sunny day at 12:16 showed:

- Front of the room: 1600 lux
- Middle: 1900 lux
- Back near windows: 6000 lux

The measurements were done with the 'light meter LM-3000' application, downloadable for smartphones, as per suggestion of one of the mentors. During measurement, the researcher sat at a table in three locations in the room. This app gives solid light measurements fit for the scope of this research. This wide range suggests a very strong natural lighting gradient across the room. While daylight is known to support focus and alertness, the high back-end lux values may also result in glare or overstimulation if not diffused.

3.6.2.3 LAYOUT AND DESIGN

The room has a square layout (12×12 m= 144 m²) and seats 72 students. Desks and chairs are arranged in a traditional format, all facing the front of the room. The front contains both a chalk blackboard and a beamer screen, supporting typical frontal instruction. While the layout supports visibility and instructional focus, it offers only limited flexibility in practice, even though the tables can technically be rearranged.

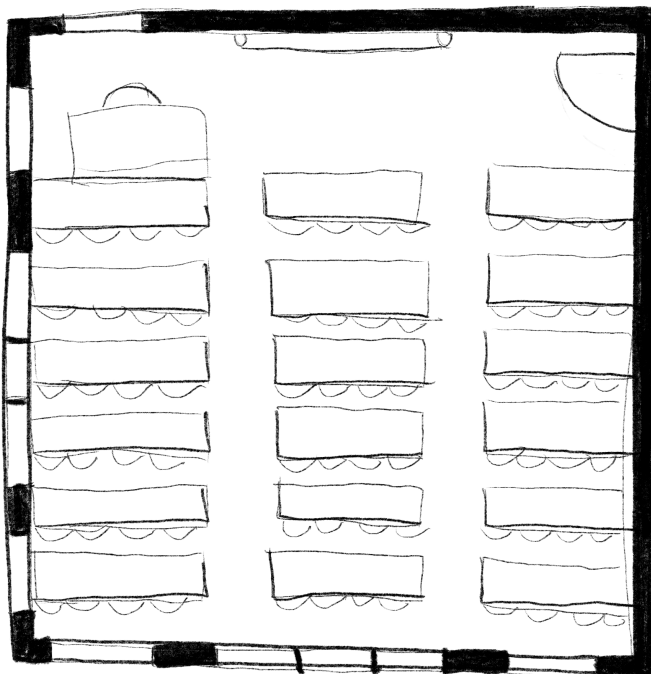


Figure 8: Floor plan sketch of Room A (own illustration)

3.6.4.4 BIOPHILIA AND VIEWS

There are no visible biophilic design elements (e.g., plants, natural materials) within the room itself. However, the large windows provide outward views of surrounding greenery. The room is located on the first floor and looks out on treetops, a small park, and an urban garden. This exposure to natural views may offer restorative or calming effects linked to biophilic design (Smith et al., 2011; Ayuso Sanchez et al., 2018)



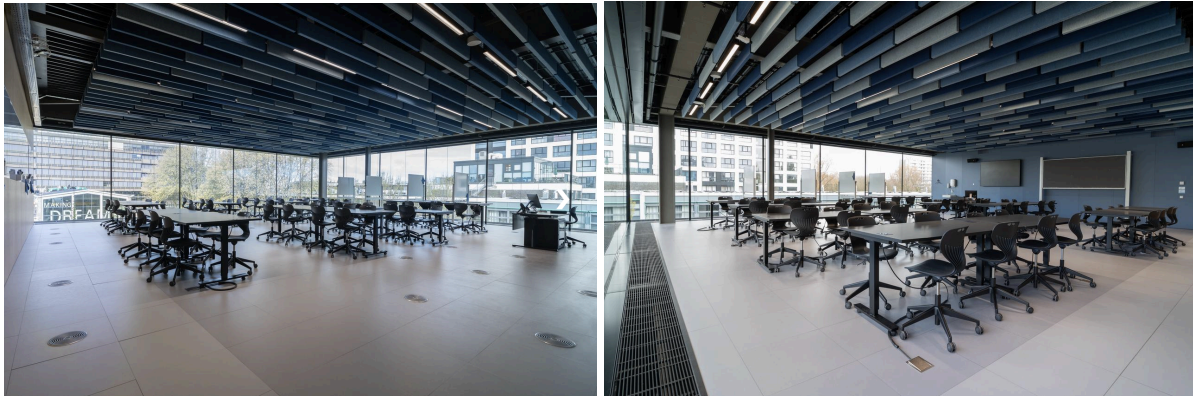
Figures 9 & 10: views from Room A (own images)

3.6.2.5 LOOK AND FEEL

The room features white-painted walls, a warm red carpeted floor, and a high unfinished ceiling with visible concrete beams and ventilation ducts. The resulting aesthetic combines academic functionality with a historic-industrial atmosphere. The warm-toned flooring may contribute to a cozy and welcoming ambiance (Linares et al., 2021; Tao et al., 2022), although some studies caution that warm colors can increase arousal depending on brightness and context (Kwallek et al., 1988). In combination with the calming white walls and outdoor views, the space is generally perceived as soothing and balanced.

3.6.3 ROOM B: HALL D IN ECHO

Room B is Hall D in the Echo building, also at Delft University of Technology. Delivered in 2022, Echo represents the latest evolution in campus architecture, emphasising sustainability and acoustic performance. The space aligns with current trends in higher education design that prioritise student well-being and concentration



Figures 11 & 12: Room B, Hall D at ECHO, own images

3.6.3.1 NOISE, ACOUSTICS AND PRIVACY

Room B exhibits very low background noise levels. A one-minute average sound level recorded in the empty room was 30,3 dB, indicating excellent acoustic insulation and minimal ambient disruption. The space benefits from acoustic ceiling panels and thick walls. When the hallway door is closed, no indoor sounds are audible. However, distant rhythmic sounds from nearby tram construction could occasionally be perceived. Overall, the room offers superior auditory privacy compared to traditional rooms.

3.6.3.2 LIGHT AND DAYLIGHT

Room B contains floor-to-ceiling windows with a total area of approximately 70 m², facing north-northwest and west-southwest, similar to Room A. These windows offer generous daylight and expansive outward views. Light levels measured during a sunny afternoon (13:06) were:

- Front: 2100 lux
- Middle: 1900 lux
- Back: 3600 lux

During measurement, the researcher sat at a table in three locations in the room, in similar places as in Room A. The levels are a lot lower than the maximum values in Room A, especially in the back of the room. Furthermore, the light in Room B is more evenly distributed, reducing potential glare and supporting sustained attention.

3.6.3.3 LAYOUT AND DESIGN

Room B has a rectangular layout (13.5×14 m= 189 m²) with seating for 64 students. Furniture is arranged in a non-traditional, side-facing format. All chairs and tables have wheels, encouraging flexibility. This adaptive layout supports diverse working styles and enhances autonomy, contrasting strongly with Room A's fixed front-facing setup.

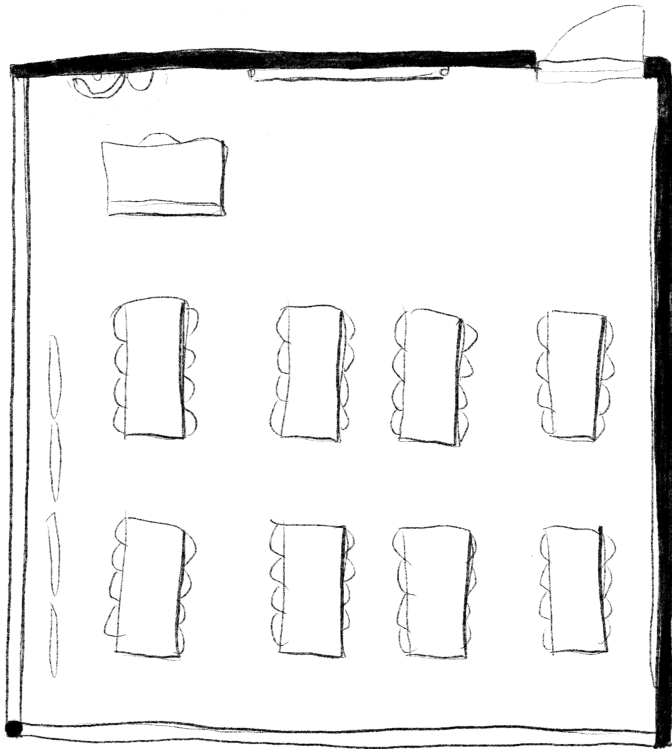


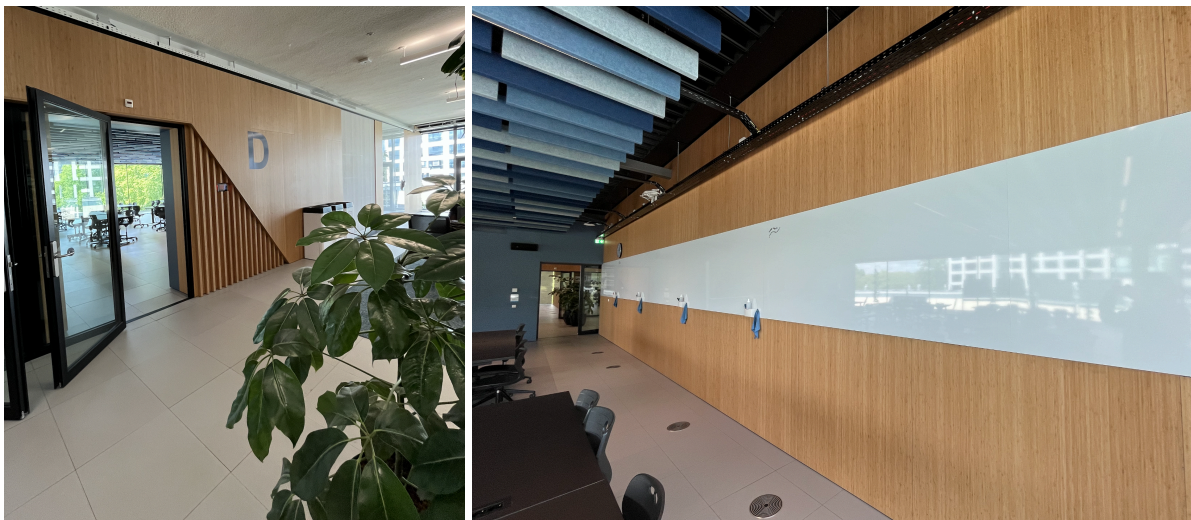
Figure 13: Floor plan sketch of Room B (own illustration)

3.6.3.4 BIOPHILIA AND VIEWS

The room offers extensive external views through its floor-height windows, including treetops and a campus square. While no indoor plants are present, the outdoor visibility of nature and people provides both biophilic and social stimulation (Smith et al., 2011; Ayuso Sanchez et al., 2018). Furthermore there are some natural elements inside the building, such as the bamboo wall paneling. The entry to the room is also naturally materialised with potted plants on the corridor.



Figures 14 & 15: views from Room B (own image)



Figures 16 & 17: Natural elements in the room and near the entrance.

3.6.3.5 LOOK AND FEEL

Room B's interior is modern, bright, and visually calming. Cool blue wall tones and natural wooden accents contribute to a tranquil atmosphere. Black furniture adds a professional contrast. These features align with literature linking cool tones to calmness and cognitive focus (Al-Ayash et al., 2016; Tiwari et al., 2024), though some research also associates them with detachment in certain contexts (Kwallek et al., 1988). In this setting, the balance of daylight, color, and texture creates a clean, focused environment.

3.6.4 ENVIRONMENTAL COMPARISON

Characteristic	Room A (Hall C – BK City)	Room B (Hall D – Echo)
Noise, Acoustics and Privacy	40 dB average; some outside noise due to old windows; limited acoustic insulation	30,3 dB average; excellent insulation with acoustic panels; high auditory privacy
Light and Daylight	6000 lux (back), 1600–1900 lux (front/middle); high gradient, potential glare	3600 lux (back), 1900–2100 lux (front/middle); more even lighting, less glare
Layout and Design	Square layout (12×12 m); fixed frontal setup; limited flexibility	Rectangular layout (13.5×14 m); flexible, mobile furniture; supports autonomy
Biophilia and Views	No indoor plants; views of treetops and park from large windows	Extensive outdoor views; bamboo wall, natural material accents and corridor plants
Look and Feel	Warm red carpet, white walls, historic-industrial ceiling; cozy but possibly arousing	Cool blue walls, wood tones, black furniture; calm, modern, cognitively focused

Table 6: Environmental comparison of Room A and Room B

The detailed documentation of Room A and Room B, using five theory-informed environmental categories, forms the foundation for interpreting their respective effects on student stress. Room A's warm tones, traditional layout, and partial biophilic access contrast with Room B's modern design, acoustic optimisation, and expansive views. These environmental differences provide a clear context for evaluating measured stress responses in the results chapter. Beyond experimental relevance, this comparison supports a broader reflection: could underutilised educational spaces be adapted into healthier, more effective self-study environments? As universities face increasing demand for quality study spaces, understanding how environmental design influences student well-being is key for long-term campus planning. While students often already make use of empty rooms, increased awareness and greater encouragement or guidance from the university could help students make better use of these spaces.

3.7 DATA ANALYSIS STRATEGY

The collected data is analysed using an experimental within-subjects design with primarily quantitative analysis, complemented by qualitative open response analysis. This combination allows the research to test for measurable effects of the physical learning environments on student stress, while also exploring the nuanced ways in which participants experienced those environments.

3.7.1 QUANTITATIVE ANALYSIS

The quantitative analysis focuses on three types of data:

- Baseline stress, measured through PSS-10 scores and contextual stressor ratings
- Session-specific perceived stress, assessed through a custom 4-item survey
- Physiological stress, measured via salivary cortisol.

To evaluate changes in stress before and after each study session, paired-sample t-tests are conducted for each of the four survey items and the cortisol values. This allows for within-subject comparisons between Room A and Room B, in line with the AB experimental design. In all cases, Cohen's d is reported as a measure of effect size, regardless of statistical significance, to indicate the practical relevance of observed differences (Cohen, 1983)..

A repeated measures analysis of variance (ANOVA) is used to examine potential interaction effects between Room (A/B), Time (before/after) and Survey item type (overall stress/difficulty focusing/self-reported physiological stress/perceived environmental influence). This tests whether certain types of stress perception are more sensitive to environmental variation than others. A second repeated measures ANOVA is later run on the physiological data, examining effects between Room and Time. To control for Type I error inflation due to multiple comparisons, Bonferroni correction was applied where appropriate. Both ANOVAs are run using SPSS software. Additionally, Pearson correlation analysis is used to explore baseline relationships. The relationship between PSS-10 scores and baseline stress levels at the start of each session, as well as the relationship between PSS-10 scores and four contextual stressors (academic, financial, family, and extracurricular) as defined by Slimmen et al. (2022). The statistical analyses are conducted in Microsoft Excel as well as in SPSS. Graphs and visualisations include standard error bars to reflect participant variability.

3.7.2 QUALITATIVE ANALYSIS

Open-ended responses from the post-session surveys were analysed using a thematic coding approach in ATLAS.ti. This analysis followed a structured, iterative process combining deductive and inductive coding, aimed at identifying meaningful patterns in students' descriptions of stress and their study environment experiences.

Deductive codes were developed in advance, informed by (1) the five environmental characteristics from the literature (Bergefurt et al., 2023; Kropman et al., 2022), (2) the two room types (A and B), and (3) the four custom survey items (e.g. overall stress, difficulty focusing). Additional contextual codes were created to reflect external stressors or participant-specific conditions.

Inductive codes were added during iterative rounds of open coding, allowing unexpected themes and emotional responses to emerge from the data. Thematic clusters were created by grouping codes with similar meanings or co-occurrence patterns.

While the analysis was primarily descriptive and semantic, care was taken to preserve the participants' original phrasing and to reflect both positive and negative interpretations of the environment. This process ensured that the qualitative data could complement the quantitative results by revealing subjective nuances that may not be captured through structured items.

4 RESULTS

This chapter presents the findings of the experiment and addresses the core hypothesis-driven aim of the research: to assess how physical learning environments influence student stress during self-study. The analysis draws on both psychological and physiological data, supplemented by qualitative feedback and environmental observations.

Two hypotheses guide the analysis:

- H1: There is a statistically significant relationship between physical learning environment and students' perceived stress, as measured through survey responses.
- H2: Students will report lower levels of perceived and physiological stress after studying in the newer learning environment (Room B), compared to the traditional environment (Room A).

Stress was measured using surveys (the validated PSS-10 and a self made four-item self-reported stress survey) and physiological indicators (salivary cortisol), with data collected before and after study sessions in two contrasting environments (Room A and Room B). In addition, open-ended reflections were collected to contextualise participant experiences and uncover factors not captured by structured instruments. The results are presented as a narrative combining descriptive statistics, statistical comparisons, and thematic insights, in order to offer a holistic understanding of how design characteristics, user perception, and stress responses interact.

4.1 STRESS BASELINES AND RELATIONSHIPS

Before analysing changes in stress across the study environments, this section presents baseline data on participants' stress levels and explores how these relate to contextual stressors. Together, these findings provide a frame of reference for interpreting individual responses to the experimental conditions.

4.1.1 PSS-10 SCORES

Participants completed the 10-item PSS-10 one day before the start of the experiment to assess their general stress levels over the past month. Across the full sample ($n=13$), the scores ranged from 29 (highest) to 8 (lowest). The average score was $M(\text{mean})=17,0$, $SD(\text{standard deviation})=6,66$, $SE(\text{standard error})=1,92$, reflecting a moderate level of stress.

Participant	1	2	3	4	5	6	7	8	9	10	11	13	14
PSS10	25	11	11	13	16	11	15	25	8	14	21	29	22
Academic pressure	8	8	8	8	7	9	10	9	4	3	8	8	8
Financial issues	4	9	6	4	4	2	5	8	4	6	4	9	6
Social /family issues	0	3	6	2	2	2	7	4	5	4	5	3	5
Extracurricular pressure	4	6	5	5	3	4	2	4	6	6	6	3	3
Base A	7	4	6	3	3	2	7	4	3	2	5	7	3
Base B	8	3	5	7	3	2	4	4	4	3	5	8	4

Table 7: the PSS-10, student specific stressors and baseline stress for all participants

4.1.2 SURVEY BEFORE EXPERIMENT

Prior to each self-study session, participants filled in a short survey reporting across four indicators:

- Overall stress
- Difficulty focusing
- Self-reported physiological stress
- environmental influence

All questions were measured with a 10 point likert scale. Responses before the self study session were comparable across both rooms, though participants reported slightly lower difficulty focusing in Room B. These pre-session values offer a reference point for evaluating post-session change.

