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Domestic Dwelling Daylighting

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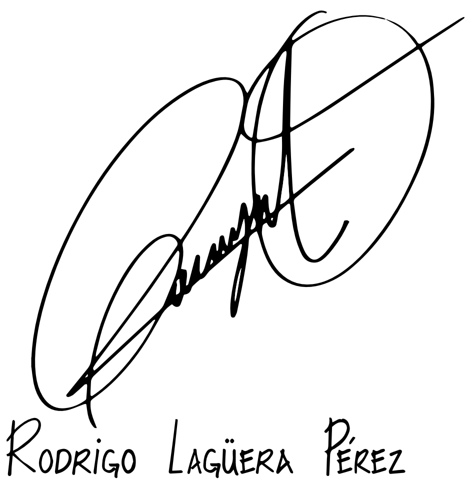

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Abstract:

Until recent years, the dwelling was used primarily as a space for sleep, with most activities taking place outside. Today, work, entertainment, socializing, eating, resting and most aspects occur indoors. There has been an exponential growth in the time we spend indoors than ever before.

The sanitary emergency worldwide events of the past few years have impacted our daily lives and stay-at-home protocols implemented by health authorities. Force society to integrate all aspects of our lives into our homes. Changing the use/meaning of the rooms of our homes while making us aware and questioning the importance of considering all the aspects that we require as individuals to fulfil psychological and physiological effects and needs.

This master thesis aims to study the domestic dwelling from three different perspectives, residential daylighting, post-pandemic and biophilic design, themes derived from each of these and finds a common language to finally propose recommendations for the domestic dwelling using daylight the pivotal point.

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ABSTRACT

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Thank you to my family and friends that did not let one day pass without constantly pushing me forward, staying motivated and accompanying me at every stage of the way.

To all the people involved in the creation of this master thesis, from all the participants that were so kind to respond to every survey, perform the test or even ask me daily about my master thesis and progress, challenging me to explain in a simple, concise way what was it about, how I was doing and what were the further action plans.

A special thank you to my advisor Georgios Triantafyllidis for all the guidance, Hossein Dini and all the outstanding teachers at Aalborg University for their knowledge and help.

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Rodrigo Lagüera Pérez

2. INTRODUCTION

MAKING A CASE FOR DAYLIGHT

Daylight is the holistic combination of the luminous characteristics of sunlight from direct solar radiation and skylight from diffuse solar radiation (Knoop et al., 2020). Daylight is required for all life to exist. Humankind and the Sun have been connected since the beginning of human civilizations; we have evolved in it throughout history.

The data agree that the presence and the quality of daylight influence our mental and physical health, including how we socially interact with one another and our environment, as well as our productivity performance and engagement and lower the absenteeism when working and/or studying. As a result, it is an essential component in building appealing and healthy domestic dwellings.

We need daylight as a framework on which to adjust our natural biorhythm; our circadian rhythm is governed by the shift from nighttime to daytime by our biological clock. (Münch et al., 2020) We relate to the 24-hour light cycle of light and dark, experiencing the high intensities during the day to the golden light in the evening; we distinguish the seasons of the year by the change of light. This instinctive knowledge of what light comes next provides us with a sense of stability amid the movement of the world. (Tregenza & Wilson, 2011) Daylight is currently acknowledged as the primary synchronizer, capable of causing either a modest or robust resetting of our internal circadian clock depending on stimulus strength and timing.

By having only, a glance at the amount of light and the quality is possible to gather a wealth of information such as mood, trigger responses required for safety and survival, weather situation or the position of the Sun related to the time or season of the year. Making all of them crucial for regulating our body functions. (DLA- DAYLIGHT ACADEMY, 2017)

"…we were born of light. The seasons are felt through light. We only know the world as it is evoked by light, and from this comes the thought that material is spent light. To me, natural light is the only light because it has mood. It provides a ground of common agreement for man; it puts us in touch with the eternal. Natural light is the only light that makes architecture, architecture…"

– Louis Kahn

People's reactions to indoor environments indicate that daylight is preferred because it meets two essential human needs: to be able to see both tasks and the space well and connectivity to experience the dynamics of the environment. (Boyce et al., 1999)

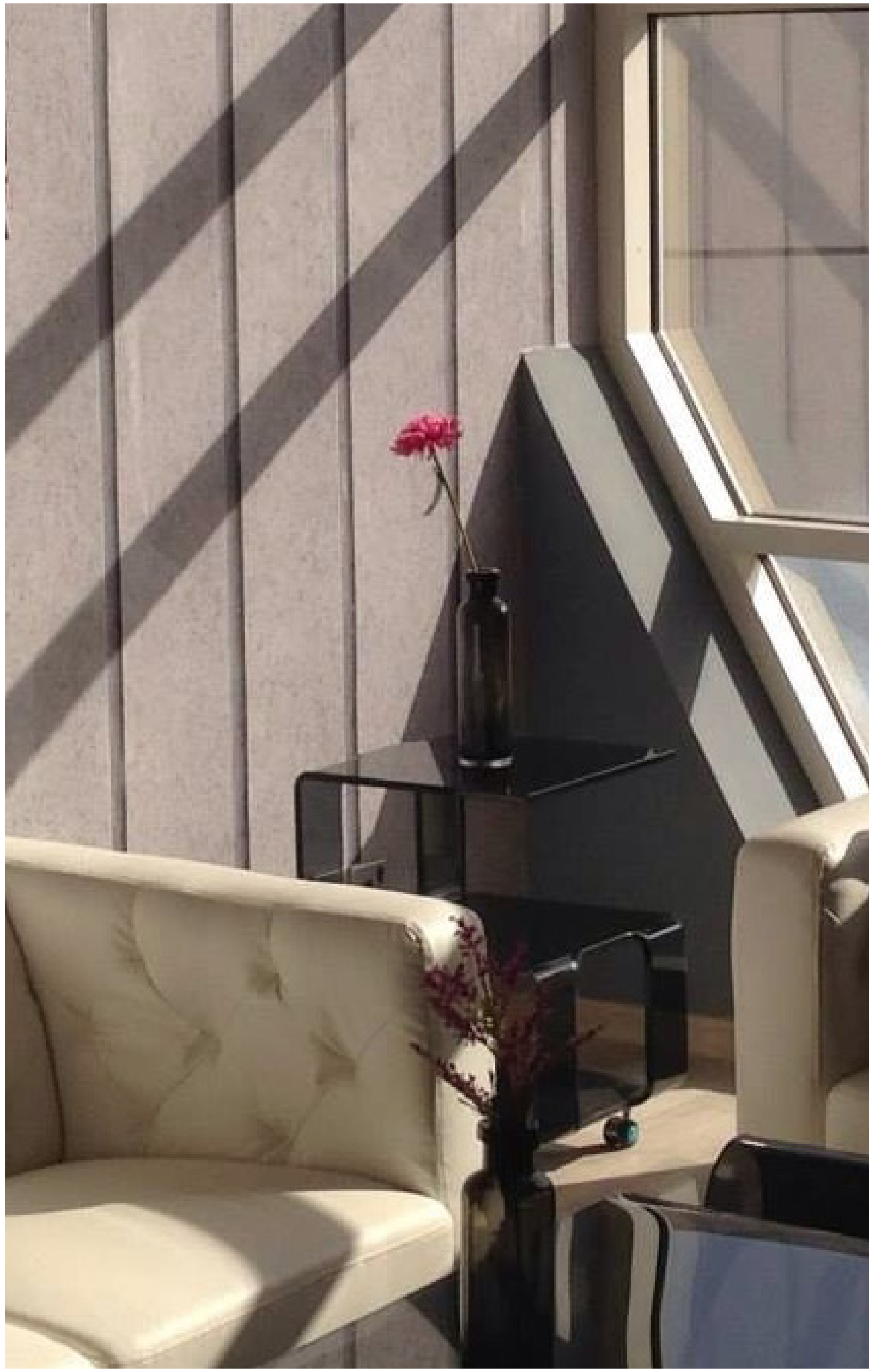
Daylight is essential for its quality, spectral composition, and variability, and it provides high illuminance and permits excellent colour discrimination and colour rendering. As a result, good vision, in addition, affects our psychological health.

From the visual perspective, it provides us with an excellent visual performance. It is flicker-free with a continuous spectral power distribution; its high illuminance enables discrimination of fine details supporting visual acuity and offers optimal colour rendering and good colour discrimination. (Knoop et al., 2020) Good eyesight is more often linked with daylight exposure; on the contrary, people with a lack of daylight exposure can develop visual disorders such as myopia or short-sightedness. (Hobday, 2016)

It gives us a wealth of positive aspects for our wellbeing, such as health, cognitive abilities, mood, and sleep quality. Which is essential for the proper functioning of the body, and sleep disorders are associated with a slew of health issues. Fatigue, irritability, and decreased focus are common symptoms, but weight gain, heart disease, and diabetes are often related to sleep disturbances and can be highly dangerous. Sleeping quality is associated with daylight. How? may ask; well, receiving the proper amount of daylight thought the day can help to rest at night. The human circadian clock uses daylight as the primary trigger to control the sleep-wake cycle; therefore, we need sufficient daylight during the day and darkness at night to get a good night's sleep.