	Room A			Room B	
Survey item (before study)	Mean (SD)	SE		Mean (SD)	SE
Overall perceived stress	4,308 (1,888)	0,524		4,615 (1,938)	0,538
Difficulty focussing	4,385 (1,938)	0,538		3,538 (1,506)	0,418
Self-perceived physiological stress	4,308 (1,888)	0,524		4,308 (2,359)	0,654
Environmental influence	3,846 (2,075)	0,576		3,923 (2,060)	0,571

Table 8: Survey items means (before study) per room

4.1.3 CORRELATION BETWEEN PSS-10 AND BASELINE STRESS

In both Room A and room B, a moderate positive correlation was found between PSS-10 scores and baseline stress levels on the self reported surveys upon entering the rooms, nearly reaching statistical significance in Room A ($p=0,094$) and reaching significance in Room B ($p=0,043$). This is indicating that participants with higher stress over the past month also reported higher immediate stress upon entering this environment.

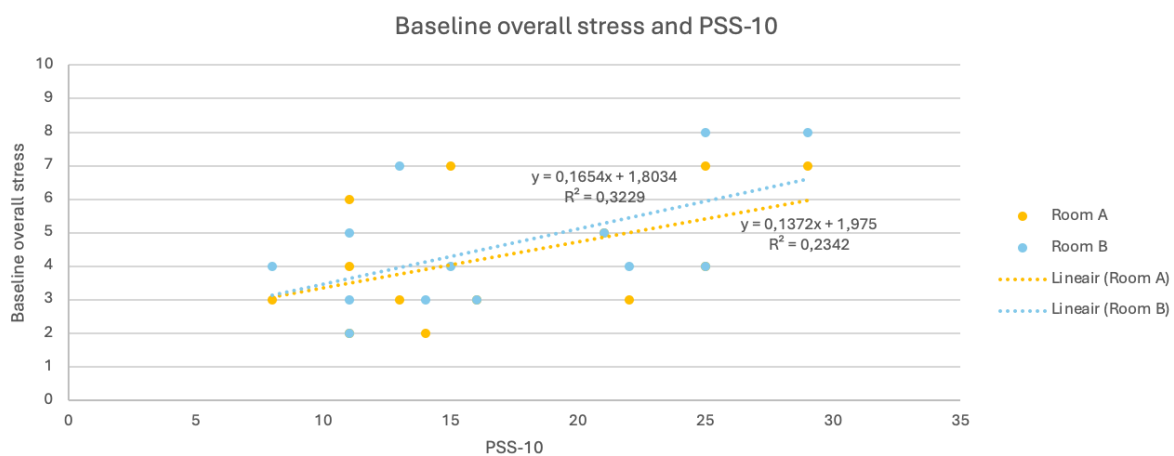


Figure 18: Correlation between PSS-10 and baseline stress in Room A and Room B (own ill.)

These results suggest that perceived psychological stress over the past month may influence overall stress perception, particularly in Room B. However, the small sample size and reliance on self-report measures necessitate cautious interpretation.

4.1.4 CORRELATION BETWEEN PSS-10 AND STUDENT STRESS

To explore the broader context of students' stress experiences, participants' PSS-10 scores were also tested for correlations with the four student specific stressors based on Slimmen et al. (2022): academic pressure, financial stress, family/social stress, and extracurricular pressure. Correlations between these domains and PSS-10 scores were explored and visualised in Figure 19, where all four stressors are plotted in a combined scatterplot with separate trendlines for each.

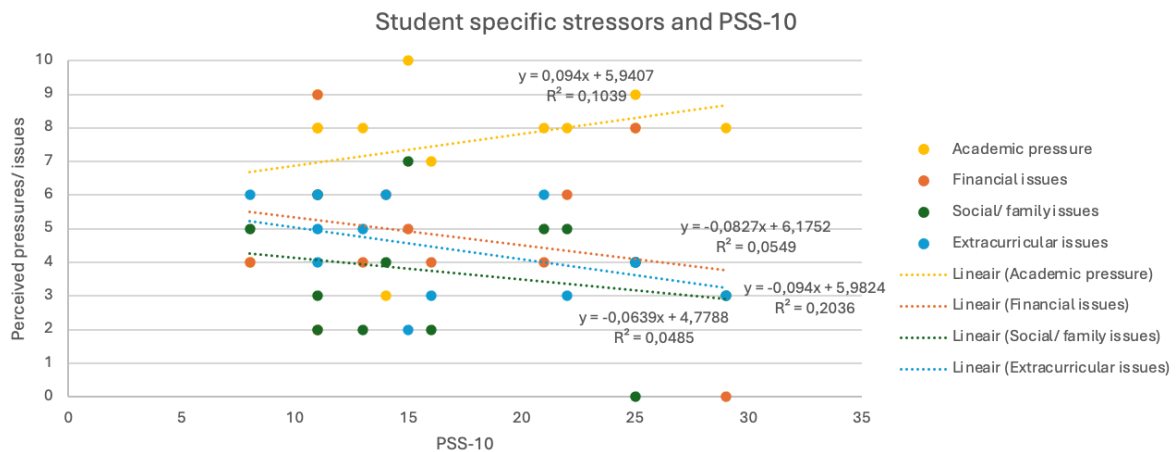


Figure 19: Correlation between PSS-10 and student specific stressors from Slimmen et al. (2022) (own ill.)

While none of the correlations reached statistical significance, the trends reflect the patterns summarised in Table 9: a modest positive association with academic pressure and weak-to-moderate negative trends for the other three domains. These negative trends are surprising, and would suggest that the higher PSS-10 scores correlate with lower scores on financial issues, social/family issues and extracurricular issues. However, no real conclusions can be made due to this correlation being not statistically significant. These visual and statistical trends suggest that participants with higher PSS-10 scores may perceive or prioritise stressors differently.

Variable pair	r	p-value	R ²	Interpretation
PSS-10 x Baseline stress (Room A)	0,484	0,094	0,234	Moderate correlation; trend-level significance
PSS-10 x Baseline stress (Room B)	0,568	0,043	0,322	Significant; moderate to strong correlation
PSS-10 x Academic pressure	0,322	-0,283	0,104	Moderate trend; not significant
PSS-10 x Financial issues	-0,234	0,441	0,055	Weak negative, not significant
PSS-10 x Social/ family issues	-0,22	0,47	0,049	Weak negative; not significant
PSS-10 x Extracurricular pressure	-0,451	0,122	0,204	Moderate negative, not significant

Table 9: Overview of baseline stress relationships

4.1.5 INTERPRETATION

While most of the relationships above are exploratory in nature and not statistically significant, they suggest that students with higher PSS-10 scores may enter learning environments with higher overall stress, both in Room A and Room B, with statistical significance in Room B. This is expected since the PSS-10 reflects on the perceived psychological stress of the past month. The correlation with academic pressure was the most pronounced among the student specific stressors, while other stressors showed weak negative trends. These patterns help contextualise the following sections, which examine how stress levels changed during the study sessions.

4.2 REPEATED MEASURES ANOVA

To address the core hypothesis that physical learning environments influence students' perceived stress levels (H1), and that Room B would be associated with lower perceived and physiological stress compared to Room A (H2), a repeated measures analysis of variance (ANOVA) was conducted. This was done using the software SPSS, a validated statistics programme. The four survey questions were treated as levels of the within-subject factor Stress Item Type, allowing the analysis to test whether different aspects of stress were affected differently by the experimental conditions. The full test of within-subjects effects can be found in appendix x.

4.2.1 OVERVIEW

This method was chosen to properly reflect the within-subjects design of the experiment: the same participants (n=13) experienced both Room A and Room B, and responded to the same set of four stress-related survey questions before and after each session.

The analysis included three within-subjects factors:

- Room (A, B),
- Time (Pre, Post), and
- Survey Item (Overall stress, Difficulty focusing, Self-reported physiological stress, Environmental influence).

This 2x2x4 setup makes it a three way repeated measures ANOVA, and was used to test for main effects and interaction effects between these variables.

4.2.2 STATISTICAL RESULTS

The results revealed no statistically significant main effects or interactions. For clarity and readability, only the F-values, p-values, and effect sizes (partial η^2) are reported. These results are summarised in Table 10. Following Cohen's guidelines, partial η^2 values around 0,01 are considered small, 0,06 moderate, and 0,14 large (Cohen, 1983).

Effect	F	p-value	Partial η^2	Interpretation
Room	1.36	267	102	Not significant (small trend toward room effect)
Time	3.01	109	200	Not significant (moderate trend toward time effect)
Survey item	0.27	808	22	Not significant (no difference across question types)
Room × Time	0.64	438	51	Not significant (minimal interaction)
Room × Survey item	1.81	191	131	Not significant (small trend across questions)
Time × Survey item	0.79	453	62	Not significant
Room × Time × Survey item	1.01	521	55	Not significant (minimal 3-way interaction)

Table 10: repeated measures ANOVA with effects Room, Time and Survey item

4.2.3 INTERPRETATION

These results indicate that there was no consistent, statistically significant difference in self-reported stress scores based on room, time, or the survey item. While Room B showed trends toward improved focus and lower physiological stress in prior analyses, these trends were not strong enough to reach significance at the group level when all variables were considered together.

Importantly, the Time effect showed a moderate effect size (partial $\eta^2=0.200$), hinting that some participants may have experienced lower stress after their sessions, regardless of room. Similarly, the Room effect (partial $\eta^2=0.102$) suggests a small trend in favour of Room B, though not conclusive. The lack of statistical significance may reflect genuine individual differences in how students experience stress in learning environments, or the limits of survey-based stress measures in detecting subtle environmental effects.

These results do not imply that the environment has no effect on stress, but rather that the effect may be too subtle to detect statistically in a small sample over short durations.

4.2.4 CONCLUSION

The repeated measures ANOVA does not support H1 or H2 in a statistically significant way. However, the small to moderate effect sizes observed align with the idea that certain aspects of environmental design might influence specific types of perceived stress. These insights justify further exploration through physiological measurements (subchapter 4.4) and qualitative data (subchapter 4.5), which may reveal environmental impacts that are not consciously perceived or easily captured in surveys.

4.3 BEFORE/ AFTER SURVEY RESULTS

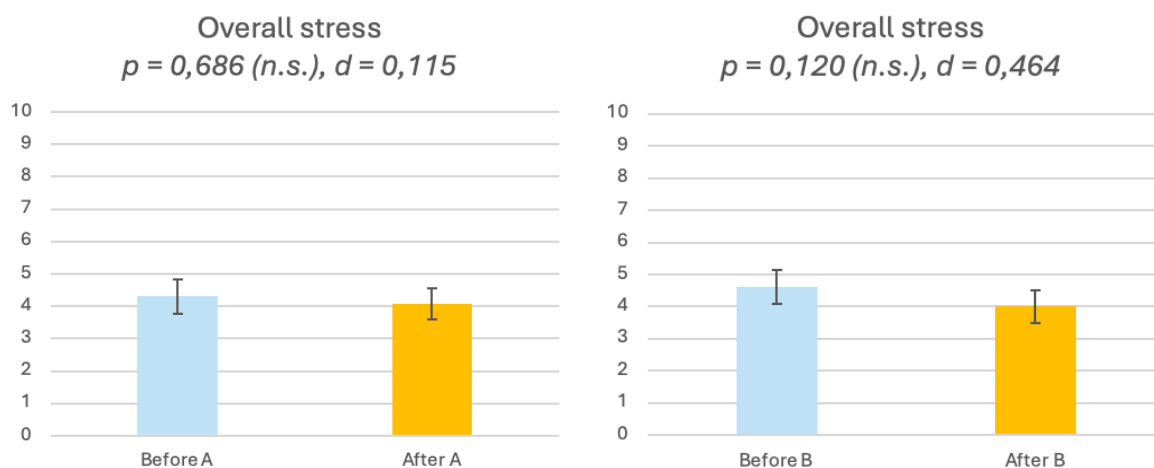
This section examines whether students' self-reported stress levels changed after studying in either of the two physical learning environments. The four survey items were used to assess perceived stress before and after each session: overall stress, difficulty focusing, self reported physiological stress, and environmental influence. All indicators were measured on a 10 item likert scale. By comparing scores across Room A and Room B, this analysis tests whether the physical setting of the learning environment influenced students' stress experiences, as proposed in H1 and H2. Each indicator is analysed separately to reveal room-specific trends in the following subchapters.

4.3.1 OVERALL PERCEIVED STRESS

This section examines how participants' self-reported overall stress levels changed before and after studying in Room A and Room B.

In Room A, participants' overall stress decreased slightly after the one-hour session. The mean stress level dropped from 4,308 (SD=1,888; SE=0,524) to 4,077 (SD=1,706; SE=0,473). However, this change was not statistically significant ($t=0,415$, $p=0,685$), and the effect size was very small ($d=0,115$), indicating negligible practical impact.

Similarly, in Room B, average stress decreased from 4,615 (SD=1,938; SE=0,538) to 4,0 (SD=1,871; SE=0,519). While the direction of change was consistent with Room A, the effect was again not statistically significant ($t=1,674$, $p=0,120$), and the effect size was minimal ($d=0,464$).



Figures 20 & 21: Self-reported overall stress before and after one-hour study session, by room (with SE error bars)

INTERPRETATION

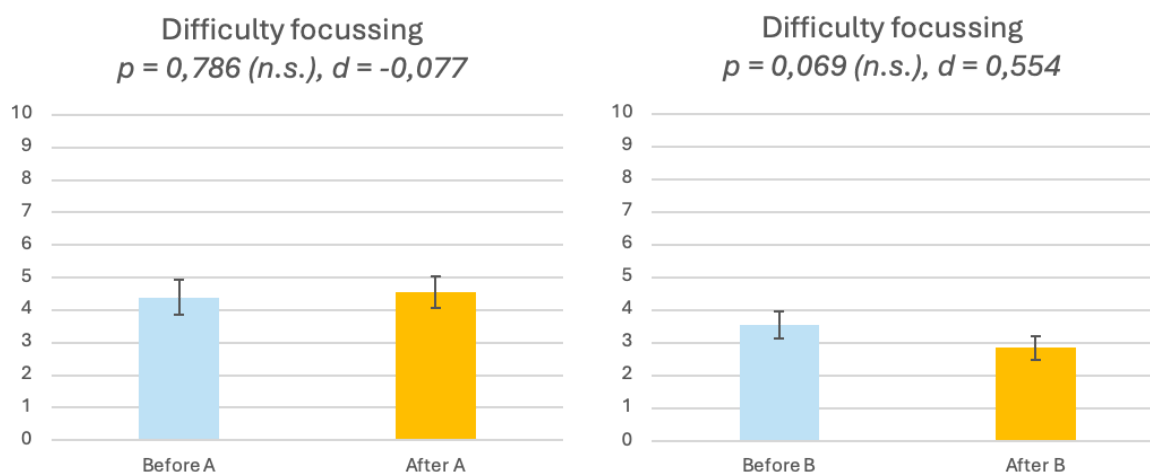
While both environments showed a small average reduction in self-reported stress, these effects were not statistically significant and the effect sizes were minimal. However, the results indicate that the newer environment (Room B) may be slightly more effective in reducing overall perceived stress. While the difference is not statistically significant, the small-to-moderate effect size in Room B suggests a trend that will be important to revisit in the discussion.

4.3.2 DIFFICULTY FOCUSING

This section explores whether the physical learning environment influenced participants' ability to concentrate, as measured by their self-reported difficulty focusing before and after each study session.

In Room A, participants reported a slight increase in difficulty focusing after the session. The mean score rose from 4,385 (SD=1,938; SE=0,538) to 4,538 (SD=1,761; SE=0,489). This change was not statistically significant ($t=0,278$; $p=0,786$), and the effect size was negligible ($d=-0,077$). The direction of change, although minor, suggests a marginal decline in concentration.

In contrast, Room B showed a more pronounced decrease in reported difficulty focusing, in other words, improved focussing. Scores dropped from 3,538 (SD=1,506; SE=0,418) to 2,846 (SD=1,281; SE=0,355). Although the result did not reach conventional significance ($t=1,996$; $p=0,069$), it approaches marginal significance, and the effect size was moderate ($d=0,554$).



Figures 22 & 23: Self-reported difficulty focusing before and after one-hour study session, by room (with SE error bars) (own ill.)

INTERPRETATION

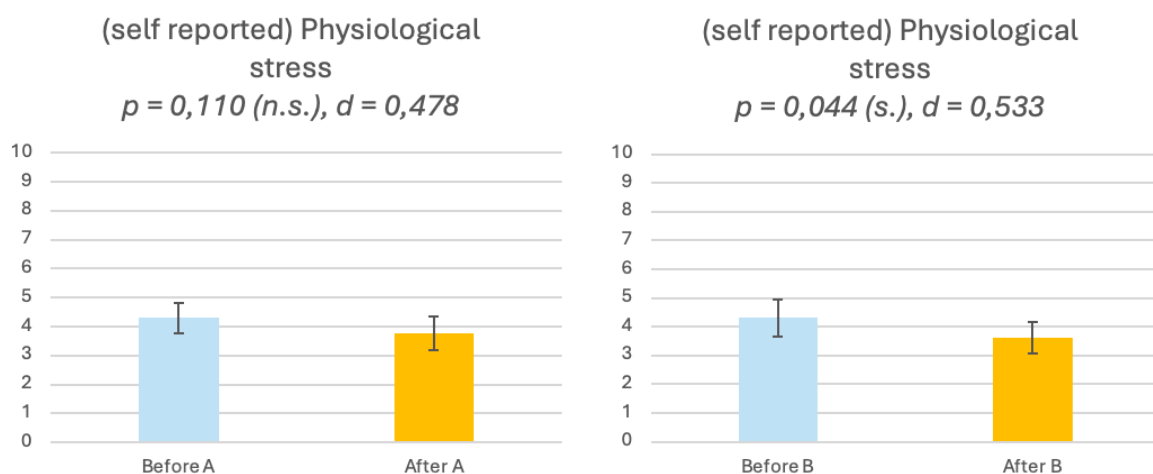
While Room A showed no measurable effect on focus, Room B displayed a promising trend toward improved concentration. The moderate effect size and downward trend in Room B support the interpretation that newer, more carefully designed environments may facilitate cognitive engagement more effectively than traditional spaces. The absence of statistical significance, however, suggests this finding should be interpreted with caution due to the small sample size.

4.3.3 SELF-REPORTED PHYSIOLOGICAL STRESS

This next section evaluates how participants felt their own physiological stress, such as muscle tension, rapid heartbeat, or sweating, before and after studying in each room. This part was included in case no actual physiological data could be collected.

In Room A, participants' self-reported physiological stress decreased slightly from 4,308 (SD=1,888; SE=0,524) to 3,769 (SD=2,048; SE=0,568). This change was close to statistical significance ($t=1,723$; $p=0,110$), and the effect size was moderate ($d=0,478$). The moderate effect, despite the lack of significance, suggests that the environment may have contributed to a small calming effect on the body.

In Room B, a similar but more pronounced decrease in self-reported physiological stress was observed. Scores dropped from 4,308 (SD=2,359; SE=0,654) to 3,615 (SD=1,938; SE=0,538). This change was statistically significant ($t=2,629$; $p=0,044$), with a moderate effect size ($d=0,533$).