Typical light levels indoors are roughly 300 lux; sitting by a window exposes subjects to around 3,000 lux; on the other hand, outside conditions provide between 10,000 lux and 100,000 lux in just 30 minutes. Outside light levels will readily overload the retinal ganglion cells in the eye, which assist control the circadian clock. In a well-balanced light-dark cycle, the proper amount of daylight is critical for maintaining a healthy biological rhythm and equilibrium. Sleep deprivation reduces productivity, increases error rates, and impairs focus and memory.

It influences our circadian clock in a non-visual fashion, dictating the daily rhythms of physiology and behaviour and modulating mood by the release of neurotransmitters dopamine and serotonin (DLA- DAYLIGHT ACADEMY, 2017). In a few words, daylight is exceptionally vital for our vision, crucial for health and wellbeing, with substantial benefits for society as a whole.



DAYLIGHT

SUN POSITION

Physical directionality of the Sun's rays' changes during the day at any given geographical point on the planet due to the rotation of the earth. Variable daylight is also influenced by the dynamism of the sky's movement of air particles—the spectral composition of daylight changes within a day and throughout the year. From dawn to dusk, the intensity of the radiation fluctuates, as do the shifting atmospheric activities throughout the year. The strength of the radiation also varies widely around the globe. The geographic coordinates of a given place in terms of latitude and altitude are fundamental in daylight analysis.

Orientation is the crucial element to consider when designing a home; knowing this information will provide information such as the sun movement in relation to dwellers' homes on any day, any time of the day. Understanding this can help shape the building in a way that responds to the movements of the Sun—allowing the Sun's light in and keeping it out as needed, as well as allowing the Sun's warmth in and keeping it out as needed.

The Sun always rises from the East and will set in the West anywhere in the world. However, in the northern hemisphere, the Sun is always to the south throughout the day, and in the southern hemisphere, this is the other way around. The Sun will travel through the north. The difference between north and south exposures is more dramatic the further the latitude is from the equator (VELUX GROUP, 2014).
The angle of the earth's axis is 23.5˚ – which causes the exposure to the Sun to vary as the earth rotates around the Sun. Therefore, the Sun appears at different angles and positions throughout the year, which can be described by two angles, the solar azimuth and the solar elevation angle (or solar altitude).

The azimuth is the projection on a plane of the position of the Sun measured from north 0˚, and the elevation angle is the projection of the position on the elevation of the Sun above the horizon. During summer, the Sun moves through the sky at a higher elevation than the winter sun. (Tregenza & Wilson, 2011) *Fig. 1*

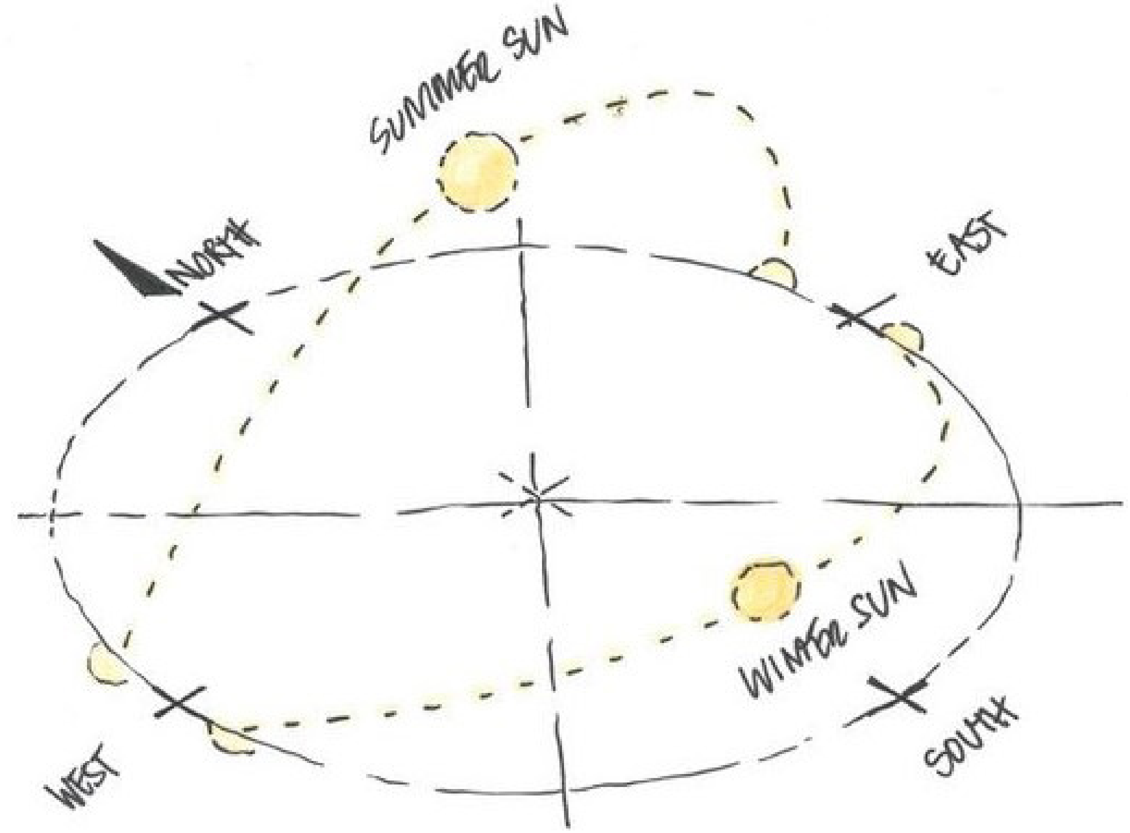


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Fig. 1 Summer and winter sun path

The quality of the lights varies depending on the orientation (Lee, n.d.):
North: Coldest light temperature and constant, characterized for its evenly distributed indirect light quality. It is excellent ambient light, diffuse, functional, and comfortable light. It is not directional, so it does not carry glare.

East: Intense light and solar heat within the early morning; for the remainder of the day, the light will have similar qualities to the north-facing skylight (even and slightly cooler) when having low sun angles can bring glare and unwanted heat gain.

South: The most beautiful abundant form of natural light. Characterized for being a direct shaft of light, intense and bright, it provides warm ambient light that does not vary much throughout the day but has a high potential of overheating spaces and carries lots of glare at certain times of the year. In northern climates can be used to heat a home in winter passively but potentially unwanted heat gain during the summer months.

West: Intense light as the one obtained by the south-facing skylight but has heat gain properties during the transition hours of the late afternoon. The changeability and quality of the light across the day, from the colder light temperature in the morning to warm light in the evenings.

Room orientation is crucial to architectural design. The following diagram has been developed as an example of this, in the context of a domestic dwelling using the same room from the same point of view, where a render has been made, one render in a white mode view to emphasize the changeability of the light quality, temperature and inflow of light and a false colour render to show where does the sunbeam reach the surfaces inside the room and how does it interact with it. These two types of renders have been made every hour in the time frame from 8:00 to 18:00. There are four groups of images; each group is oriented to a different cardinal point South, North, East, and West, respectively.

The dynamism and interaction of the daylight in the same space drastically shape the perception and functionality. This fundamental principle of architectural daylight design allows the space to have its own identity and adds a layer of phenomenology to the space. *Fig. 2*