Figures 24 & 25: Self-reported physiological stress before and after one-hour study session, by room (with SE error bars) (own ill.)

INTERPRETATION

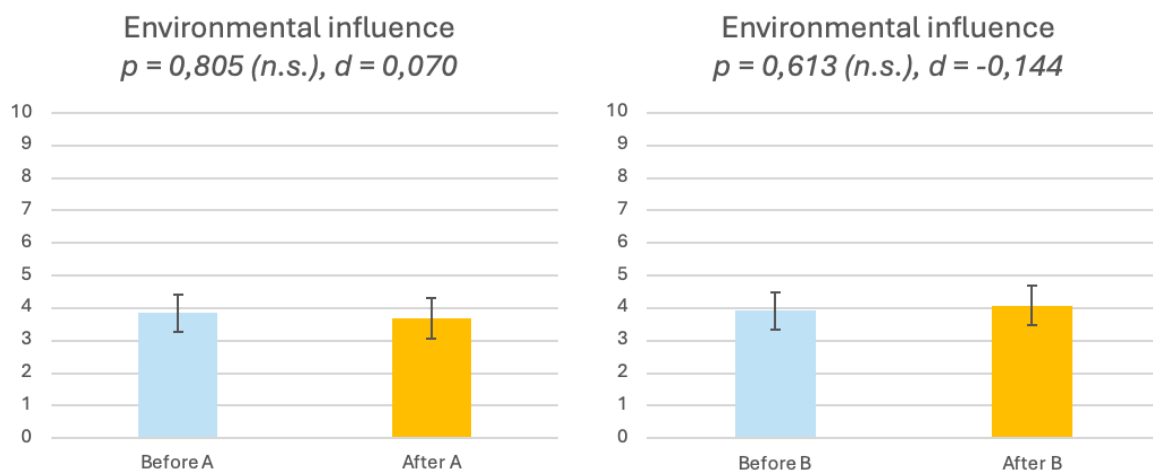
These findings suggest that Room B had a statistically measurable calming effect on participants' bodies, as reflected in the significant reduction in self-reported physiological stress. Room A showed a comparable trend, though with a slightly weaker statistical support. These results support the potential of newer, thoughtfully designed learning environments to promote (self-reported) physiological relaxation during study sessions. However, since the results are so similar, no big conclusions can be attributed to this factor.

4.3.4 PERCEIVED ENVIRONMENTAL INFLUENCE

This final item assesses how participants perceived the environment's influence on their stress, comparing responses before and after each study session.

In Room A, participants reported a very slight decrease in perceived environmental influence on their stress levels, with mean scores dropping from 3,846 (SD=2,075; SE=0,576) to 3,692 (SD=2,250; SE=0,624). This change was not statistically significant ($t=0,253$; $p=0,805$), and the effect size was very small ($d=0,070$), suggesting negligible perceived impact.

In Room B, the perceived influence of the environment on stress increased slightly, from 3,923 (SD=2,060; SE=0,571) to 4,070 (SD=2,178; SE=0,604). This difference was also not statistically significant ($t=0,519$; $p=0,613$), and the effect size was again small ($d=-0,144$). The slight upward trend may indicate that some participants became more aware of the environment's role in shaping their stress, but no clear pattern emerged.



Figures 26 & 27: Perceived environmental influence on stress before and after one-hour study session, by room (with SE error bars) (own ill.)

INTERPRETATION

Both rooms produced inconclusive results regarding how participants perceived the environment's influence on their stress. The lack of significant change, combined with very small effect sizes, suggests that participants' opinions about environmental impact remained stable, or were too individually varied, to detect consistent trends. These findings imply that perceived environmental influence may require longer exposure or more direct prompting to yield measurable insights. It is also possible that the influence of the environment was too subtle for the participants to accurately identify. This will be delved further into in the discussions.

4.3.5 SUMMARY

Across the four survey indicators, results show a consistent pattern: Room B produced more favourable changes than Room A, particularly for difficulty focusing and self-reported physiological stress. The reduction in self-reported physiological stress in Room B was statistically significant, and the improvement in focus approached significance.

In contrast, Room A showed fewer changes, with a slight increase in difficulty focusing, a near significant reduction in self-reported physiological stress, and only modest reductions in the other items. The results of these separate analyses are also summarised in the table below.

Indicator	Room	Pre (M)	Post (M)	t	p	Cohen's d	Interpretation
Overall stress	A	4,308	4,077	0,415	0,685	0,115	Slight decrease, not significant
	B	4,615	4	1,674	0,12	0,464	Moderate decrease, not significant
Difficulty focusing	A	4,385	4,538	0,278	0,786	-0,077	Slight increase in difficulty (worse focus)
	B	3,538	2,846	1,996	0,069	0,554	Moderate decrease, near-significant improvement
Self-reported physiological stress	A	4,308	3,769	1,723	0,11	0,478	Moderate decrease, not significant
	B	4,308	3,615	2,629	0,044*	0,533	Moderate decrease, statistically significant
Environmental influence	A	3,846	3,692	0,253	0,805	0,07	Very slight decrease, negligible impact
	B	3,923	4,07	0,519	0,613	-0,144	Very slight increase, negligible impact

Table 11. Summary of Before/After Survey Results by Room and Indicator * $p < 0,05$

These findings provide limited support for H1, which proposed that the physical learning environment influences students' perceived stress, as measured through survey responses. The effects appear to depend on the specific stress indicator: self-reported physiological stress and difficulty focusing were more responsive to environmental variation than overall stress or environmental influence. The latter is especially interesting considering the explicitly different environments where the participants studied.

H2, which predicted that students would report lower levels of perceived and physiological stress in the newer learning environment (Room B), is partially supported. The findings show more favourable trends in Room B for all four indicators, but the only statistically supported effect was in self-reported physiological stress. No conclusions can yet be drawn about physiological stress (as measured via cortisol), which is addressed in Section 4.4.

Importantly, these results reflect correlations rather than causation. Although the within-subject design strengthens internal validity, external factors such as mood, time of day, and personal stressors may also have influenced participant responses. These nuances are explored further in the next sections, where physiological and qualitative data help interpret the survey findings.

4.4 CORTISOL

4.4.1 INTRODUCTION

To assess physiological stress responses, salivary cortisol was measured using the Demeditec Salivary Cortisol Free in Saliva ELISA kit, a widely validated method for non-invasive stress biomarker analysis (Demeditec manual 2023, Hellhammer et al., 2009). Cortisol reflects HPA axis activation and provides insight into hormonal responses to stress over short time intervals.

Saliva samples were collected from 10 participants, each providing four samples: before and after self-study in both Room A and Room B. The study session lasted approximately one hour, which exceeds the 25 minute time window during which salivary cortisol typically peaks following a stressor (Gunnar & Quevedo, 2007). While this extended interval may have influenced the detectability of short-term physiological changes, this limitation is discussed in more detail in Section 6.X.

This within-subject design enabled direct comparison of cortisol changes between learning environments. Participants followed standardised collection protocols outlined in the Demeditec manual (version 12-08-2023), including dietary and behavioral restrictions to minimise confounding influences. Optical density (OD) was measured at 450 nm, and cortisol concentrations (ng/ml) were derived using a 5-point calibration curve. The calibration standards provided with the kit spanned a range from 0 to 30 ng/ml, with the following OD values:

Calibration sample	Cortisol (ng/ml)	OD (450nm)
Cal 0	0,0	3,099
Cal 1	0,1	7,420
Cal 2	0,4	6,000
Cal 3	1,7	0,880
Cal 4	7,0	6,500
Cal 5	30	3,697

Table 12: OD values and provided calibration standards

In addition, two control samples were included to verify calibration accuracy:

Control sample	Assigned value (ng/ml)	OD (450nm)
Con 1	0,31	7,000
Con 2	1,89	0,864

Table 13: Verification of control samples

Cortisol values for all participant samples were calculated by fitting the calibration data using Excel and the mycurvefit.com tool, which allowed for interpolation between OD readings. This process ensured consistency and enabled precise conversion of OD values into concentration estimates (ng/ml) for all samples.

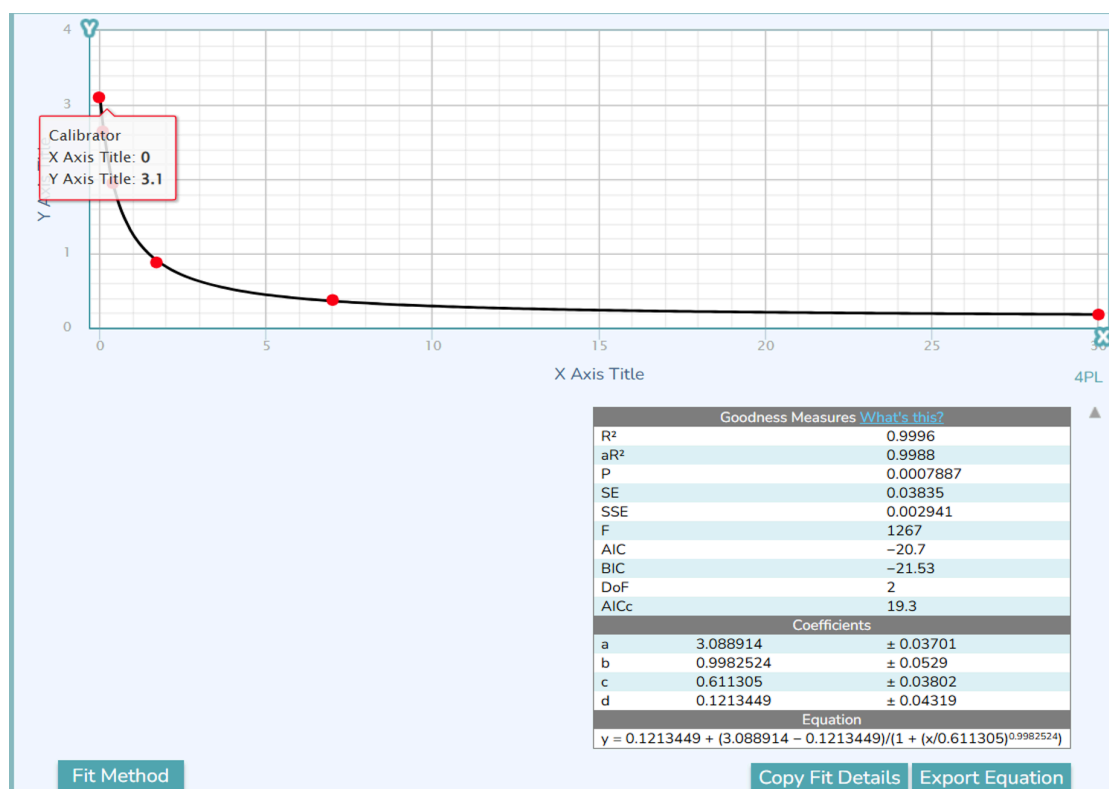


Figure 28: Calibration curve used to calculate ng/ml values from OD measurement values. (mycurvefit.com/)

4.4.2 CORTISOL RESULTS

This section presents the results of the salivary cortisol analysis conducted before and after participants' self-study sessions in Room A and Room B. Cortisol values are reported in ng/ml and compared using paired-sample t-tests.



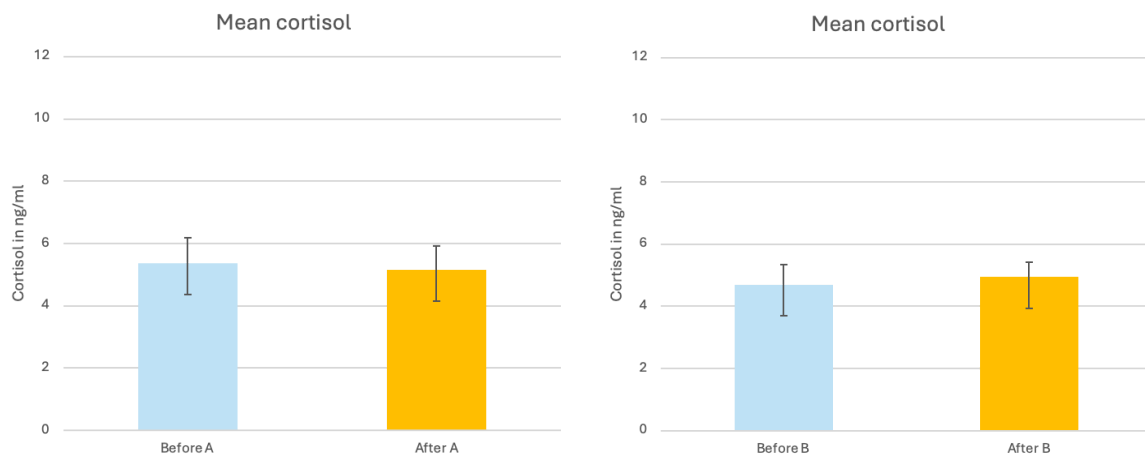
Figures 29 & 30: salivary samples before being analysed and plate with processed samples ready for OD measurement. (own images)

	Room A	Room B
Mean Before	5,353 ng/ml	4,690 ng/ml
Mean After	5,147 ng/ml	4,938 ng/ml
SD Before	2,634	2,02
SD After	2,451	1,535
SE Before	0,833	0,639
SE After	0,775	0,485
t-value	0,195	-0,266
p-value	0,849	0,796
Cohen's d	0,062 (very small)	-0,084 (very small)

Table 12: Cortisol summary statistics

In Room A, participants' mean cortisol levels decreased slightly from 5,353 ng/ml (SD=2,634; SE=0,833) to 5,147 ng/ml (SD=2,451; SE=0,775). This difference was not statistically significant ($t=0,195$; $p=0,849$) and showed a small effect size ($d=0,062$), indicating minimal change in physiological stress levels after one hour of study.

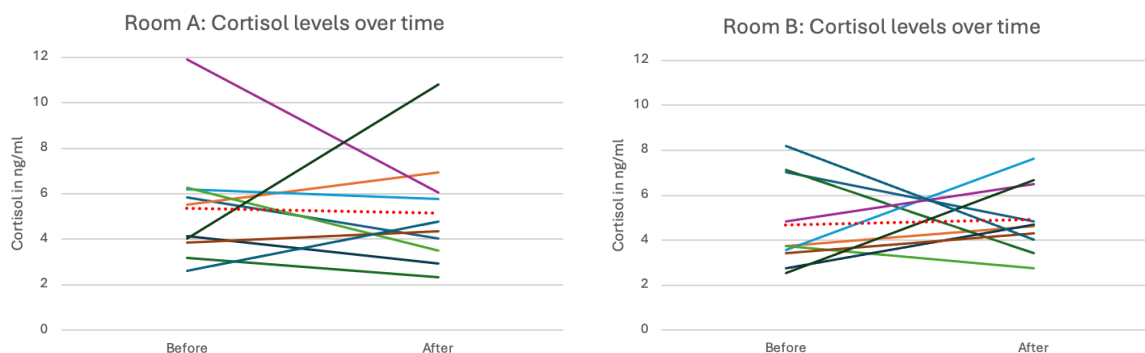
In Room B, cortisol levels slightly increased on average, from 4,690 ng/ml (SD=2,020; SE=0,639) to 4,938 ng/ml (SD = 1,535; SE = 0,485). This change was also not statistically significant ($t=-0,266$; $p=0,796$), with a similarly small effect size ($d=-0,084$). The direction of change was opposite to that in Room A, but again within the bounds of expected physiological variability.



Figures 31 & 32: salivary cortisol levels Room A and Room B (own ill.)

4.4.3 INDIVIDUAL CHANGE PATTERNS

The individual change trajectories shown in figures 33 & 34 show some trends, but also underscore the considerable variation in physiological response between participants. While some show strong decreases, others display major increases, underscoring the difficulty of identifying consistent physiological patterns attributable to environmental variation in small-sample, short-duration studies.



Figures 33 & 34: Cortisol levels over time of all participants (own ill.)

4.4.4 OUTLIER ANALYSIS

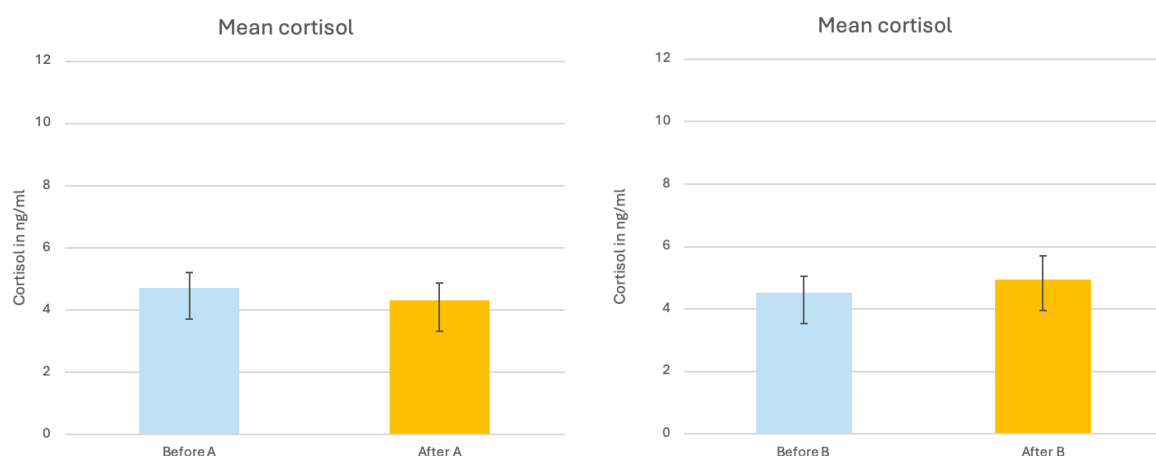
During review of the data, two datasets in Room A were found to have cortisol values that deviated noticeably from the rest of the sample. One participant recorded a starting value of 12 ng/ml, another had a post-session value of 11 ng/ml, while most values ranged between 2,5 and 8,0 ng/ml. These data points were retained in the primary analysis due to the small sample size ($n=10$). However, a secondary analysis was conducted excluding these two values to test the robustness of the findings.

	Room A	Room B
Mean Before	4,699 ng/ml	4,690 ng/ml
Mean After	4,328 ng/ml	4,938 ng/ml
SD Before	1,431	2,02
SD After	1,506	1,535
SE Before	0,506	0,639
SE After	0,532	0,485
t-value	0,634	-0,266
p-value	0,546	0,796
Cohen's d	-0,224 (small effect size)	-0,144 (small effect size)

Table 13: Cortisol summary statistics without outliers

In Room A, participants' mean cortisol levels decreased from 4,699 ng/ml (SD=1,431; SE=0,506) to 4,328 ng/ml (SD=1,506; SE=0,532). This change was still not statistically significant ($t=0,634$; $p=0,546$) and showed a small effect size ($d=0,224$).