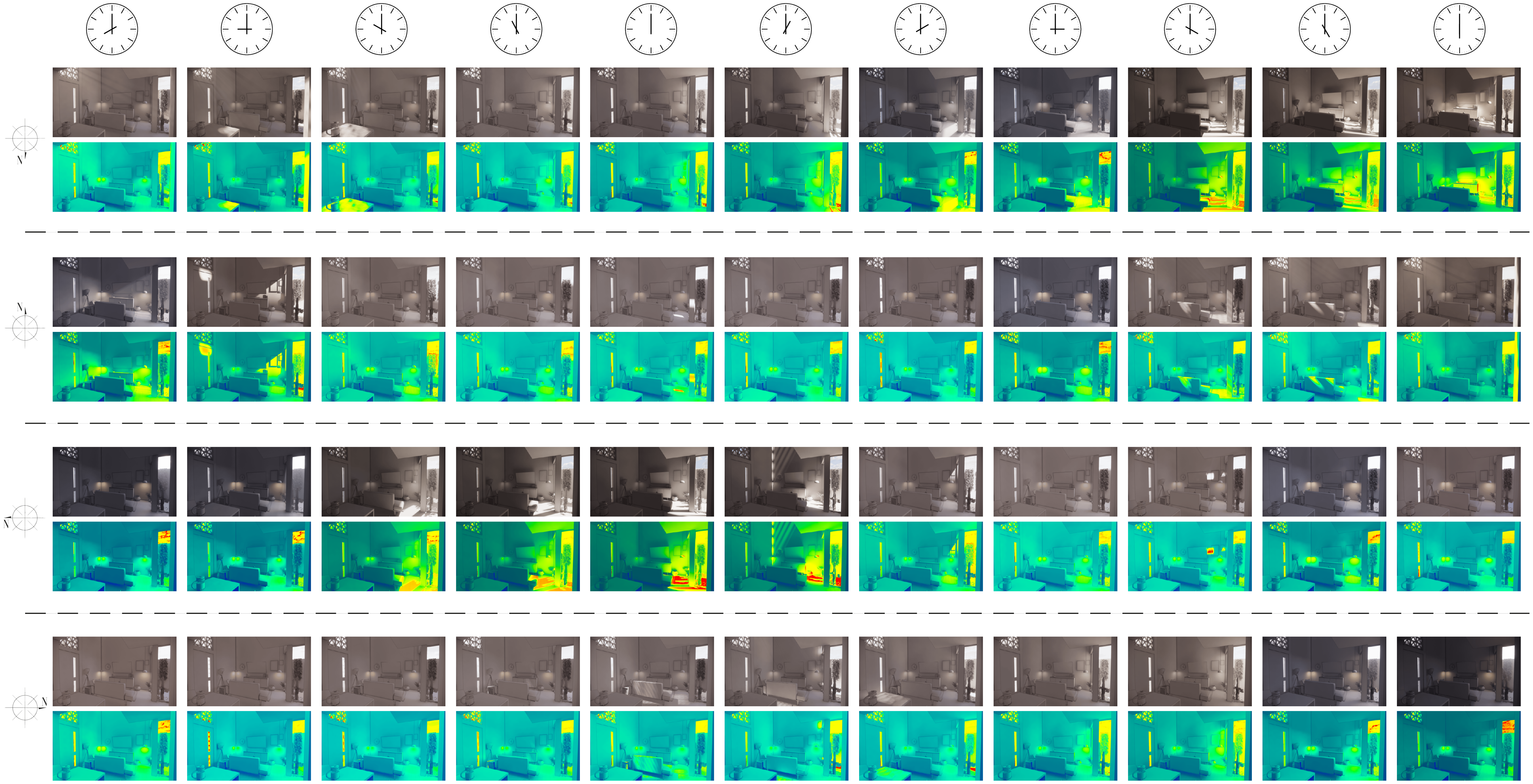

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Fig. 2 Sunlight Quality

DAYLIGHTING

The controlled admission of natural light into a space is referred to as daylighting. The science of daylighting is concerned with delivering daylight in an area and how to do so without generating any unwanted side effects. In photometric terms, daylight consists of direct light from the Sun and diffuse light from the sky. Aside from merely adding windows and skylights to building envelopes, daylighting includes balancing heat gain and heat loss, minimizing glare, and allowing for fluctuations in natural light availability. (Esquivias Fernández, 2017)

It is undeniable the crucial role that daylight plays in our architecture. For centuries it has been the single most important source of indoor illumination. It shapes our perception, behaviour, navigation, and wayfinding, creates a narrative, and an attractive visual environment, saves electrical energy and provides the light needed for our biological needs. (Lam, 1977) A good luminous environment is simultaneously comfortable, pleasant, relevant, and appropriate for the intended uses and the users.

HEALTHY DOMESTIC DWELLING

Architecture has been used for a long time to respond to pandemic-causing diseases that have threatened humanity throughout ancient and modern history.

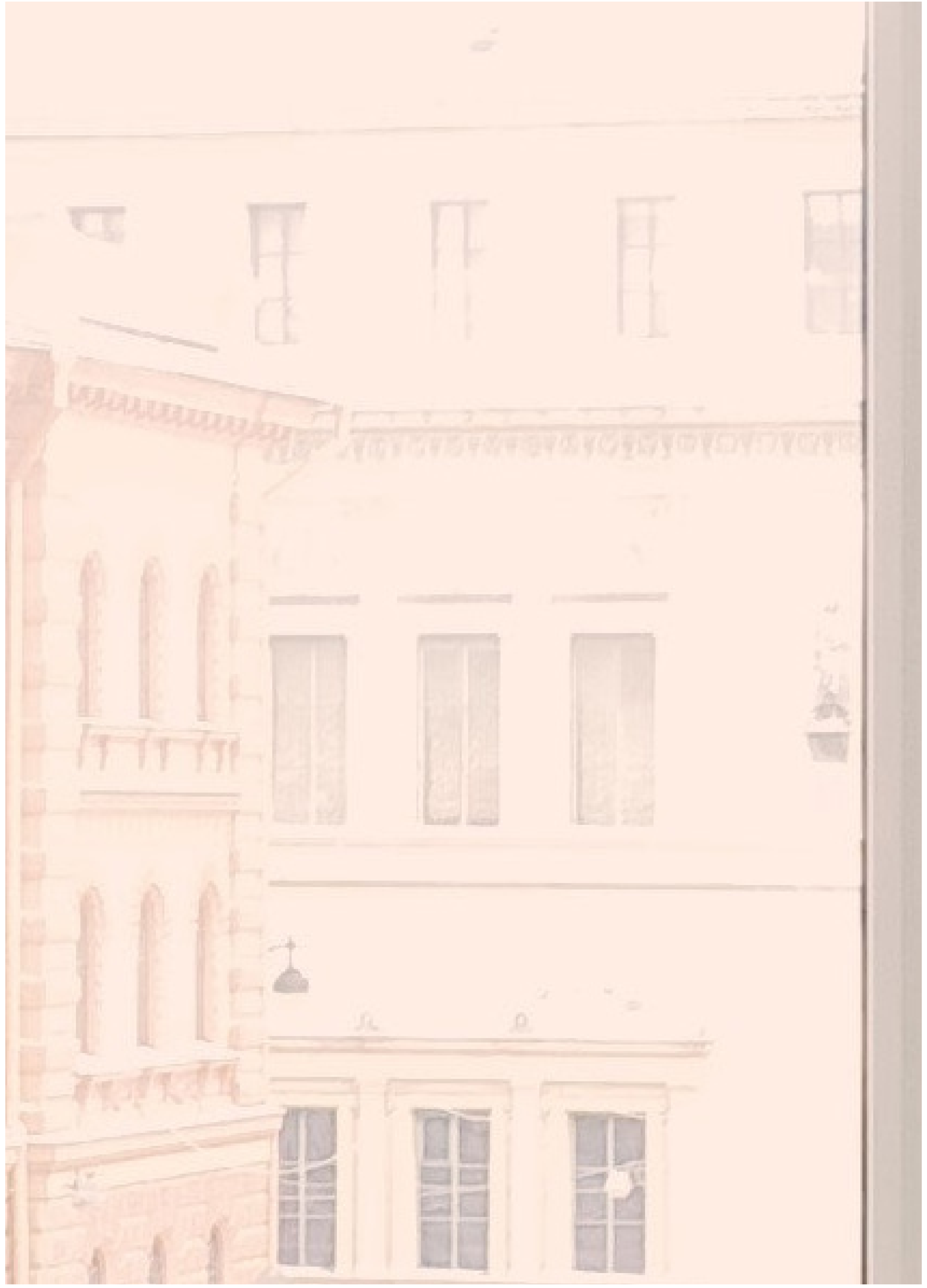
The Tenement House Acts were enacted in New York in the 1800s acts as an example of this as being a response to deplorable conditions in tenement dwellings. Every habitable room was required by law to have a window opening to open air, which was accomplished by including air shafts connecting adjacent buildings.

The Acts improved safety, ventilation, and health standards in houses, leading to the adoption of the "dumbbell" housing design, which included a central light well to boost ventilation and daylighting throughout the home. (Arbuckle, 2016; Schuman, 1993) In 1918 the "Spanish Flu" pandemic followed by the world war led to the formation of public health regulations. Until medicines became widely available, one of the most effective ways to combat the disease was to expose oneself to sunlight and fresh air. The late-nineteenth and early-twentieth brought the use of Sanatoriums [1]. For instance, the Paimio Sanatorium from Alvar Aalto (1933) is a building majestically integrated into the natural landscape of Finland; the facility offers patients plenty of natural light, open daylight balconies, and nearby walking routes. (ArchEyes, 2020) At the time, patients were given state-of-the-art treatment in the form of daylight and exercise. Perhaps some of the design concepts of sanatoriums will become the new design basis for all buildings in the future, with light and air at the centre of health-promoting architecture. It is possible that post-COVID-19 housing will have similar goals and prioritize health and wellness.

1. Medical facility for long term illness most typically associated with the treatment to combat tuberculosis.

Designing domestic dwellings to provide healthy, comfortable living and working environments is more critical than ever. The provision of daylight is one such area where design can be improved. Offering dwellers improved comfort through the benefits of daylight and connection to the natural surroundings. Numerous studies show that natural light and proximity to nature improve home health and wellbeing. (Veitch & Galasiu, 2012) However, light in the built environment is not designed to affect circadian rhythms. (Figueiro et al., 2017)

Compared to other building types such as schools, offices, and hospitals, research on daylight and health advantages in residential structures is minimal. Poor lighting levels at home have been demonstrated to have a negative impact on quality of life. (Grimaldi et al., 2008)



"If managed poorly, [buildings] can spread disease. But if we get it right, we can enlist our schools, offices, and homes in this fight."
- Joseph Allen, DSc, MPH

Our homes could become environments that improve our wellbeing, comfort, quality of life, and mental and physical health.

Insufficient daylighting in our homes is associated with depression (Brown & Jacobs, 2011), sleep disruption, and higher cancer rates. On the contrary, higher daylight levels exposure stimulates physical activity and longer sleep duration. (Boubekri et al., 2014).

We all must reconsider how we live indoors. Individuals, architects, businesses, and governments all have a responsibility to do everything possible to ensure that our houses are healthy places to live and grow up in.