In Room B, cortisol levels increased slightly, from 4,529 ng/ml (SD=2,124; SE=0,751) to 4,942 ng/ml (SD=1,439; SE=0,509). This change was likewise non-significant ($t=0,408$; $p=0,695$), with a small effect size ($d=-0,144$). These updated results reflect recalculated values with two outliers removed. While the outliers are removed, the results are still similar.



Figures 35 & 36: salivary cortisol levels without outliers Room A and Room B (own ill.)

4.4.5 ANOVA RESULTS

To further assess physiological stress differences between learning environments, a two-way repeated measures ANOVA was conducted on salivary cortisol concentrations. The within-subject factors were Room (A vs. B) and Time (before vs. after study session), with four values per participant. This analysis tested whether cortisol levels changed significantly as a function of the room, time, or their interaction. The full test of within-subjects effects can be found in appendix x.

Effect	F	p-value	partial η^2	Interpretation
Room	0,460	0,515	0,048	Not significant (very small trend)
Time	0,000	0,979	0,000	Not significant (no trend)
Room $\times$ Time	0,130	0,728	0,014	Not significant (minimal interaction)

Table 14: Main Analysis: Full Sample ($n = 10$)

These results indicate that cortisol levels remained stable across both rooms and timepoints. No systematic increase or decrease was observed. The absence of significant effects may reflect limited environmental stressors, individual variation, or the temporal mismatch between stress exposure and peak cortisol response.

To evaluate whether outlier values distorted results, a secondary ANOVA was performed excluding two extreme Room A cortisol values (12,0 and 11,0 ng/ml). All other values fell within the 2,5-8,0 ng/ml range.

Effect	F	p-value	partial η^2	Interpretation
Room	0,140	0,720	0,019	Not significant (very small trend)
Time	0,490	0,509	0,065	Not significant (slight trend)
Room $\times$ Time	0,000	0,973	0,000	Not significant (no interaction)

Table 15: Robustness Check: Excluding Visual Outliers ($n = 8$)

The removal of outliers did not materially change the results. However, the partial η^2 for Time increased from 0,0 to 0,065, indicating a small rise in explained variance. While not statistically significant, this may reflect a subtle time-related trend previously masked by outlier effects. Due to the reduced sample size ($n=8$), the power of this robustness check is limited. Any small but meaningful physiological effects related to room design or session duration may remain undetected.

4.4.6 INTERPRETATION

These results, supported by both paired t-tests and repeated measures ANOVA, suggest that neither Room A nor Room B had a statistically measurable effect on salivary cortisol levels during the one-hour exposure period. Although Room A showed a slight decrease in average cortisol concentration and Room B showed a slight increase, neither change was statistically significant, and both effect sizes were small. Two participants in Room A exhibited cortisol levels substantially above the rest of the sample, but even after these outliers were removed, the overall interpretation remained unchanged. This reinforces the conclusion that, in this small sample, the learning environments did not produce consistent physiological shifts detectable via salivary cortisol.

Compared to the self-reported physiological stress ratings (see Section 4.3.3), which showed moderate improvements in Room B, the cortisol data do not follow the same pattern. This divergence between hormonal and perceived stress responses highlights the importance of combining subjective and objective stress measures. It also aligns with prior findings in the literature, which suggest that psychological and physiological indicators often diverge, particularly in response to mild stressors or in short-duration studies (Sommerfeldt et al., 2019; Becker et al., 2022).

Taken together, these findings offer limited support for H2, which predicted lower physiological stress in the newer learning environment. While participants in Room B reported fewer physical symptoms of stress, their cortisol levels, across both t-tests and ANOVA, did not show a corresponding reduction. These findings underscore the challenges of capturing hormonal responses in naturalistic research settings and reaffirm the value of multi-method stress assessment. They also reflect the known delay between stress exposure and peak cortisol response, which may have obscured more immediate physiological effects.

4.5 QUALITATIVE RESULTS

4.5.1 THEMATIC ANALYSIS OF PARTICIPANT COMMENTS

This section explores open-ended responses from participants to the survey questions, using thematic coding in ATLAS.ti to identify environmental features, stress experiences, and room preferences. The qualitative coding process combined deductive and inductive approaches. Deductive codes were developed in advance based on insights from the literature on environmental stressors (e.g. Al Horr et al., 2016; Kropman et al., 2020), as well as the structure of the custom-designed survey items (e.g. overall stress, difficulty focusing). Contextual codes were also included to capture factors such as external stressors or personal conditions. In contrast, inductive codes were derived through iterative reading of the open-ended responses, allowing for emerging themes. A total of 80 coded quotations were analysed across 19 codes. This analysis complements quantitative findings with subjective insights.



Figure 37: code frequencies (Atlas.ti 2025)

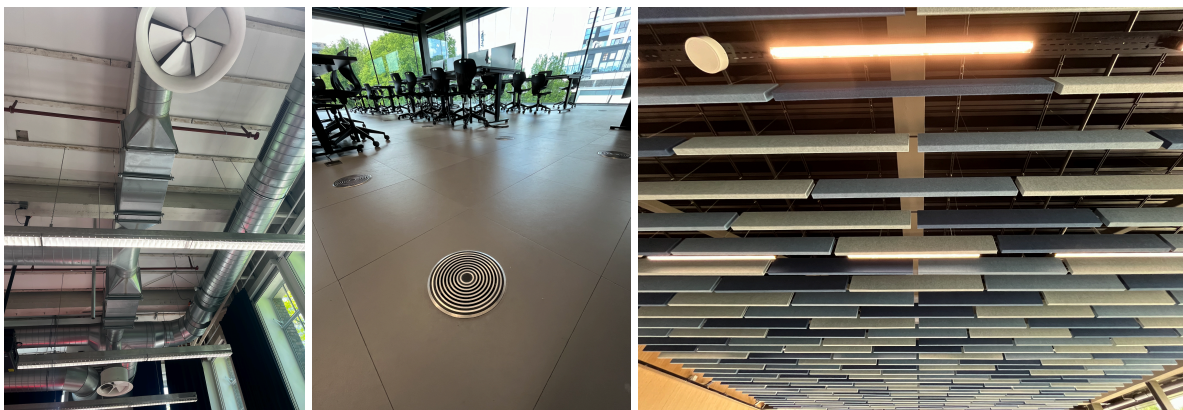
4.5.2 PHYSICAL CHARACTERISTICS

4.5.2.1 NOISE, ACOUSTICS AND PRIVACY

Room B was widely praised for its silence and good sound insulation. Room A had slightly more ambient noise, but participants rarely reported this as a major problem.

"Very silent, I didn't hear anything from the adjacent rooms." (Participant, Room B, session 2)

"Only the noise of the air ventilation is slightly irritating, but not annoying." (Participant, Room A, session 1)



Figures 38, 39 & 40: Left, the 'noisy air ventilation', Room A, right, the quiet floor ventilation and acoustic insulation, Room B (own ill.)

4.5.2.2 LIGHTING AND DAYLIGHT

Lighting was one of the most frequently mentioned factors (14 coded quotes), with participants consistently highlighting the importance of natural light. Co-occurrence analysis showed strong links between lighting and positive experience (12 connections) as shown in figure 41.

"There's a lot of natural light in the room, which is nice." (Participant, Room A, session 1)

Room B was also praised for its daylight, though one participant noted a darker visual tone despite the large windows.

4.5.2.3 LAYOUT AND DESIGN

Layout and design features (10 quotes) were often linked to personal comfort or distraction. Participants commented on seating arrangements, desk spacing, and room openness. Room B's flexible layout was appreciated by some, but others preferred the more traditional layout in Room A for its predictability and reduced visual noise.

"Less suitable than the previous one. I dislike the structure of people facing each other... I much prefer a clear setup facing one wall." (Participant, Room B, session 2)

4.5.2.4 BIOPHILIA AND VIEWS

The views and views on green were commented on in both rooms. In Room A the focus was mainly positively on the outside green, and in Room B it was mixed on the views

"Great plus for this room is that it's surrounded by trees, so if you sit close to the windows you can feel the soothing tranquility of nature around you." (participant, Room A, session 1)

"I sat next to the window, which did distract me a bit because there's a lot of people walking by outside who catch my eye every now and then." (participant, Room B, session 2)

4.5.2.5 LOOK AND FEEL

The aesthetic atmosphere of the rooms (24 coded quotes) showed up as a central theme. Participants described Room A as cozy and calming, with warm tones and wooden finishes contributing to comfort. Room B was seen as more modern and clean, but occasionally referred to as "clinical" or "cold."

"The entire building and the ambiance it brings feels much calmer." (Participant, Room A, session 2)

"This one is a little more 'clinical'." (Participant, Room B, session 2)

4.5.3 CO-OCCURANCE

The co-occurrence matrix below shows which environmental aspects were most frequently mentioned in relation to each room. Room A was more strongly associated with “look and feel” and “layout and design”, suggesting its atmosphere and structure played a larger role in participant experience. In contrast, Room B was more often linked with “noise, acoustics and privacy”, “room equipment”, and also scored for “look and feel”, reflecting a more technically oriented or performance-focused experience.

		◆ .Biophilia and... ⑪ 4	◆ .Layout and d... ⑪ 10	◆ .Lighting and... ⑪ 14	◆ .Look and feel ⑪ 24	◆ .Noise, acous... ⑪ 16	◆ .Room equip... ⑪ 9
◆ .Room A ⑪ 28			3	0	6	0	1
◆ .Room B ⑪ 36			1	1	3	2	3

Table 16: Co-occurrence table between characteristics and rooms (Atlas.ti, 2025)

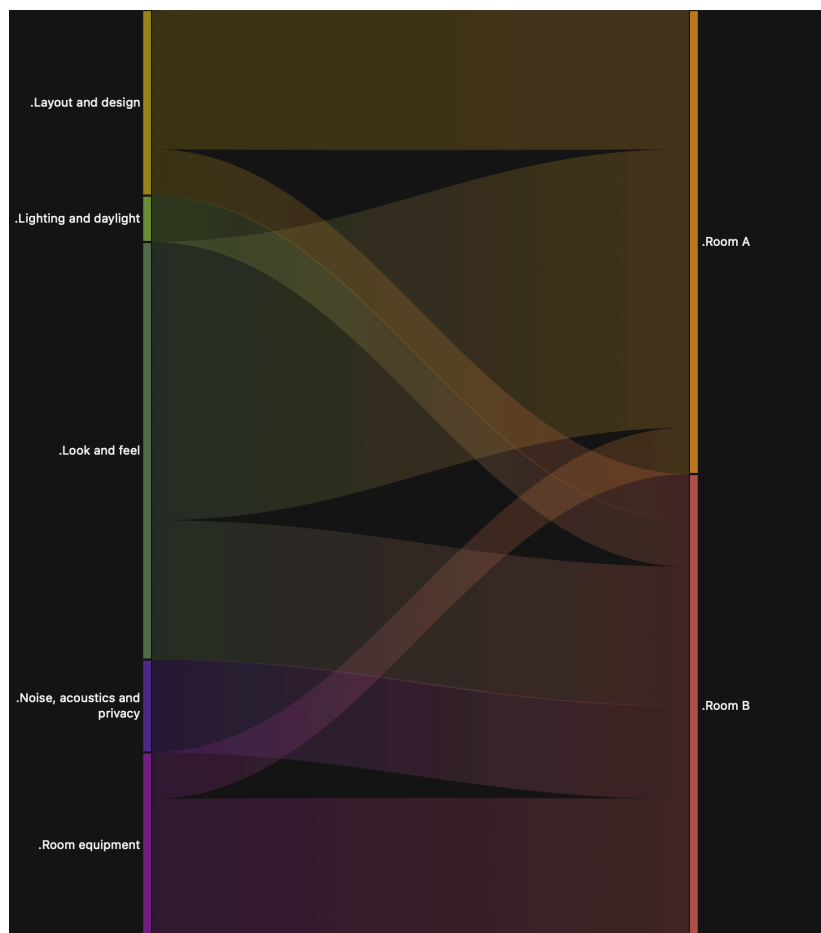


Figure 41: Sankey diagram showing flow between characteristics and rooms (Atlas.ti, 2025)

This Sankey diagram complements the matrix by visually mapping the thematic flows. The strength of the “look and feel” connection to both rooms is clearly visible, as is the distinct pathway from “noise, acoustics and privacy” and “room equipment” toward Room B, and the “layout and design” toward Room A. These patterns reflect how each room offered a different balance of atmosphere and functionality.

4.5.4 ADDITIONAL EMERGING THEMES

4.5.4.1 ROOM EQUIPMENT

Room equipment, including desks, chairs, tables, power sockets, and screens, emerged as a recurring theme in both positive and negative comments. While some participants appreciated the available resources, many voiced concerns about comfort, adjustability, or practicality. Notably, several participants mentioned that the Echo room (Room B) featured modern design but lacked basic ergonomic comfort.

"The tables at Echo were unstable and the chairs less comfortable." (Participant, Room B session 2)

Others expressed a wish for more advanced study tools:

"I would really like an extra screen and higher desk and chair." (participant, Room A, session 1)

"Not all the tables have power outlets." (participant, Room A session 2)



Figures 42, 43 & 44: Some tables with and others without power outlets, unadjustable chairs, Room A (own ill.)

This equipment-related discomfort sometimes outweighed otherwise positive impressions of the room. Despite being mentioned by fewer participants, comments about room equipment emerged in both rooms, often with strong emotional tone. This suggests that ergonomic design and furnishing quality may strongly influence how well an environment supports sustained focus and stress reduction. Not all quotes on equipment were negative:

"I think I prefer this one ... the seats and desks are adjustable" (participant, Room B, session 2)



Figures 46 & 47: adjustable seats and desks, Room B (own ill.)

4.5.4.2 EXTERNAL STRESSORS AND PERSONAL CONDITITIONS

Several responses revealed that personal stressors, such as academic deadlines, medication, or sleep, affected participants' mood during the session. These contextual pressures may have been more dominant than environmental influences. Such observations underline the importance of interpreting room-related findings in light of broader situational and individual conditions.

4.5.5 ROOM PREFERENCES

Participant preferences between Room A and Room B were highly divided. Many participants found both rooms to be suitable and pleasant places to study, but their reasons for preference varied based on individual needs. Some preferred room A for its warm, cozy, and atmospheric qualities.

"This room! The entire building and the ambiance it brings feels much calmer." (participant, Room A, session 2)

"I think I prefer this room (Room A) to study in because of its cozy feel." (participant, Room A, session 2)

Others favored Room B for its perceived support for focus, quietness, and modernity:

"It is quiet, there is enough light, there are sufficient outlets and space between students." (participant, Room B, session 2)

"I think I prefer this one, but the other room was also good. This one is quieter and it looks nicer." (participant, Room B, session 2)

A few noted that their preference depended on the type of work they were doing, some environments were better for deep concentration, while others provided a more relaxed, general-purpose atmosphere.

"If I have to concentrate on a deadline, the other room is better, I think." (participant, Room A, session 2)

Taken together, these comments suggest that while both rooms were broadly considered suitable, Room B was more frequently associated with improved ability to concentrate, especially by participants focused on productivity. Room A, on the other hand, was often appreciated for its atmosphere and comfort. To deepen these insights, a co-occurrence analysis was also conducted.

	● .Biophilia and...	● .Layout and d...	● .Lighting and...	● .Look and feel	● .Noise, acous...	● .Room A	● .Room B	● .Room equip...
	Ⓜ 4	Ⓜ 10	Ⓜ 14	Ⓜ 24	Ⓜ 16	Ⓜ 28	Ⓜ 36	Ⓜ 9
● .Negative experience Ⓜ 14	1	2	4	2	3	7	7	4
● .Neutral experience Ⓜ 2	0	0	0	0	0	0	1	0
● .Positive experience Ⓜ 36	3	6	12	11	10	15	19	3
● .Preference Ⓜ 14	0	4	1	9	2	6	8	4
● .Unexpected theme Ⓜ 2	0	0	0	1	0	1	0	0

Table 17: Co-occurrence between rooms, characteristics, experience and preference ([Atlas.ti 2025](#))

This co-occurrence matrix shows how participant experiences (positive, negative, neutral), room preference, and emergent themes correspond with mentions of specific rooms and physical design aspects. Room B is strongly associated with positive experiences. And is also slightly more preferred. The codes look and feel, lighting and daylight, layout and design and room equipment are most often linked to both positive experiences and preference. Despite fewer mentions, room equipment was clearly linked to both positive and negative experiences, and to overall room preference, suggesting its practical impact outweighed its frequency.

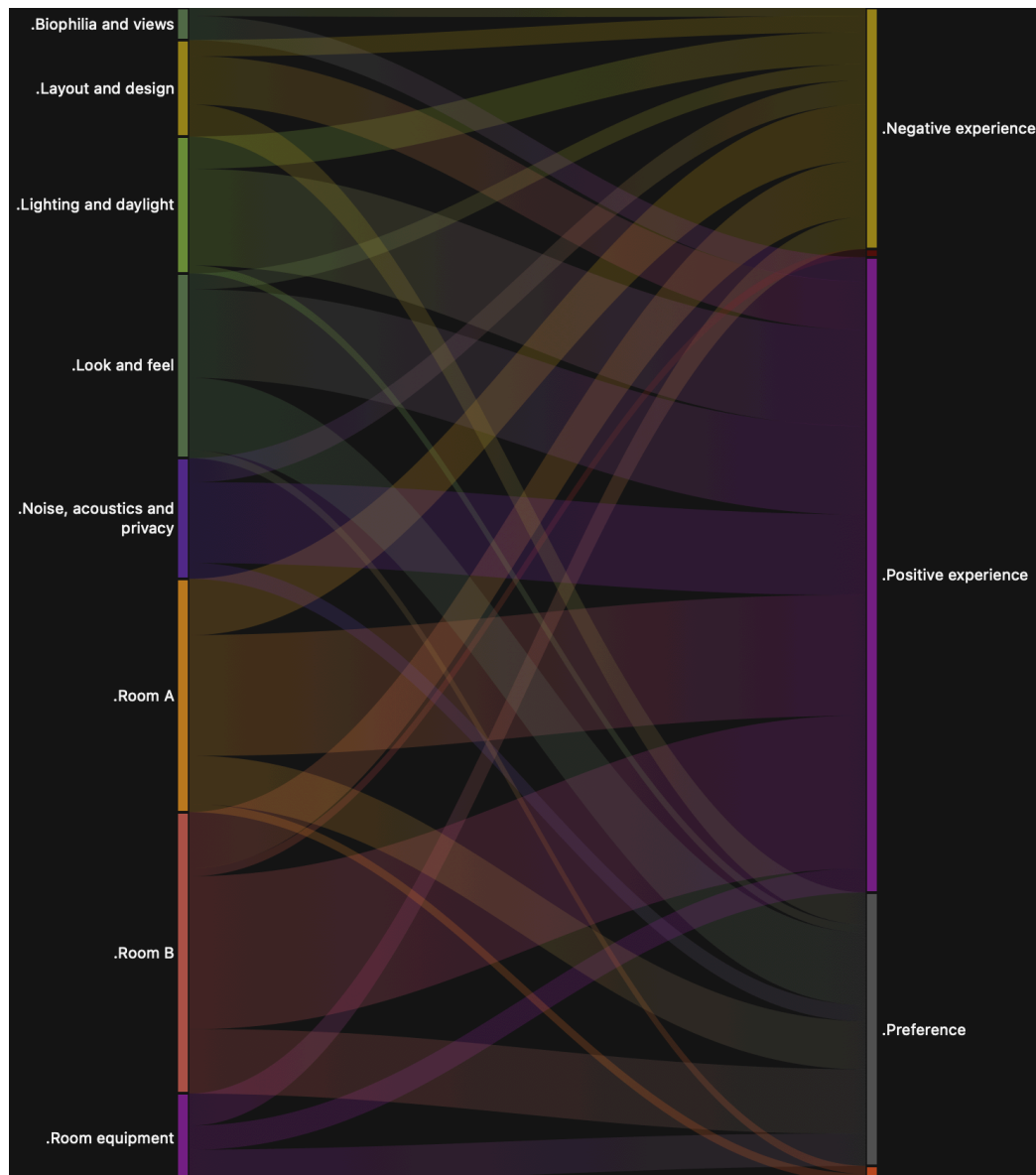


Figure 48: Sankey diagram showing flow of rooms and characteristics toward experience and preference, (Atlas.ti 2025)

This Sankey diagram visualises how participant comments flowed from mentions of specific rooms and environmental features to coded experiences and preferences, talked about in the paragraph and co-occurrence table above. Notable observations include the mixed preferences between the two rooms, as well as the codes linked to causing the preferences, where look and feel is strongly linked. It is interesting to see that the code room equipment was also linked visibly with both positive and negative experience as well as the preference.

4.5.6 UNEXPECTED THEMES

A few unexpected themes surfaced. One participant mentioned the psychological effect of room structure on supervision and privacy.

"It looks like a strict boarding school... It is also a very large space, which has a negative influence on my concentration." (Participant, Room A, session 2)

Another participant mentioned being glad to have a space to study in, since during exam periods it is often busy. This statement highlights the lack of sufficient study spaces as described in wider research on student workspace scarcity (Goodnight & Jeitner, 2016).

"The few amount of people in a study room made studying more relaxing. Much better than studying in a crowded room, which is often the case during exam periods." (Participant, Room B, session 2)

4.5.7 SUMMARY

Participants expressed a wide range of perceptions related to the physical characteristics of the two study environments. The most frequently discussed features were look and feel, lighting and daylight, and layout and design, followed closely by room equipment. While both rooms were generally seen as suitable for studying, their perceived strengths diverged. Room B was more often associated with improved focus, acoustic quality, and technical readiness, especially among participants aiming for high productivity. In contrast, Room A was frequently described as more cozy, calming, and aesthetically warm, with a stronger emotional atmosphere that some found more supportive for relaxed studying. Preferences were highly individual and sometimes task-dependent, with some participants favoring one room for deep concentration and the other for general study.

Room equipment emerged as a key point of contention. Participants praised modern design and adjustability in Room B, but also criticised discomfort, lack of outlets, and ergonomic issues in both rooms. This feature had a surprisingly strong influence on room preference, despite being mentioned less frequently than other characteristics. The qualitative findings provide valuable context for interpreting the quantitative results. In line with H1, they support the idea that the physical environment shapes students' perceived stress and comfort, though the specific factors vary widely between individuals. These insights also reinforce the need for environments that are not only visually and acoustically optimised, but also practically supportive and ergonomically designed.

4.6 SUMMARY OF KEY FINDINGS

This chapter investigated whether and how different physical university learning environments influence student stress during self-study. A within subjects experimental design was used, combining self-report surveys, salivary cortisol data, and open-ended qualitative responses, supported by environmental observations. The results provide a multifaceted perspective on both perceived and physiological stress experiences across two contrasting rooms (Room A and Room B), addressing the study's central hypotheses.

4.6.1 QUANTITATIVE: SURVEY AND CORTISOL

Across all participants, self-reported overall stress decreased slightly in both rooms, but these changes were small and not statistically significant. Effect sizes were negligible (Room A: $d=0,115$; Room B: $d=0,464$), indicating minimal environmental influence on general stress levels. Difficulty focusing improved in Room B ($d=0,554$; $p=0,069$), suggesting a moderate effect of the newer room design on concentration. In contrast, Room A showed a small, non-significant increase in difficulty focussing ($d=-0,077$). Self-reported physiological stress decreased in both environments. In Room B, this change was statistically significant ($p=0,044$; $d=0,533$), indicating a moderate effect. Room A also showed a moderate, non-significant reduction ($d=0,478$). Perceived environmental influence on stress remained stable in both rooms, with inconsistent trends and minimal effect sizes (Room A: $d=0,070$; Room B: $d=-0,144$).

A three-way repeated measures ANOVA on the survey data revealed no statistically significant effects for room, time, or survey item, nor any interaction between them. While Room B showed trends toward improved focus and lower physiological stress in the paired comparisons, these patterns were not strong enough to reach significance when all variables were considered simultaneously. Importantly, the Time effect showed a moderate effect size (partial $\eta^2 = 0,200$), hinting that some participants may have experienced reduced stress after their sessions, regardless of room. The Room effect (partial $\eta^2 = 0,102$) also suggested a small trend in favour of Room B, though inconclusive. These results suggest that the effect of learning environment may be subtle and context-dependent, and that the limits of small-sample, short-duration designs may obscure some genuine variation in environmental experience.

Cortisol measurements also did not show significant changes in either room (Room A: $p=0,546$; Room B: $p=0,695$). After outlier removal, Room A showed a slight average decrease, while Room B showed a slight increase, diverging from the self-reported physiological stress trend, which had indicated a significant decrease in Room B. A separate repeated measures ANOVA on cortisol levels confirmed that there were no significant main or interaction effects. These results underscore the diverse relationship between perceived and hormonal stress responses, particularly over short experimental exposures.

4.6.2 QUALITATIVE: PERCEPTIONS AND PREFERENCES

Participants frequently commented on look and feel, lighting and daylight, and layout and design. Room A was described as warm and atmospheric, in line with statements from Llinares et al. (2021); while Room B was noted for its cool appearance, in line with Küller et al. (2006), quietness, and acoustic quality. Comments on focus aligned with survey data: Room B was more often associated with improved concentration, supported by its silence, layout, and lighting. Room equipment (desks, chairs, outlets) was a strong differentiator. Participants in both rooms cited issues with furniture comfort or functionality, with some stating that these elements impacted their ability to focus or relax. While less frequently mentioned, this theme showed strong co-occurrence with both positive and negative experience codes and was tightly linked to room preference. Room preferences were divided. Some preferred Room A for its comfort and aesthetic warmth, while others favored Room B for its focus-supporting design. A few described task-based preferences, suggesting that different environments may support different cognitive needs. External stressors (e.g. deadlines) were often cited as more dominant than the room context, highlighting the need to interpret environmental effects in relation to broader individual conditions.

4.6.3 OVERALL INTERPRETATION

The two central hypotheses were partially supported:

- H1 proposed a relationship between physical environment and perceived stress. This was supported by item-level effects in Room B, especially for focus and self-reported physiological stress.
- H2 proposed that students in newer environments would report lower perceived and physiological stress. While supported by subjective responses in room B, this was not reflected in the physiological (cortisol) data.

These findings suggest that physical learning environments can influence specific aspects of stress and concentration, but that these effects are individual, variable-specific, and moderated by context. Subjective and physiological indicators may diverge, particularly in short experimental exposures.

Rather than framing one room as better than the other, the results point to the importance of personalisation in study environments. Atmosphere, layout, acoustic privacy, and ergonomic comfort all contribute to how environments are experienced, and ultimately, how they may influence stress. The next chapter reflects on these results and considers their implications for design, research, and educational practice.

5 DISCUSSION

This chapter interprets the results of the study in the context of this thesis and in light of existing literature, and broader implications. While the data from survey responses, cortisol sampling, and qualitative analysis provide varied insights, their integration reveals patterns and tensions that extend beyond what any single method could offer. The following sections consider the potential interpretation of the cortisol results, the role of restoration versus concentration, the unconscious influence of space, and the value of multi-method approaches in environmental stress research.

5.1 CORTISOL AND CONCENTRATION

One of the most intriguing findings of this study is the contrast between physiological and self-reported stress outcomes, particularly in Room B. While self-reported physiological stress significantly decreased in this space, salivary cortisol showed a slight but consistent increase after the session. This divergence challenges the assumption that lower stress perception must correspond to lower hormonal stress levels. Instead, it raises the possibility that the cortisol increase may reflect a form of adaptive or productive stress, sometimes referred to as eustress. Room B was consistently associated with improved focus and concentration, quietness, and adequacy of equipment. Survey results showed a near-significant improvement in difficulty focusing, and qualitative responses described the space as conducive to concentration. From a physiological perspective, moderate cortisol elevation is not inherently negative. Cortisol is part of the body's natural stress response and plays a key role in cognitive functioning, including attention and memory consolidation (Lupien et al., 2007). In the context of this research, slightly elevated cortisol levels may indicate task engagement rather than distress.

This interpretation aligns with studies that view cortisol reactivity as a context-dependent indicator, modulated by the meaning and demands of the situation. When participants are engaged in challenging but manageable tasks, cortisol can rise without causing negative effects (Kemeny, 2003). In this study, the environment in Room B may have supported a mental state that required alertness, thereby explaining the increase in cortisol despite the participants reporting reduced physical stress symptoms. The combination of cognitive stimulation, quietness, and fewer distractions may have created conditions that promoted focused arousal, a state associated with enhanced performance and mildly elevated physiological activation. It is important to note, however, that these findings are based on a small sample ($n=13$ / $n=10$) and may not be generalisable. In larger studies or different conditions, these patterns may look different. Nonetheless, the observed discrepancy between cortisol and perceived stress offers a valuable starting point for interpreting environmental effects on physiological engagement.

These results do not prove that cortisol reactivity is beneficial in all learning contexts, nor do they confirm that Room B was universally experienced as helpful. However, they point toward a more nuanced understanding of stress, one in which physiological activation is not always maladaptive, especially in spaces that support cognitive engagement. The apparent contradiction between lower self-reported stress and slightly elevated cortisol suggests that these measures capture different facets of the stress experience, and that not all stress-related responses are uniformly negative.

5.2 RESTORATION AND ROOM PREFERENCES

Room A was frequently described by participants as calm, cozy, and aesthetically warm. These impressions were often linked to its wooden finishes, warm lighting, and green exterior views, qualities associated with emotional comfort and reduced stress. In contrast, Room B was more often described as quiet, modern, and clean, with stronger associations to concentration and task performance. This divergence highlights the multidimensional nature of study environments: some promote restoration, while others support cognitive control.

In environmental psychology, Attention Restoration Theory (Kaplan, 1995) proposes that natural environments and soft fascination (e.g., daylight, greenery, gentle stimuli) can help replenish directed attention capacity. Similarly, biophilic design draws on these restorative principles by incorporating nature-related elements into indoor spaces to reduce stress and support well-being. Room A's popularity among some participants can be partially interpreted through this lens, its visual softness, natural views, and emotional tone likely fostered a restorative state.

However, the results also challenge the assumption that all learning environments should be restorative. Participants who preferred Room B often cited its ability to support deep focus, even though it was perceived by some as more sterile or less emotionally warm. While restorative qualities are important for reducing fatigue and long-term stress, focus-oriented environments may require different spatial cues, such as minimal distractions, quietness, or clear structure, even if they are perceived as less emotionally inviting. This raises a tension between restoration and concentration. Room A may have promoted emotional relaxation but was not consistently seen as conducive to demanding cognitive tasks. Conversely, Room B appeared to support focus and task engagement, even if it felt more impersonal. These findings align with the idea that study environments serve different functions at different times, and that no single design can universally optimise all dimensions of student well-being and performance.

Participant comments further reinforce this idea. Several indicated that their room preference depended on the task at hand, choosing Room A for general study or relaxation, and Room B when deadlines or concentration were required: *"I think I prefer this room (Room A) to study in because of its cozy feel. But if i have to concentrate on a deadline the other room (Room B) is better I think for concentration maybe"*. This suggests that students intuitively select environments based on functional needs, rather than fixed emotional responses. It also highlights the need for diverse spaces that accommodate both recovery and productivity.

5.3 UNCONSCIOUS PROCESSING OF SPACE

Although many participants reported in the surveys that the room didn't influence them, the combined qualitative, physiological, and survey data suggest otherwise, indicating that architectural spaces often operate at an unconscious level. This section of the discussion explores how environmental cues and spatial heuristics subtly shape students' experiences and preferences.

5.3.1 NEUROARCHITECTURE

The field of neuroarchitecture explores how built environments influence emotional and cognitive states through subtle, often unconscious, sensory cues. Features in the physical environment can shape human wellbeing, performance, and emotional responses without requiring active awareness (Lee et al., 2022). In our study, these frameworks help explain why some participants initially believed the rooms didn't influence them, yet still showed measurable responses. Room A's warm colours, and views on nature likely fostered calmness even without conscious recognition. Meanwhile, Room B's clean design, quiet environment, and structural clarity may have promoted cognitive alertness and focus, again, primarily through unconscious sensation.

5.3.2 HEURISTICS AND ASSOCIATIONISM

Cognitive theories such as associationism and heuristics describe how environmental stimuli become linked to emotional and behavioral responses over time. Heuristics act as fast, automatic shortcuts, formed through repeated exposure, that help individuals interpret surroundings with minimal cognitive effort (Gigerenzer, 2021). Meanwhile, associationism explains how elements of our environment, through repeated co-occurrence, form mental links that can trigger corresponding emotional or behavioural reactions at an unconscious level (Stanford, 2015).

In our study, participants' reactions may have been guided by these automatic processes: Room A's traditional layout could evoke feelings of comfort and relaxation (or in some cases associations with strict boarding schools), while Room B's clean structure and quietness might cue focus and productivity. These associations operate beneath conscious awareness, influencing experience and preference even when participants reported no detectable effect from the room. Such mechanisms reinforce the idea that atmosphere and peripheral perception can shape emotional responses before conscious interpretation.

5.4 COMBINING PHYSIOLOGICAL AND SELF REPORTED

This study highlights the importance of combining multiple stress measurement methods when investigating environmental effects on well-being. The divergence between self-reported stress and physiological indicators, most notably in Room B, where self-reported stress decreased while cortisol increased, underscores how each method captures a different facet of the stress experience. Self-reported survey data offer insight into participants' conscious perceptions and subjective interpretations. In this study, participants could articulate how the room made them feel or how easily they could concentrate. However, these responses may be shaped by memory, mood, social desirability, and limited introspective access. People may not be fully aware of how the environment affects them, or they may misattribute their internal state to other causes.

In contrast, salivary cortisol provides a biochemical snapshot of physiological arousal, a more objective but also more opaque measure. However its time-delayed peak (typically 25 minutes) complicates the alignment with moment-to-moment experiences. Cortisol can rise due to stress, but also engagement, meaning its interpretation requires context. The slight increase observed in Room B may reflect this nuance: not distress, but a physiological correlation of focus and alertness. Together, these tools allow for a more complete understanding. By triangulating physiological signals, subjective responses, and qualitative input, this study was able to surface discrepancies that would have been invisible with a single method. Rather than invalidating one another, these differences point to the layered nature of stress: how we feel, what we report, and how our bodies respond do not always align, especially in short-term, real-world exposures. From a research perspective, this discrepancy also proved personally instructive. The decision to rely on a one-hour exposure window for cortisol sampling, while practical and aligned with prior studies, may have limited the sensitivity of the biomarker. Similarly, the survey items used were designed specifically for this research and not validated by prior instruments.

These choices reflect both constraints and learning moments. They do not invalidate the findings, but rather highlight the value of multi-methods in making sense of complex, multidimensional outcomes. This self-critique is an essential part of the research process, and future work can build on these insights by refining measurement protocols and extending study durations. Ultimately, the divergence between physiological and self-reported stress is not a flaw, but a finding. It reinforces the importance of seeing stress as a dynamic, context-sensitive process, one that cannot be reduced to a single number or score. For researchers, designers, and educators interested in the relationship between space and stress, this study illustrates why integrating multiple lenses is not just valuable, it is necessary

5.5 SOCIETAL AND SCIENTIFIC RELEVANCE

Understanding and reducing student stress has become an urgent concern in higher education, as mental health issues, burnout, and cognitive overload increasingly affect academic performance and wellbeing. While many stress-reduction strategies focus on psychological support, workload management, or curriculum design, the physical learning environment remains a relatively overlooked factor, despite being a constant presence in students' daily academic routines.

By examining the influence of physical university spaces on perceived stress, this research has the potential to inform practical interventions for improving student well-being. Findings could guide university administrators, campus planners, and policymakers in creating spaces that better support students' mental health and academic success. Additionally, the emphasis on designing inclusive and adaptive environments aligns with broader societal goals of promoting equity, accessibility, and sustainability in education. The research offers actionable insights that may contribute to fostering healthier, more supportive campus experiences for future generations of students. From a scientific perspective, this research contributes to a growing body of literature exploring the interplay between environmental design and mental well-being. While prior studies have extensively examined stress in workplace or outdoor campus settings, there remains a gap in understanding how physical university learning environments specifically influence student stress. This research addresses that gap by focusing on physical university learning environments.

This study contributes to a growing recognition that environmental design can meaningfully influence stress perception and cognitive performance. Whereas most existing research on physical environments and stress stems from the workplace domain (e.g. Bergefurt et al., 2023; Kropman et al., 2022), its application in university settings, particularly self-study spaces, has received limited attention. This is notable given the importance of quiet, private, and comfortable study environments for maintaining focus, and mental wellbeing (Beckers et al., 2016; Goodnight & Jeitner, 2016). By combining perceived psychological and measured physiological data in a controlled within-subject study, this research addresses a gap in both environmental psychology and educational design literature. The comparison between two real, contrasting university rooms allows for ecologically valid insights into how learning environments affect students during self-study.

5.6 BROADER IMPLICATIONS

The findings contribute to a growing body of evidence that the physical environment influences students' academic experiences. While the differences between Room A and Room B were not universally significant, consistent trends in self-reported focus and physiological stress suggest that environmental features shape how students experience study spaces. These findings challenge the notion of a universal "ideal" learning environment. Room A was appreciated for its warmth and comfort; Room B for its quietness and visual order. Preferences were often linked to working style and task type. This supports a shift away from

one-size-fits-all spatial design, and toward a diversified campus infrastructure offering both focused and restorative spaces.

The study also reinforces the need to view student stress as a layered experience, shaped by both physical context and personal condition. Even when physiological stress markers remained unchanged, students reported feeling calmer or more focused, demonstrating that perception matters. Carefully designed environments can foster psychological ease, even when biological signals are static. Finally, the project highlights a broader opportunity for universities, designers, and researchers: to treat learning spaces not just as functional infrastructure, but as supportive elements in stress mitigation, cognitive support, and emotional wellbeing.