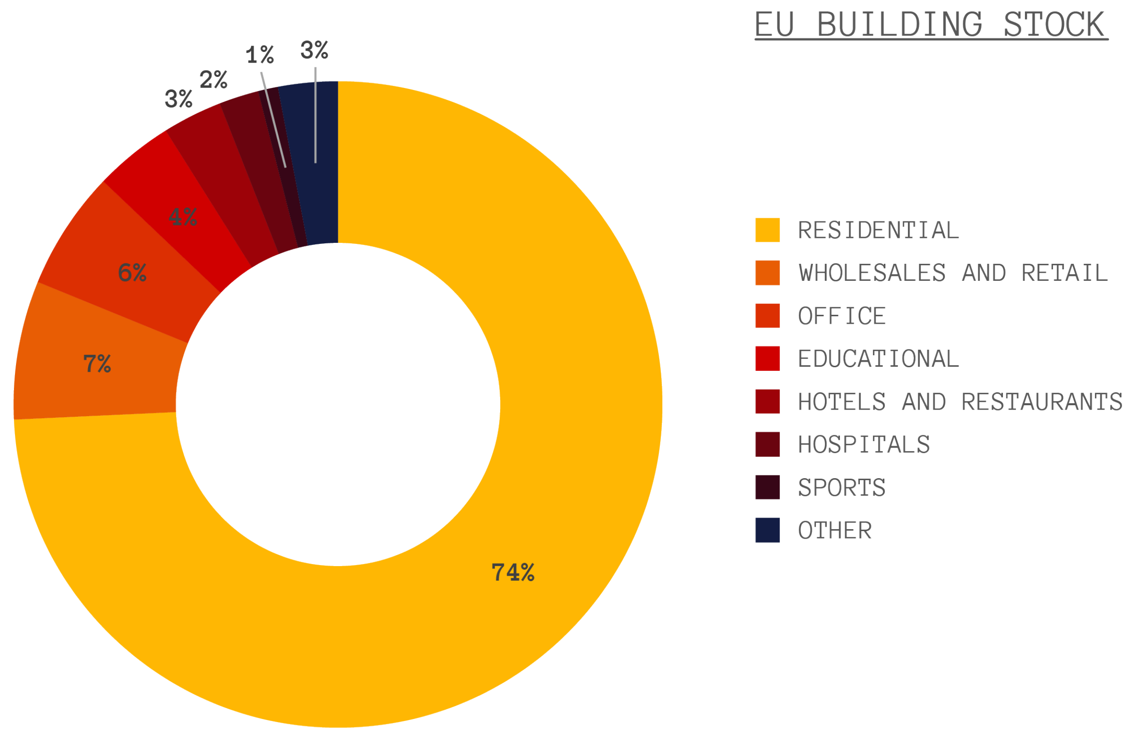
The value of the view of the outdoors is essential for the residents' wellbeing through physiological calming and improved focus, mood and residents satisfaction. (R. Kaplan, 2001) Windows in residences are necessary for occupant comfort and health, possibly even more during a pandemic. When activities outside are limited, the quality of the view to the external is critical to a home's ability to create a sense of restoration for its residents. Environments that encourage "soft fascination," allowing the mind to reflect on unresolved thoughts that have the potential to deprive more vital attentional resources, are a source of respite and repair. According to studies, glancing outside throughout the day delivers micro-restorative experiences that have the potential to provide restorative properties of nature to residents within their residence. Nature can capture one's interest and attention while reducing fatigue and stress and repairing the mind and body. In an era when anxiety and loneliness are on the rise, the benefits of the natural environment have become critical to the wellbeing of individuals living in dwellings. (S. Kaplan, 1995).

A clear view of the sky can also be restorative. (Masoudinejad & Hartig, 2020) Nevertheless, people tend to naturally seek a private zone/ refuge inside their residence that allows them to observe outdoor activities yet cannot be easily overlooked by others. The sensation of shelter can be achieved in areas where the occupant feels at ease and secure in their own home. As people spend more time at home, privacy within the house is predicted to become increasingly important. The prioritization of window views and spatial variety is scientifically shown to promote occupant health, wellness, stress reduction, and restoration.

3. BACKGROUND

Well over half the world's population already lives in towns and cities, and by 2050, that number is predicted to rise to over 70% (WHO, 2021). This means that more dwellings will be required to provide shelter. In fact, recent research reveals those residential buildings account for 75% of the EU building stock. This includes single-family houses, multi-family houses and high-rise buildings. (Dr. Herczeg et al., 2014).

Grf. 1. EU Building Stock



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Until recent years, the dwelling space was used primarily as a space for sleep, with most activities taking place outside. Today, work, entertainment, socializing, eating, resting and most aspects occur indoors. There has been an exponential growth in the time we spend indoors than ever before. In fact, according to a recent survey, people believe they spend less time than they do. 82% of the respondents stated that they spend less than 21hr indoors each day, and 62% think they spend less than 18hr indoors. On average, respondents believe they spend 66% of their time indoors.