5.6 ETHICS AND DATA MANAGEMENT

To ensure this research was conducted in line with the ethical standards of Delft University of Technology and the graduation thesis protocol, a comprehensive data management and ethics procedure was followed. A data management plan (DMP) was developed prior to data collection, detailing how participant data would be gathered, stored, processed, and anonymised. This plan is included in the appendix. Because the research involved both self-reported survey data and biometric cortisol sampling, the project was split into two DMPs for practical and procedural reasons. The first covered the survey component and was submitted, along with the research summary and informed consent materials, for review by the Human Research Ethics Committee (HREC) on 28 February 2025. Minor adjustments were made on 8 April 2025, and full ethical approval was granted on 12 May 2025. Prior to participation, all students received an informed consent form clearly outlining the purpose of the study, the procedures involved, their data rights, and the option to withdraw at any time without penalty. Consent was explicitly required for participation in both the survey and the physiological data collection, in accordance with TU Delft ethical standards.

To prepare for the cortisol data collection, a second DMP was created specifically for biometric data. Although salivary cortisol is non-invasive and anonymised, the inclusion of physiological measurements required further review. The DMP has been reviewed by the BK data steward on 22 May 2025, and was submitted for additional approval through the TU Delft privacy team to assess whether a Data Protection Impact Assessment (DPIA) is needed. The DPIA was deemed unnecessary by Lieke Font Freide on 13 June 2025. The second application, with inclusion of cortisol sampling as well as the advice on DPIA, was handed in on 15 June 2025.

Throughout the research, all data were handled responsibly, stored securely, and anonymised to protect participant privacy. No personally identifying information was retained, and all ethical procedures were designed to minimise potential risks while maximising participant transparency and comfort. This research contributes to an emerging understanding of student stress in learning environments and was conducted with full respect for participant autonomy, data integrity, and institutional research ethics.

6 LIMITATIONS

Like all research, this study was shaped by practical constraints, methodological trade-offs, and conceptual boundaries. Acknowledging these limitations is essential not only for interpreting the results with appropriate caution, but also for guiding future research toward more robust and generalisable insights.

6.1 EXPERIMENTAL DESIGN LIMITATIONS

The study was conducted with a small sample size ($n=13$ for survey data; $n=10$ for cortisol), which limits statistical power and the ability to generalise findings. While the within-subject design helped mitigate individual differences, a larger sample would have enabled more confident conclusions and subgroup analyses (e.g. gender, study programme, time of day effects). Another limitation concerns the duration of each session. Study periods lasted one hour, which may not have aligned well with the delayed physiological response curve of cortisol. Since cortisol typically peaks around 20–30 minutes after a stressor, it is possible that peak values were missed by sampling only at the beginning and end of each session. This limits the ability to detect acute environmental effects. However, resource constraints allowed for only four measurements per participant, divided across both sessions. Despite this, the sampling design still allowed for meaningful comparison between environments. Additionally, study sessions were self-directed rather than task-controlled. While this enhanced ecological validity, it introduced variability in cognitive demand across participants. Room selection was also constrained by availability. Although Room A and Room B were clearly different in design and atmosphere, they were not matched in terms of acoustic insulation, layout flexibility, or lighting conditions. This complicates attribution of stress responses to specific environmental features.

6.2 MEASUREMENT LIMITATIONS

The most prominent limitation on the measurement level concerns the physiological data. Salivary cortisol, while widely used, is sensitive to a number of external factors, food intake, time of day, physical activity, and emotional state. Despite clear instructions and standardisation, some uncontrolled variation likely remained. As noted above, cortisol's delayed response may not have aligned with the study's timing, increasing the risk of missing peak hormonal levels.

Other physiological indicators, such as EDA and HRV, could have provided supplementary insights into short-term arousal or stress. However, these instruments were not available due to budgetary and logistical limitations. Their absence reduced the ability to triangulate moment-to-moment stress changes using objective data. The reliance on self-report measures also carries inherent limitations. Participants' responses may have been influenced by mood, expectations, or social desirability. Although open-ended reflections added depth, the subjective nature of these data means that not all insights can be generalised or verified independently.

6.3 LITERATURE AND CONCEPTUAL LIMITATIONS

Several of the environmental design frameworks used in this study were developed in workplace contexts and adapted for educational environments. While this transfer is supported by theoretical parallels (e.g. concentration, stress regulation), these models have not been formally validated for student populations. Their applicability to educational settings, while promising, remains an open question. There is also no universally accepted definition of "learning environment stress," which makes it difficult to isolate this concept from broader academic, social, or personal stressors. Some participants referenced external factors (e.g. deadlines, medication) that were not controlled for but clearly influenced their experience. This highlights the complex interplay between environment and context in real-world settings.

Finally, because the study was conducted during a relatively calmer period in the academic calendar (week 7 and week 8), stress levels may not have been high enough to activate meaningful physiological responses. A similar study during exam periods or under more demanding cognitive tasks might yield different results.

7 CONCLUSIONS

This study explored how physical learning environments influence stress among university students, combining subjective and physiological stress measures with qualitative reflections and environmental documentation. By comparing two contrasting rooms at a Dutch university, the research offers a nuanced perspective on how elements such as layout, lighting, acoustic conditions, feel, and equipment contribute to students' stress experiences during self-study.

7.1 RQ1: *What are the different types of stress and stressors relevant to university students in learning environments?*

University students experience both psychological and physiological forms of stress in learning environments, often influenced by overlapping academic, personal, and spatial conditions. Based on the framework by Slimmen et al. (2022), relevant psychological stress domains include academic pressure, financial concerns, family or social obligations, and extracurricular responsibilities. According to the literature, these background stressors influence how students enter and experience study environments.

In addition to these contextual pressures, students also encounter more immediate, environment-related stressors during study, such as noise, discomfort, visual overstimulation, or perceived lack of privacy. These can lead to cognitive stress (e.g. difficulty concentrating), emotional stress (e.g. frustration or overwhelm), and physiological stress responses (e.g. tension, increased heart rate, fatigue). This study distinguishes between self-perceived stress, including general (PSS-10) and situational (custom survey) indicators, and measured physiological stress via salivary cortisol. Together, these capture stress as it is experienced in real-world learning environments.

7.2 RQ2: *How can different types of stress in university students be measured?*

Stress in university students can be measured through a range of subjective and physiological methods, each targeting different aspects of the stress response. Self-report instruments, such as the Perceived Stress Scale (PSS-10), are widely used to assess general psychological stress over a longer time frame. For shorter exposures or specific study contexts, moment-specific surveys can be used to measure situational stress indicators, such as difficulty focusing, emotional strain, or physical tension. Open-ended questions are often added to capture nuance, interpretation, and unanticipated stressors.

Physiologically, stress can be measured through several biomarkers linked to autonomic or hormonal systems. Salivary cortisol is commonly used to reflect activity in the HPA axis and provides insight into hormonal stress responses. In parallel, EDA and HRV offer moment-to-moment data on sympathetic nervous system arousal, often associated with acute or immediate stress reactions.

Each method carries trade-offs in terms of sensitivity, invasiveness, temporal resolution, and interpretability. While physiological data offer objectivity, they are susceptible to timing, context, and individual variability. Conversely, self-reports capture personal interpretation and lived experience but are influenced by mood, expectation, and memory. As this study illustrates, combining these methods offers a more holistic understanding of how stress is experienced and expressed in real-world learning environments.

7.3 RQ3: *What is a (new) university learning environment?*

A “new” university learning environment does not refer to a single fixed model, but rather to a design approach that reflects evolving ideas about learning, focus, and wellbeing. Based on this study’s observations and analysis, newer environments typically feature a combination of modern materials, modular and adjustable furniture, acoustic optimisation, access to daylight, and a flexible layout that allows for varied configurations and uses.

These environments are often built to support not just instructional needs, but also individual work, cognitive focus, and emotional comfort. Compared to traditional environments, which often emphasise static layouts, durable furniture, and frontal teaching setups, newer designs aim to create multifunctional spaces that balance performance, flexibility, and atmosphere.

Room B, used in this study, illustrates these principles. It offered acoustic insulation, floor-to-ceiling windows, and movable furniture, creating a space optimised for quiet, independent study. In contrast, Room A had a fixed layout, warmer tones, and an ambient, more traditional atmosphere. Both rooms were appreciated by participants, but for different reasons, highlighting that “new” does not inherently mean better, but rather different in emphasis, oriented toward adaptability and student-centered design.

While the term “new learning environment” is not yet consistently defined in literature, this study suggests that it can be understood as a shift away from one-size-fits-all lecture halls toward diverse, responsive, and psychologically supportive spaces. It also needs to be noted that in this study, only two different learning environments were studied. Other “old” and “new” physical learning environments at this or other universities may fit different descriptions, and need to be researched separately.

7.4 RQ4: *What observable characteristics of (new) university learning environments influence stress among university students?*

Based on the framework by Bergefurt et al. (2023) and Kropman et al. (2022), seven physical characteristics are associated with mental wellbeing and stress response in indoor environments: (1) noise, acoustics and privacy, (2) lighting and daylight, (3) layout and design, (4) biophilia and views, (5) indoor air quality, (6) thermal comfort, and (7) look and feel. This study focused on the first five, as they were the most feasible to observe and assess within the university context.

These characteristics were analysed through environmental observation, participant feedback, and thematic coding. Among them, noise, acoustics and privacy, lighting and daylight, layout and design, and aesthetic atmosphere (“look and feel”) were most frequently mentioned by participants in relation to their stress experience.

Room B was praised for its quietness, openness, and visual order, qualities that supported focus and reduced distraction. Room A, by contrast, was appreciated for its warmth, natural views, and calming ambiance. In addition to the five studied characteristics, room equipment, including furniture comfort, desk height, and power outlet access, emerged as an influential factor. Although not part of the original framework, participants frequently commented on the ergonomic and functional impact of desks and chairs, linking them to both positive and negative study experiences. This suggests that furnishing quality and usability may play a more prominent role in perceived stress than previously recognised.

Together, these observations confirm that physical characteristics of learning spaces can influence students’ cognitive and emotional stress responses. However, the impact of each feature appears to be interactional and context-dependent, shaped by individual needs, study goals, and prior expectations.

7.5 RQ5: *How do newer university learning environments differ from traditional ones in their influence on student stress?*

Newer learning environments, such as Room B, differed from traditional ones like Room A in both their design features and their influence on students’ stress experience. This comparison also tested two hypotheses formulated based on the literature review and experimental design:

H1: There is a statistically significant relationship between physical learning environment and students’ perceived stress, as measured through survey responses.

H2: Students will report lower levels of perceived and physiological stress after studying in the newer learning environment (Room B), compared to the traditional environment (Room A).

Room B was more often associated with improved concentration and reduced self-reported physiological stress, supported by both survey responses and qualitative reflections. These effects were moderate in strength and suggest that acoustic control, visual simplicity, and spatial order can support task focus and emotional regulation during self-study.

However, Room A was not viewed negatively. It was frequently described as calming, warm, and emotionally comfortable, qualities that several participants associated with general ease and relaxation. Some even preferred it for specific tasks, such as reading or non-urgent study, highlighting that traditional design does not necessarily induce stress, but may suit different cognitive or emotional needs. The physiological data (salivary cortisol) did not show significant differences between the rooms, emphasising that the influence of space may be more perceptual than hormonal, at least in short-term exposures.

Taken together, these results offered partial support for the study's hypotheses: H1 predicted a statistically significant relationship between physical learning environment and perceived stress. While not all differences reached significance, participants reported improved concentration and reduced bodily stress symptoms in Room B, supported by qualitative reflections and moderate effect sizes. H2 predicted lower perceived and physiological stress in Room B compared to Room A. While perceived stress did decrease in Room B, cortisol levels did not show significant variation between rooms, likely due to the short exposure window and cortisol's known delay. Together, these outcomes confirm the perceptual sensitivity of students to physical space, but also highlight the challenges of capturing short-term physiological stress responses using hormonal data alone.

Overall, the influence of newer vs. traditional environments on stress appears to be nuanced and context-dependent. Newer environments may better support focus-intensive tasks and physical comfort, but emotional comfort and subjective preference can still be strong in more traditional settings. This underlines the need for campuses to offer diverse spaces that match students' varying needs, rather than assuming a single design style will suit all users.

7.6 KEY INSIGHTS

This study's findings support overarching insights about the relationship between learning environments and student stress.

Diverse environments support diverse needs. Students valued both Room A and Room B, but for different reasons. While newer environments supported focus and concentration, traditional spaces offered emotional comfort. This underscores the need for a diverse campus infrastructure, not one "ideal" space, but a range of options matching different tasks and student preferences.

Stress responses are interactional. Environmental features did not operate in isolation. The same acoustic or lighting condition could support or hinder well-being depending on individual goals, mental states, and study habits. This confirms that the impact of space is not fixed, but shaped by the interaction between person and place.

Spatial design operates unconsciously. Participants often reported that the room had "no effect," yet still showed measurable or described responses. This suggests that unconscious spatial cues, such as light quality, colour tone, layout, or furniture arrangement, can shape stress experience without entering conscious awareness. As shown in this study, students sometimes denied any environmental influence, yet still reported mood changes or concentration shifts that aligned with room features. These findings support recent work in neuroarchitecture and spatial cognition, showing that built environments operate through subtle perceptual heuristics and emotional associations.

Multi-method research is essential. The discrepancy between cortisol data and self-report results highlights the limitations of any single measurement approach. Self-reports captured immediate perception; cortisol reflected physiological arousal that may relate to focus or stress. These differences were not contradictions, but complementary. This study illustrates the value of combining subjective, physiological, and qualitative methods to understand complex emotional experiences in real-world settings. Together, these findings partially support the hypotheses and reinforce the idea that learning spaces are active participants in student well-being. While not all effects were strong or significant, the directional consistency, thematic insights, and physiological nuance build a compelling case for taking space seriously in academic stress research

7.7 MAIN RESEARCH QUESTION: *What is the relationship between (new) physical learning environments and stress among students at a Dutch university?"*

This study found that physical learning environments do influence how students experience stress, particularly in terms of focus and self-reported physiological symptoms. Newer environments, such as Room B, were more frequently associated with improved concentration, a greater sense of quiet and order, and statistically significant reductions in perceived physiological stress. These effects were consistently supported by survey responses and qualitative reflections. However, this influence was not general. No significant differences were observed in cortisol levels between the rooms, and general overall stress remained largely unchanged. In addition, many participants valued the ambiance and warmth of the traditional room (Room A), suggesting that emotional comfort and subjective preference can be just as important as spatial optimisation. This also reinforces the idea that much of the environment's influence occurs below conscious awareness, through subtle design cues that shape attention, mood, and arousal, often without students explicitly noticing.

Taken together, these findings show that the relationship between learning environment and stress is real but variable, shaped by both physical features and personal factors. Rather than identifying a single ideal environment, the results emphasise the importance of providing diverse, task-appropriate, and student-sensitive spaces. Environmental characteristics can support or hinder wellbeing, but their impact depends on the student, the task, and the context. Stress in learning environments is best understood as a multi-layered experience, emerging from the interaction between internal state and external space. Rather than searching for one perfect environment, universities should design with flexibility, sensory awareness, and psychological diversity in mind, acknowledging that stress is not only internal, but also spatial.

8 RECOMMENDATIONS

This study highlights the often-overlooked role that physical environments play in shaping students' stress experiences during self-study. While the findings were exploratory, they offer concrete and actionable insights for campus design, student wellbeing, and future research on learning environments.

8.1 RECOMMENDATIONS FOR UNIVERSITIES

Universities should invest in flexible and diverse study environments that support both cognitive focus and emotional restoration. The contrasting student responses to Room A and Room B suggest that no single environment can meet all academic needs. Some students prefer warm, restorative spaces for general study or stress relief; others thrive in minimalist, quiet spaces that support intense concentration. Future campus design should not aim for a "one-size-fits-all" approach and strive to create spatial variety, through atmosphere, lighting, acoustic control, and furniture setup.

A practical insight from this study is that repurposed lecture or project rooms, when vacant and properly equipped, can serve as highly effective self-study spaces. Participants found both rooms suitable for academic work, despite neither being dedicated study environments. Universities can expand study capacity without new construction by rethinking the scheduling and use of underutilised rooms. Key features that support effectiveness include acoustic insulation, daylight access, ergonomic furniture, power outlets, and clear layout structures. While students are a creative target group, and are known to make use of any space they find is empty, recognising this double room usage and making this an official strategy could improve the quality of its usage. Perhaps a system could be set up for room reservation, or each faculty could have an analysis on what rooms can be used more efficiently. Strategic investment in these areas can enhance student concentration and comfort with minimal infrastructure change.

8.2 ADVICE FOR STUDENTS

Students are encouraged to match their environmental choice to the task at hand. Concentration-intensive tasks like reading or writing may benefit from quiet, structured spaces (like Room B), whereas relaxed, reflective, or creative tasks may be better suited to warmer, softer environments (like Room A). Personal preference plays a central role, and students should explore which settings help them feel calm, motivated, or mentally clear. Choosing the right space is a form of self-regulation.

8.3 RECOMMENDATIONS FOR FUTURE RESEARCH

Future studies should refine and expand the approach taken in this thesis to strengthen insight into how physical learning environments affect stress.

- Larger, more diverse samples are needed to improve generalisability and allow subgroup analyses (e.g., gender, academic discipline, neurodivergence, or time-of-day effects).
- Longer and/or repeated study sessions should be tested. The one-hour format used here offered ecological validity but may have been too short to detect reliable cortisol shifts.
- Three-point cortisol sampling is strongly recommended in future protocols, before, halfway through, and after the session. This would improve alignment with the known 25-minute cortisol peak window. However, researchers must balance this need with the risk of disrupting participant focus, as repeated sampling can interfere with deep work. Creative solutions (e.g. quick, silent saliva collection or passive monitors) should be explored.
- The addition of real-time physiological indicators such as EDA or HRV would help capture moment-to-moment arousal and stress patterns that cortisol alone cannot reflect.
- Future studies should attempt to isolate specific environmental variables. This research compared two ecologically valid but complex room types, which limited the ability to attribute effects to specific design elements. Controlled experiments manipulating one feature at a time (e.g. only lighting or only acoustics) would allow for cleaner interpretation.
- Further work is also needed to explore task-specific spatial needs. Different learning activities, writing, group work, deep reading, or brainstorming, may require different environmental conditions. Matching space type to task type is a promising next step for evidence-based campus design.

9 REFLECTION

This chapter reflects on the research as both a product and a process, before turning to a more personal reflection in the following section. The aim is to offer a critical look at the development of the thesis and the journey taken to complete it.

9.1 PRODUCT: THE THESIS

The end product presented here integrates both qualitative and quantitative findings from four experiment sessions, supported by a comprehensive literature review. The aim was to arrive at a deeper understanding of how physical university learning environments influence students' stress. While the findings were often nuanced and context-dependent, as discussed in the preceding chapters, they nonetheless led to valuable insights, particularly concerning how differently designed spaces are perceived, used, and appreciated by students.

At the outset, I expected a clear distinction in outcomes between the two rooms used in the experiment. While this sharp contrast did not emerge, the results proved more layered and interesting than anticipated. If I were to repeat the study, I would still opt to compare two distinct rooms. Although isolating single environmental variables might lead to more definitive results, the room-to-room comparison allowed for real-world, multifaceted insights. Both rooms were appreciated by participants for different reasons, hinting that learning environments are experienced subjectively and task-dependently.

This thesis was developed as the final graduation project for the Management in the Built Environment master track, within the Faculty of Architecture and the Built Environment at Delft University of Technology. The chosen topic, how physical learning environments affect student stress, aligns closely with the studio theme "Adding value in public or corporate real estate." By improving learning environments in ways that positively affect mental health, universities can add value not just to their physical buildings, but also to the wellbeing of their users. The thesis integrates perspectives from psychology, design, and real estate management, addressing challenges relevant to both academic institutions and society more broadly. In this sense, the work embodies the interdisciplinary character expected at the master's level.

9.2 PROCESS: FROM PLANNING TO COMPLETION

The path from initial research plan to final results was anything but linear. After completing a P2 repair, the available timeline was shortened, and careful planning became essential. In hindsight, that repair was pivotal: it led to a more focused, feasible experiment design. Still, time pressure was high, especially since the experiment needed to be completed before Week 9-10 of Q3, and we were already halfway through the quarter.

Initially, the goal was to include 20 first-year MBE students. I coordinated with a course coordinator to present during lectures and offered free lunch as an incentive, but despite using every available outreach method (presentation, Brightspace, email, and WhatsApp), zero students signed up. Fortunately, I was granted permission to broaden the participant pool beyond the MBE cohort, which saved the experiment. This adjustment came with a trade-off: a smaller and more diverse sample ($n=13$), but still valid for the study's goals.

The experiment sessions themselves were among the highlights of the thesis process. Preparing and providing lunch, including several kilos of homemade hummus, which proved both budget-friendly and surprisingly popular, was logistically challenging, but the sessions went smoothly. Participants were serious, engaged, and followed the procedures with care. There was only one near-mishap, when we realised we hadn't brought enough testing tubes. My experiment partner (also my roommate) drove to Rotterdam and back just in time.

Processing the data, however, was a steep learning curve. As someone new to statistical analysis, I relied heavily on online tutorials and resources, especially YouTube. I performed all the quantitative analysis in Excel, the software I was most comfortable with, and eventually found the process both educational and enjoyable. For the qualitative analysis, I used Atlas.ti, a programme I had encountered during the RM2 course and while assisting postdoc candidate Thomas Vogl with literature screening. This prior exposure helped streamline the coding and analysis.

The cortisol research was both a blessing and a curse. It added an extra layer of depth to the findings, enabling a compelling comparison between perceived psychological stress and measured physiological data. But the path to including it was fraught with uncertainties, around funding, ethical approval, planning, and lab capacity. These challenges caused more than one sleepless night. In the end, despite the modest significance of the results, the effort was worthwhile. It brought together multiple perspectives on stress in a way that aligned with the interdisciplinary ambitions of the thesis.

The long-anticipated, yet also dreaded, P4 presentation was a pivotal moment in the process. It required me to bring everything together into a near-final version of the thesis, and when I finally heard the long-awaited words, "it is a go," I couldn't hold back my emotions. That moment, where uncertainty gave way to acceptance and then to joy, is one I will remember for the rest of my life. Following P4, I had a series of highly constructive feedback sessions with all my mentors. With their guidance, the P4 draft has now become something that truly resembles a completed master thesis. The final weeks of this project have been especially rewarding, refining and finalising the text has felt like reaching the summit of a long and deeply instructive journey. Looking back, this project brought me into new research domains, pushed me to learn unfamiliar methods, and resulted in a study that I believe contributes something meaningful, both to the university environment, and to my own growth as a researcher and professional.

9.3 PERSONAL

The last 20 weeks of thesis work, preceded by 20 intense weeks in the graduation lab, have been among the most challenging, yet rewarding periods of my time as a student. There were moments when I felt overwhelmed, lonely, and deeply stressed about everything still ahead of me. I often envied other students who had a clear idea of their topic right from the start of gradlab. I'm fairly certain I was the only one who attended every introductory lecture of every studio before deciding.

Initially, I was drawn to the idea of graduating abroad, inspired by a six-month hiatus I had taken earlier. I picked a studio that might make this possible, despite having no idea what I wanted to research. In hindsight, that was... let's say optimistic. I spent more time daydreaming and corresponding with professors overseas than actually shaping a realistic graduation topic. That energy might have been better spent elsewhere, but the winds blew me this way, and eventually, with the guidance of Monique and Vitalija, I was steered toward a topic I would never have expected to explore: stress in the learning environment.

That turning point led to a meeting with Sophie, who became not just a source of insight and information, but also of steady mental support, something I needed more than once. At the time of my P2, I had already fallen behind significantly. Sitting in mentor meetings, I often felt ashamed of how much further along my peers were. At this time I was also helping a PHD candidate connected to Campus NL (along with two peer students) with an extensive literature review. I hoped that this review would provide me with a holy grail of references, to steer my thesis, but while it was interesting to read many different articles on new learning environments, the time invested in these reviews was not worth it for my own thesis. In Q2, I was still working multiple jobs to afford the rent, which was twice what I was used to since moving to Rotterdam. It wasn't sustainable. I eventually quit all jobs, subsisted on a diet of water and peanut butter, and did my best to catch up, but still, I didn't make it. I heard I had to do a P2 repair. Standing there, genuinely (maybe naively optimistic) expecting a pass, hearing "no go" felt surreal.

That disappointment did, however, force me to refocus. It led to a better, more achievable research plan. I never told my mentors this, but the day of my P2 repair, I was fully expecting another no go. I had mentally prepared myself to drop out or redo the entire gradlab from scratch. So when I got the green light, it lit a spark. With clear feedback and a renewed sense of direction, I tried to pick myself back up.

I started my graduation internship at VKZ BV shortly after, which turned out to be both grounding and uplifting. I met great people, found a rhythm, and, crucially, got an internship stipend that allowed me to buy proper food again. One of my colleagues there introduced me to the idea of adding cortisol sampling to the experiment. It was a rush against the clock: I had already lost two weeks due to the P2 repair, and I needed to secure rooms, participants, and equipment before the end of Q3. Luckily, I got the rooms (thank you to the kind people at the BK and Echo service desks) and although no one from the original MBE cohort signed up, I was allowed to reach out beyond the track. Thirteen students stepped in. I'm deeply grateful for their time and interest.

After data collection, I met with Sophie again to discuss the preliminary results, and then with Monique and Vitalija to prepare for my P3. That presentation came a week sooner than I expected, but it forced me to distill everything clearly. I even got my first 'smiley' in the feedback document, which was to me much more meaningful and emotional than it probably should have been. Still, the message was clear: if I wanted to succeed, I had to step it up. I did what I could. I ordered a cortisol kit directly from the supplier, managed to get the lab work done through the incredibly helpful team at the Faculty of Applied Sciences, and worked tirelessly on writing and analysis.

After giving it my all and stepping up to deliver something worthy of the P4, the moment finally arrived: the presentation. I had rehearsed it so many times I could almost recite it in my sleep, I was as ready as I'd ever be. Still, the possibility of failure lingered in the back of my mind. A situation with a fellow student that day only reinforced that fear, and by the time I began presenting, I was fully prepared to take the hit of a 'no-go'. So when I heard the word 'go', it caught me completely off guard. In that moment, I was not entirely able to suppress my emotions, which is something I've come to learn over the past years is nothing to be ashamed of. From there on out, with the guidance and encouragement of my mentors, the final stretch of the project became something I genuinely enjoyed.

Now, as I write the final words of this graduation process and revisit the reflection I wrote for P4, it's hard to express how different I feel compared to then. I feel proud, relieved, and above all, grateful, to my mentors, my roommates, my colleagues at my internship, my friends, and my family. I'm thankful for the entire journey of this graduation project. Looking back, I realise that you don't simply learn how to make a thesis, it's the thesis process that teaches you the final lessons in becoming a TU Delft graduate. This city and this university have given me so much, and shaped me into the person I am today, and for that I am thankful.

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APPENDICES

Appendix I	Before experiment interview survey questions
Appendix II	After experiment interview survey questions
Appendix III	Student specific stressors survey questions
Appendix IV	PSS-10
Appendix V	Informed consent form
Appendix VI	Informed consent form Cortisol
Appendix VII	Test of within-subject effects, survey items
Appendix IIX	Test of within-subject effects, Cortisol 1
Appendix IX	Test of within-subject effects, Cortisol 2
Appendix X	Data Management Plan

Appendix I: Before experiment interview survey questions

Thanks for coming to the second stress experiment session. Please fill in this small survey before partaking in self study for one hour.

Your day

What activity did you do before coming to this session?

Overall Stress

On a scale from 0 to 10, how would you rate your current stress level?

0 = Not stressed 10 = Extremely stressed

Focussing

On a scale from 0 to 10, how difficult is it for you to focus right now?

0 = Not difficult at all 10 = Extremely difficult

Self perceived physiological stress

To what extent are you experiencing physical symptoms of stress (e.g. muscle tension, rapid heartbeat, sweating)?

0 = None at all 10 = Extreme symptoms

Environmental influence

To what extent do you feel your current environment is influencing your stress level?
(Can be positively or negatively)

0 = Not at all 10 = Extremely

Other remarks

Is there anything else you would like to add?

Appendix II:After experiment interview survey questions

Please fill in this small survey after doing one hour of self study. Thanks again for your participation!

Overall Stress

On a scale from 0 to 10, how would you rate your current stress level?

0 = Not stressed 10 = Extremely stressed

Focussing

On a scale from 0 to 10, how difficult is it for you to focus right now?

0 = Not difficult at all 10 = Extremely difficult

Self perceived physiological stress

To what extent are you experiencing physical symptoms of stress (e.g. muscle tension, rapid heartbeat, sweating)?

0 = None at all 10 = Extreme symptoms

Environmental influence

To what extent do you feel your current environment is influencing your stress level?
(Can be positively or negatively)

0 = Not at all 10 = Extremely

Suitablilty

Do you think this room is a suitable study space?

Why yes or no?

(only for second session)

Do you prefer this room or the room you studied in the previous session?

Please explain why.

Debriefing

Is there anything else you would like to say or add after completing this experiment?

Appendix III: Student specific stressors survey questions

Please fill in this small addition to the experiment. It is about stressors other than the room which could have caused your stress levels.

Academic pressure

On a scale from 0 to 10, how would you rate the academic pressure in the past term? (around the time of the experiment)

0 = No pressure 10 = Extreme pressure

Financial issues

On a scale from 0 to 10, how would you rate the pressure due to financial issues in the past term? (around the time of the experiment)

0 = No pressure 10 = Extreme pressure

Social/ family issues

On a scale from 0 to 10, how would you rate the pressure due to social/ family issues in the past term? (around the time of the experiment)

0 = No pressure 10 = Extreme pressure

Extracurricular activity pressure

On a scale from 0 to 10, how would you rate the pressure due to extracurricular activities, like jobs, committees, or student life, in the past term? (during the time of the experiment)

0 = No pressure 10 = Extreme pressure

Other remarks

Is there anything else you would like to add concerning your stressors in the past month?

Appendix IV : PSS-10

The questions in this scale ask you about your feelings and thoughts during the last month.

In each case, you will be asked to indicate by circling *how often* you felt or thought a certain way.

Name _____

Date _____ Age _____

Gender (*Circle*): M F Other _____

0 = Never 1 = Almost Never 2 = Sometimes 3 = Fairly Often 4 = Very Often

- | | | | | | |
|--|---|---|---|---|---|
| 1. In the last month, how often have you been upset because of something that happened unexpectedly? | 0 | 1 | 2 | 3 | 4 |
| 2. In the last month, how often have you felt that you were unable to control the important things in your life? | 0 | 1 | 2 | 3 | 4 |
| 3. In the last month, how often have you felt nervous and "stressed"? | 0 | 1 | 2 | 3 | 4 |
| 4. In the last month, how often have you felt confident about your ability to handle your personal problems? | 0 | 1 | 2 | 3 | 4 |
| 5. In the last month, how often have you felt that things were going your way? | 0 | 1 | 2 | 3 | 4 |
| 6. In the last month, how often have you found that you could not cope with all the things that you had to do? | 0 | 1 | 2 | 3 | 4 |
| 7. In the last month, how often have you been able to control irritations in your life? | 0 | 1 | 2 | 3 | 4 |
| 8. In the last month, how often have you felt that you were on top of things? | 0 | 1 | 2 | 3 | 4 |
| 9. In the last month, how often have you been angered because of things that were outside of your control? | 0 | 1 | 2 | 3 | 4 |
| 10. In the last month, how often have you felt difficulties were piling up so high that you could not overcome them? | 0 | 1 | 2 | 3 | 4 |

Scoring: PSS scores are obtained by reversing responses (e.g., 0 = 4, 1 = 3, 2 = 2, 3 = 1 & 4 = 0) to the four positively stated items (items 4, 5, 7, & 8) and then summing across all scale items. A short 4 item scale can be made from questions 2, 4, 5 and 10 of the PSS 10 item scale.

Appendix V: Informed consent form

Delft University of Technology HUMAN RESEARCH ETHICS INFORMED CONSENT FORM

Informed Consent Form

You are being invited to participate in a research study titled *Stress in the Learning Environment*. This study is being done by Bauke Meijer from the TU Delft, as part of a larger research for Campus NL, in collaboration with VKZ BV. The final results of this research will be shared with the parties mentioned, but your (anonymised) responses will not.

The purpose of this research study is to provide insights into characteristics of physical learning environments that influence students' perceived stress and will take you approximately 60 minutes to complete. The data will be used for generating findings and comparing the perceived stress in different physical learning environments. We will be asking you to fill in two different surveys, indicating your own perception of your experienced stress. There are no right or wrong answers in this study!

The data collected in this study will be used in the master's thesis of Bauke Meijer and other research outputs (e.g., publications, presentations) produced by his research team and supervisors. This data will be used to generate findings. Your participation in this study is entirely voluntary **and you can withdraw at any time**. You are free to omit any questions that you don't feel comfortable answering. You have the right to reevaluate the consent you give in this form at any time.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks as much as possible by anonymisation and safe data storing on the TU Delft project storage drive. You can get in touch with the research team at any time for further questions or remarks.

Contact details for the corresponding researcher, Bauke Meijer
Contact details for the responsible researcher, Monique Arkesteijn

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated [28/03/2025], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions, and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves: • Filling in the Perceived Stress Scale (PSS) • Partaking in self-study for a one-hour session • Filling in a survey before and after the session	☐	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
4. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach: • anonymisation of any identifiable data • All data being stored on secured TU Delft project data drive	☐	☐
5. I understand that personal information collected about me that can identify me, such as names and contact details, will not be shared beyond the study team.	☐	☐
6. I understand that the (identifiable) personal data I provide will be destroyed after the research is concluded	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
7. I understand that after the research study the de-identified information, I provide will be used for generating findings for the thesis.	☐	☐
8. I agree that my responses, views or other input can be quoted anonymously in research outputs	☐	☐
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		
9. I give permission for the de-identified survey responses that I provide to be archived in the 4TU.ResearchData-repository so it can be used for future research and learning.	☐	☐

Signatures

Name of participant [printed]

Signature

Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

*Bauke Meijer**28-03-2025*

Name researcher

Signature

Date

Contact details for further information

Appendix VI : Informed consent form Cortisol

Delft University of Technology HUMAN RESEARCH ETHICS INFORMED CONSENT FORM: Cortisol

Informed Consent Form

You are being invited to participate in a research study titled *Stress in the Learning Environment*. This study is being done by Bauke Meijer from the TU Delft, as part of a larger research for Campus NL, in collaboration with VKZ BV. The final results of this research will be shared with the parties mentioned, but your (anonymised) responses will not.

The purpose of this research study is to provide insights into characteristics of physical learning environments that influence students' physiological stress and will take you approximately 60 minutes to complete. The data will be used for generating findings and comparing the physiological stress in different physical learning environments. We will be asking you to provide a small sample of saliva by spitting into a test tube. This sample will be stored and will potentially be used for cortisol testing, but please note that the testing will only take place if funding is available for laboratory analysis. If funds are not available, your sample will be destroyed after being collected. You will not be informed about the cortisol levels unless the testing is performed. All samples will be coded to ensure your privacy. The samples will not be linked to any personal identifying information. Results, if obtained, will be used for research purposes only.

The data collected in this study will be used in the master's thesis of Bauke Meijer and other research outputs (e.g., publications, presentations) produced by his research team and supervisors. This data will be used to generate findings. Your participation in this study is entirely voluntary **and you can withdraw at any time**. You have the right to reevaluate the consent you give in this form at any time.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks as much as possible by anonymised and safe data storing on the TU Delft onedrive. You can get in touch with the research team at any time for further questions or remarks.

Contact details for the corresponding researcher, Bauke Meijer

Contact details for the responsible researcher, Monique Arkesteijn

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated [28/03/2025], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves: • Providing a salivary sample by spitting in a test tube, which will potentially be tested for cortisol, under the conditions outlined in the introduction.	☐	☐
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
4. The procedure is non-invasive and involves minimal discomfort. There are no known risks associated with providing a saliva sample. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach: • Anonymisation of any identifiable data • All data being stored on secured TU Delft onedrive	☐	☐
5. I understand that personal information collected about me that can identify me, such as names and contact details, will not be shared beyond the study team.	☐	☐
6. I understand that the (identifiable) personal data I provide will be destroyed after the research is concluded	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
7. I understand that after the research study the de-identified information, I provide will be used for generating findings for the thesis.	☐	☐
8. I agree that my responses, views or other input can be quoted anonymously in research outputs	☐	☐
D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE		

9. I give permission for the de-identified survey responses that I provide to be archived in the 4TU.ResearchData-repository so it can be used for future research and learning.	☐	☐
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Signatures Name of participant [printed] Signature Date I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting. <i>Bauke Meijer</i> Name researcher Signature <i>28-03-2025</i> Date Contact details for further information: Bauke Meijer, +31657187116, bjgmeijer@tudelft.nl		
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Appendix VII: Test of within-subject effects, Survey items [N=13]

Tests of Within-Subjects Effects							
Measure: MEASURE_1							
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	
Room	Sphericity Assumed	3.250	1	3.250	1.357	.267	.102
	Greenhouse-Geisser	3.250	1.000	3.250	1.357	.267	.102
	Huynh-Feldt	3.250	1.000	3.250	1.357	.267	.102
	Lower-bound	3.250	1.000	3.250	1.357	.267	.102
Error(Room)	Sphericity Assumed	28.750	12	2.396			
	Greenhouse-Geisser	28.750	12.000	2.396			
	Huynh-Feldt	28.750	12.000	2.396			
	Lower-bound	28.750	12.000	2.396			
Time	Sphericity Assumed	5.558	1	5.558	3.005	.109	.200
	Greenhouse-Geisser	5.558	1.000	5.558	3.005	.109	.200
	Huynh-Feldt	5.558	1.000	5.558	3.005	.109	.200
	Lower-bound	5.558	1.000	5.558	3.005	.109	.200
Error(Time)	Sphericity Assumed	22.192	12	1.849			
	Greenhouse-Geisser	22.192	12.000	1.849			
	Huynh-Feldt	22.192	12.000	1.849			
	Lower-bound	22.192	12.000	1.849			
Question	Sphericity Assumed	5.481	3	1.827	.270	.847	.022
	Greenhouse-Geisser	5.481	2.451	2.236	.270	.808	.022
	Huynh-Feldt	5.481	3.000	1.827	.270	.847	.022
	Lower-bound	5.481	1.000	5.481	.270	.613	.022
Error(Question)	Sphericity Assumed	243.769	36	6.771			
	Greenhouse-Geisser	243.769	29.413	8.288			
	Huynh-Feldt	243.769	36.000	6.771			
	Lower-bound	243.769	12.000	20.314			
Room * Time	Sphericity Assumed	.942	1	.942	.644	.438	.051
	Greenhouse-Geisser	.942	1.000	.942	.644	.438	.051
	Huynh-Feldt	.942	1.000	.942	.644	.438	.051
	Lower-bound	.942	1.000	.942	.644	.438	.051

Error(Room*Time)	Sphericity Assumed	17.558	12	1.463			
	Greenhouse-Geisser	17.558	12.000	1.463			
	Huynh-Feldt	17.558	12.000	1.463			
	Lower-bound	17.558	12.000	1.463			
Room * Question	Sphericity Assumed	18.635	3	6.212	1.805	.164	.131
	Greenhouse-Geisser	18.635	1.775	10.501	1.805	.191	.131
	Huynh-Feldt	18.635	2.061	9.044	1.805	.185	.131
	Lower-bound	18.635	1.000	18.635	1.805	.204	.131
Error(Room*Question)	Sphericity Assumed	123.865	36	3.441			
	Greenhouse-Geisser	123.865	21.295	5.817			
	Huynh-Feldt	123.865	24.726	5.009			
	Lower-bound	123.865	12.000	10.322			
Time * Question	Sphericity Assumed	2.635	3	.878	.788	.508	.062
	Greenhouse-Geisser	2.635	1.760	1.497	.788	.453	.062
	Huynh-Feldt	2.635	2.039	1.292	.788	.468	.062
	Lower-bound	2.635	1.000	2.635	.788	.392	.062
Error(Time*Question)	Sphericity Assumed	40.115	36	1.114			
	Greenhouse-Geisser	40.115	21.121	1.899			
	Huynh-Feldt	40.115	24.471	1.639			
	Lower-bound	40.115	12.000	3.343			
Room * Time * Question	Sphericity Assumed	2.250	3	.750	.697	.560	.055
	Greenhouse-Geisser	2.250	2.220	1.013	.697	.521	.055
	Huynh-Feldt	2.250	2.747	.819	.697	.549	.055
	Lower-bound	2.250	1.000	2.250	.697	.420	.055
Error(Room*Time*Question)	Sphericity Assumed	38.750	36	1.076			
	Greenhouse-Geisser	38.750	26.642	1.454			
	Huynh-Feldt	38.750	32.960	1.176			
	Lower-bound	38.750	12.000	3.229			

Appendix IIX: Test of within-subject effects, Cortisol [N=10]

Tests of Within-Subjects Effects							
Measure: MEASURE_1							
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	
Room	Sphericity Assumed	1.900	1	1.900	.459	.515	.048
	Greenhouse-Geisser	1.900	1.000	1.900	.459	.515	.048
	Huynh-Feldt	1.900	1.000	1.900	.459	.515	.048
	Lower-bound	1.900	1.000	1.900	.459	.515	.048
Error(Room)	Sphericity Assumed	37.286	9	4.143			
	Greenhouse-Geisser	37.286	9.000	4.143			
	Huynh-Feldt	37.286	9.000	4.143			
	Lower-bound	37.286	9.000	4.143			
Time	Sphericity Assumed	.004	1	.004	.001	.979	.000
	Greenhouse-Geisser	.004	1.000	.004	.001	.979	.000
	Huynh-Feldt	.004	1.000	.004	.001	.979	.000
	Lower-bound	.004	1.000	.004	.001	.979	.000
Error(Time)	Sphericity Assumed	53.111	9	5.901			
	Greenhouse-Geisser	53.111	9.000	5.901			
	Huynh-Feldt	53.111	9.000	5.901			
	Lower-bound	53.111	9.000	5.901			
Room * Time	Sphericity Assumed	.515	1	.515	.129	.728	.014
	Greenhouse-Geisser	.515	1.000	.515	.129	.728	.014
	Huynh-Feldt	.515	1.000	.515	.129	.728	.014
	Lower-bound	.515	1.000	.515	.129	.728	.014
Error(Room*Time)	Sphericity Assumed	35.912	9	3.990			
	Greenhouse-Geisser	35.912	9.000	3.990			
	Huynh-Feldt	35.912	9.000	3.990			
	Lower-bound	35.912	9.000	3.990			

Appendix IX: Test of within-subject effects, Cortisol 2 [N=8]

Tests of Within-Subjects Effects							
Measure: MEASURE_1							
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	
Room	Sphericity Assumed	.394	1	.394	.139	.720	.019
	Greenhouse-Geisser	.394	1.000	.394	.139	.720	.019
	Huynh-Feldt	.394	1.000	.394	.139	.720	.019
	Lower-bound	.394	1.000	.394	.139	.720	.019
Error(Room)	Sphericity Assumed	19.850	7	2.836			
	Greenhouse-Geisser	19.850	7.000	2.836			
	Huynh-Feldt	19.850	7.000	2.836			
	Lower-bound	19.850	7.000	2.836			
Time	Sphericity Assumed	1.230	1	1.230	.485	.509	.065
	Greenhouse-Geisser	1.230	1.000	1.230	.485	.509	.065
	Huynh-Feldt	1.230	1.000	1.230	.485	.509	.065
	Lower-bound	1.230	1.000	1.230	.485	.509	.065
Error(Time)	Sphericity Assumed	17.754	7	2.536			
	Greenhouse-Geisser	17.754	7.000	2.536			
	Huynh-Feldt	17.754	7.000	2.536			
	Lower-bound	17.754	7.000	2.536			
Room * Time	Sphericity Assumed	.004	1	.004	.001	.973	.000
	Greenhouse-Geisser	.004	1.000	.004	.001	.973	.000
	Huynh-Feldt	.004	1.000	.004	.001	.973	.000
	Lower-bound	.004	1.000	.004	.001	.973	.000
Error(Room*Time)	Sphericity Assumed	20.542	7	2.935			
	Greenhouse-Geisser	20.542	7.000	2.935			
	Huynh-Feldt	20.542	7.000	2.935			
	Lower-bound	20.542	7.000	2.935			

Appendix X: Data Management Plan

PLAN OVERVIEW

A Data Management Plan created using DMPonline

Title: Stress in the Learning Environment

Creator: Bauke Meijer

Affiliation: Delft University of Technology

Template: TU Delft Data Management Plan template (2025)

Project abstract:

Project Title: Stress in the Learning Environment

Stress among university students has become an increasingly pressing issue, driven by academic pressures, social transitions, and personal challenges. This research explores the relationship between physical university learning environments and students' perceived stress, focusing on how design elements can influence well-being and academic performance. By investigating the characteristics of traditional and modern learning environments, this study aims to identify environmental factors that influence stress. By focusing on self-study areas, the study contributes actionable recommendations for designing stress-reducing environments tailored to the needs of university students.

The research employs a mixed-methods approach, combining desk research with an empirical AB study comparing distinct types of physical learning environments at TU Delft. Desk research forms the theoretical foundation, synthesising existing literature on the impact of learning spaces, types of stress, and stress measurement methods. The empirical phase involves real-world experiments where students engage in self-study in both traditional and modern learning spaces.

Data collection includes the Perceived Stress Scale (PSS), additional surveys, and one physiological measure. Specifically, salivary cortisol samples, collected before and after each session to non-invasively assess biological stress responses. These samples are anonymised and linked only to random participant numbers. After analysis the samples were destroyed

This findings of this research are shared with Campus NL, intended to benefit university stakeholders by providing insights into how physical environments influence student stress. The research is also conducted as an internship for consultancy company VKZ BV, who are working together with multiple Universities..

ID: 168242

Start date: 10-03-2025

End date: 24-06-2025

Last modified: 14-06-2025

STRESS IN THE LEARNING ENVIRONMENT

0. ADMINISTRATIVE QUESTIONS

1. Provide the name of the data management support staff consulted during the preparation of this plan and the date of consultation. Please also mention if you consulted any other support staff.

This edited DMP has been shared with my thesis supervisor Monique Arkesteijn and with Janine Strandberg, the data steward of the faculty of Architecture and the Built Environment via DMPonline on 21-05-2025.

Upon inclusion of additional experiment/data, the Data Steward (Janine Strandberg) had a consultation with the student on May 22 and provided feedback on the second version of the DMP on May 23, 2025 via PDF+email.

2. Is TU Delft the lead institution for this project?

- Yes, leading the collaboration – please provide details of the type of collaboration and the involved parties below

Yes the TU Delft is the leading institution. The research will also be shared with Campus NL after publishing, a larger research into the collaboration between and the future of Dutch Universities, to which my responsible teacher Monique Arkesteijn is connected.

Finally the student is doing an internship at VKZ bv, a consultancy company collaborating with multiple universities in the Netherlands. The data will not be shared with the internship company VKZ, only the end result of the thesis.

I. DATA/CODE DESCRIPTION AND COLLECTION OR RE-USE

3. Provide a general description of the types of data/code you will be working with, including any re-used data/code.

Type of data/code	File format(s)	How will data/code be collected/generated? <i>For re-used data/code: what are the sources and terms of use?</i>	Purpose of processing	Storage location	Who will have access to the data/code?
Anonymised survey data	.csv	Percieved Stress Scale for the 13 participants, through Qualtrics.	To analyse the influence of different types of rooms on stress	Qualtrics server (temporary storage) + TU Delft onedrive	Student, supervisors
Anonymised survey data	.csv	4 question survey for the 13 participants before and after the study session, through Qualtrics.	To analyse the influence of different types of rooms on stress	Qualtrics server (temporary storage) + TU Delft onedrive	Student, supervisors
Informed consent forms	PDF	0-10 scale quesions on: -overall stress - difficulty focussing - (self-reported) physiological stress - and environmental influence Informed consent forms signed digitally.	To obtain and document informed consent.	TU Delft onedrive	Student

Salivary samples/ Cortisol value data	.xlsx	Salivary cortisol data is collected using a non-invasive passive drool method, where participants provide small saliva samples by spitting into sterile tubes. This takes place before and after a self-study session as part of the experiment. The procedure is simple, painless, and commonly used in human stress research. Samples are later processed in a TU Delft lab using the 'Cortisol Free in Saliva ELISA' kit to determine cortisol concentrations in ng/ml. Each participant's data consists of four values (pre/post cortisol levels in two rooms), linked only to a random, anonymised participant number. No identifiable data is stored with the samples or results.	To analyse the influence of different physical learning environments on physiological stress responses in university students, by comparing salivary cortisol levels before and after self-study sessions in two distinct room types. The aim is to identify environmental factors that contribute to or alleviate stress, in order to inform the design of healthier, student-centred study spaces.	Saliva samples are temporarily stored in a -20°C freezer. After laboratory analysis using the ELISA kit, the biological samples will be safely destroyed in accordance with lab protocols.	During the laboratory processing phase, lab staff and a designated lab technician at TU Delft will have temporary access to the saliva samples for the purpose of conducting the ELISA analysis.
				The only remaining data consists of four anonymised cortisol values per participant (in ng/ml), which are stored in an Excel file on the TU Delft onedrive, accessible only to the researcher.	After processing, the samples will be destroyed. The resulting anonymised data (four cortisol values per participant) will only be accessible to the student researcher and stored securely on the TU Delft onedrive.

II. STORAGE AND BACKUP DURING THE RESEARCH PROCESS

4. How much data/code storage will you require during the project lifetime?

- < 250 GB

5. Where will the data/code be stored and backed-up during the project lifetime? (Select all that apply.)

- TU Delft OneDrive
- Another storage system – please explain below, including provided security measures

The data will be stored on the students computer during the writing of the research thesis, and backed up on the personal onedrive, but be deleted after.

Another back-up will be made on the BK Campus NL onderzoekers-COLLAB private folder in teams, labeled: "Bauke Meijer Stress in the learning environment"

III. DATA/CODE DOCUMENTATION

6. What documentation will accompany data/code? (Select all that apply.)

- Data – Methodology of data collection

IV. LEGAL AND ETHICAL REQUIREMENTS, CODE OF CONDUCTS

7. Does your research involve human subjects or third-party datasets collected from human participants?

If you are working with a human subject(s), you will need to obtain the HREC approval for your research project.

- Yes – please provide details in the additional information box below

I intend to apply for ethical approval from the Human Research Ethics Committee.

8. Will you work with personal data? (This is information about an identified or identifiable natural person, either for research or project administration purposes.)

- Yes

9. Will you work with any other types of confidential or classified data or code as listed below? (Select all that apply and provide additional details below.)

If you are not sure which option to select, ask your [Faculty Data Steward](#) for advice.

- No, I will not work with any other types of confidential or classified data/code

10. How will ownership of the data and intellectual property rights to the data be managed.

For projects involving commercially-sensitive research or research involving third parties, seek advice of your [Faculty Contract Manager](#) when answering this question.

During the research, data will be managed within the university and only accessible to the project team. After graduation, the thesis will be publicly accessible and uploaded to the thesis repository of TU Delft.

The researching student has also signed an internship agreement with the internship company VKZ BV. They do not have the ownership of the data or intellectual property rights.

11. Which personal data or data from human participants do you work with? (Select all that apply.)

- Special categories of personal data (specify which): race, ethnicity, criminal offence data, political opinion, union membership, religious or philosophical beliefs, sex life and/or sexual orientation, health data, biometric or genetic data – please provide details in the additional information box below
- Gender
- Proof of consent (such as signed consent materials which contain name and signature)
- Date of birth and/or age

Salivary cortisol data is collected using a non-invasive passive drool method, where participants provide small saliva samples by spitting into sterile tubes. This takes place before and after a self-study session as part of the experiment. The procedure is simple, painless, and commonly used in human stress research. Samples are later processed in a TU Delft lab using the 'Cortisol Free in Saliva ELISA' kit to determine cortisol concentrations in ng/ml. Each participant's data consists of four values (pre/post cortisol levels in two rooms), linked only to a random, anonymised participant number. No identifiable data is stored with the samples or results.

4 question survey for the 13 participants before and after the study session, through Qualtrics.

0-10 scale questions on: -overall stress - difficulty focussing - (self-reported) physiological stress - and environmental influence

Perceived stress scale (PSS) of the 13 participants through Qualtrics

12. Please list the categories of data subjects and their geographical location.

About 13 participants will be subject of the project, all studying at Delft University of Technology.

13. Will you be receiving personal data from or transferring personal data to third parties (groups of individuals or organisations)?

- No

16. What are the legal grounds for personal data processing?

- Informed consent

17. Please describe the informed consent procedure you will follow below.

The researcher will inform the potential participants about the goals and procedures of the research project. The researcher will also inform them about the personal data that are being processed and for what purpose. This information will be provided to the potential participants as follows: a digital copy of the information will be emailed to participants before the interview. All participants will be asked for their consent for taking part in the study and for data processing by signing a digital or printed informed consent form before the start of the interview/experiment.

18. Where will you store the physical/digital signed consent forms or other types of proof of consent (such as recording of verbal consent)?

The proof of consent (digital copy of signed document) will be preserved on the TU Delft Project Data Storage (U:) drive.

19. Does the processing of the personal data result in a high risk to the data subjects? (Select all that apply.)

If the processing of the personal data results in a high risk to the data subjects, it is required to perform a [Data Protection Impact Assessment \(DPIA\)](#). In order to determine if there is a high risk for the data subjects, please check if any of the options below that are applicable to the processing of the personal data in your research project.

- Special category of personal data

We have consulted the privacy team for advice and have been in contact with Lieke Font Freide concerning the assesment whether DPIA is necessary.

20. Did the Privacy team advise you to perform a DPIA?

- No – please provide details in the additional information box below

After consulting with Lieke Font Freide of the privacy team, in her email received on 13-06-2025, she wrote: Considering the fact that there is no large-scale data processing (only 10 participants) of health data, and the use of pseudonymization, the processing will most likely not result in a high risk to the individual. Therefore, a DPIA is not necessary.
So no DPIA is necessary.

23. What will happen with the personal data used in the research after the end of the research project?

- Other – please explain below

All the data will be anonymised, and published as a graduation thesis as a result. This thesis will go into the TU Delft repository. If a participants hasn't given consent, their data will be deleted

24. For how long will personal research data (including pseudonymised data) be stored?

- Other – please state the duration and explain the rationale below

Necessary personal data is stored for the duration of the project, plus one month for cleanup.
The results will be backed up on the BK Campus NL onderzoekers-COLLAB private folder in teams, labeled: "Bauke Meijer Stress in the learning environment"

25. How will your study participants be asked for their consent for data sharing?

- In the informed consent form: participants are informed that their personal data will be anonymised and that the anonymised dataset is shared publicly

V. DATA SHARING AND LONG TERM PRESERVATION

27. Apart from personal data mentioned in question 23, will any other data be publicly shared?

Please provide a list of data/code you are going to share under 'Additional Information'.

- Other – please explain below

The data produced in this thesis will go into the TU Delft repository and be shared with the supervisors. Findings produced in this thesis (no personal data) will be shared with Campus NL, under supervision of Monique Arkesteijn, as well, with a small overview of the findings published in their year report.

29. How will you share research data/code, including those mentioned in question 23?

- I am a Bachelor's/Master's student at TU Delft and I will share the data/code in the body and/or appendices of my thesis/report in the Education Repository

31. When will the data/code be shared?

- As soon as corresponding results (papers, theses, reports) are published

VI. DATA MANAGEMENT RESPONSIBILITIES AND RESOURCES

33. If you leave TU Delft (or are unavailable), who is going to be responsible for the data/code resulting from this project?

My supervisor, Monique Arkesteijn, of the department of MBE with email address m.h.arkesteijn@tudelft.nl

34. What resources (for example financial and time) will be dedicated to data management and ensuring that data will be FAIR (Findable, Accessible, Interoperable, Re-usable)?

4TU.ResearchData is able to archive 1TB of data/code per researcher per year free of charge for all TU Delft researchers. We do not expect to exceed this and therefore there are no additional costs of long term preservation