However, we know that people spend 90% of their time (or over 22 hours each day) indoors on average (Sarigiannis, 2013). Of which, 13hr out of that 22hr we spend inside our homes (Schweizer et al., 2007). Meaning that people spend a considerable amount of time at home.

"From the year 1800 to 2000, we have moved from 90% of people working outside to less than 20%. In a very short space of time, we have gone from being an outdoor species to spending most of our time in dim, dark caves."

– Russell Foster [2]

2. Head of the Nuffield Laboratory of Ophthalmology and the Sleep and Circadian Neuroscience Institute, University of Oxford.

On this concern, VELUX launched a campaign seeking to raise awareness of the importance of the topic that they very suitably called the "Indoor Generation", revealing the problems, implications, and impacts these topics have on human health.

These findings highlight a considerable gap between our perception and reality. However, a quick study of the literature available on the subject demonstrates that much of the present daylighting research is primarily focused on workplaces, with hardly consideration given to the domestic dwelling. A keyword search across academic search engines reveals that out of 6865 publications, 65% focus on office spaces while only 35% focus on residential architecture. Also, according to Dogan and Park (Dogan & Park, 2017), most current research on daylighting focuses on office buildings, with only a few studies on residential spaces.

Considering that all these studies were made in a pre-pandemic context. Before working from home was a norm, schools, businesses, and workspaces were open. This triggers the inspiration to research the domestic dwelling daylighting in a modern perspective and how is this topic being approached in the post-pandemic context.

The epidemic has catalyzed debates about the health-promoting features of our houses, focusing attention on a critical issue that must address.

Taking advantage of this element in our homes not only impacts on a positive way our cognitive health needs but can have a tremendous impact on the environment.

4. METHOD

This master thesis will use a highly essential subject for humankind as a central point, such as the domestic dwelling daylight. The first section of the thesis will use a transdisciplinary approach by identifying critical elements in the modern historical context relevant topic such as the ***RESIDENTIAL DAYLIGHTING:*** what do we know about the relation to the spaces that make up our homes with the Sun's path, orientation, or latitude? How can the integrations of these fundamental considerations on daylight substantially elevate the performance and dynamism of our homes in our daily routines? ***POST-PANDEMIC:*** how does our conceptualization of what a home is has been transformed? What has triggered the health disorders most found in recent years? ***BIOPHILIC DESIGN:*** How can this branch of the design take us closer to nature? What is the relation between daylight, biophilia and architecture? How can this transform our homes into a healthy environment to offset post-pandemic disorders?

This will be accomplished through extensive literature review and peer review. The following section will be the analysis investigating the daylight standards and human emotions.

Identifying the critical elements in the modern historical context will strengthen the following phase of the thesis by combining all the knowledge to develop various strategies that address the concerns outlined in the previous section.

5. RESEARCH

RESIDENTIAL DAYLIGHTING

With a growing emphasis on sustainable design methods, efficient use of natural light daylight in our homes is no longer a luxury; it has become an obligation. Daylight is a valuable natural resource linked to the quality of space, occupants' health and wellbeing. (Dogan & Park, 2017).
Therefore, to gain the most out of the daylight in the residential space, our home floor plan layout should be closely associated with the transition of the Sun. In this way, the design can assure that the daylight and light levels provided for the specific space relate to its intended use and goes according to the time of the day, additionally reducing the need for electrical lights for an extended period on a daily basis. Daylighting and access to direct sunlight perform a predominant role in the domestic dwelling design.
The first systematic references to the integration of natural illumination in rooms can be found in Marcus Vitruvius Pollio's work "De architectura" (1st century BC) (Vitruvius Pollio & Gwilt, 1826). This work includes directions for resolving the issue of obstructions that hinder natural lighting from entering the rooms. Architectural manuals such as the Neufert Architect's Data (Neufert et al., 2012) remark how specific domestic programs and room types should be oriented in a specific cardinal direction so that daylight is most accessible during the time frame the space is most frequently being used. Not only to embrace the use of daylight as an architectural design element or as a helpful energy-efficiency building design tool. Nevertheless, to have an environment that responds to our human needs, e.g., the human body is at its coldest in the early morning. It helps to revitalize the body by exposing it to the bright and early Sun. Morning light exposure during the "resetting period," from 6 am to 10 am, is significant for circadian stimulation. (Konis, 2017) in other words, it is a good idea to use daylight with minimal spectral filtering delivered when it is most needed for circadian regulations; for example: allocate the bedroom on the east side of people's homes.
Fig. 3.

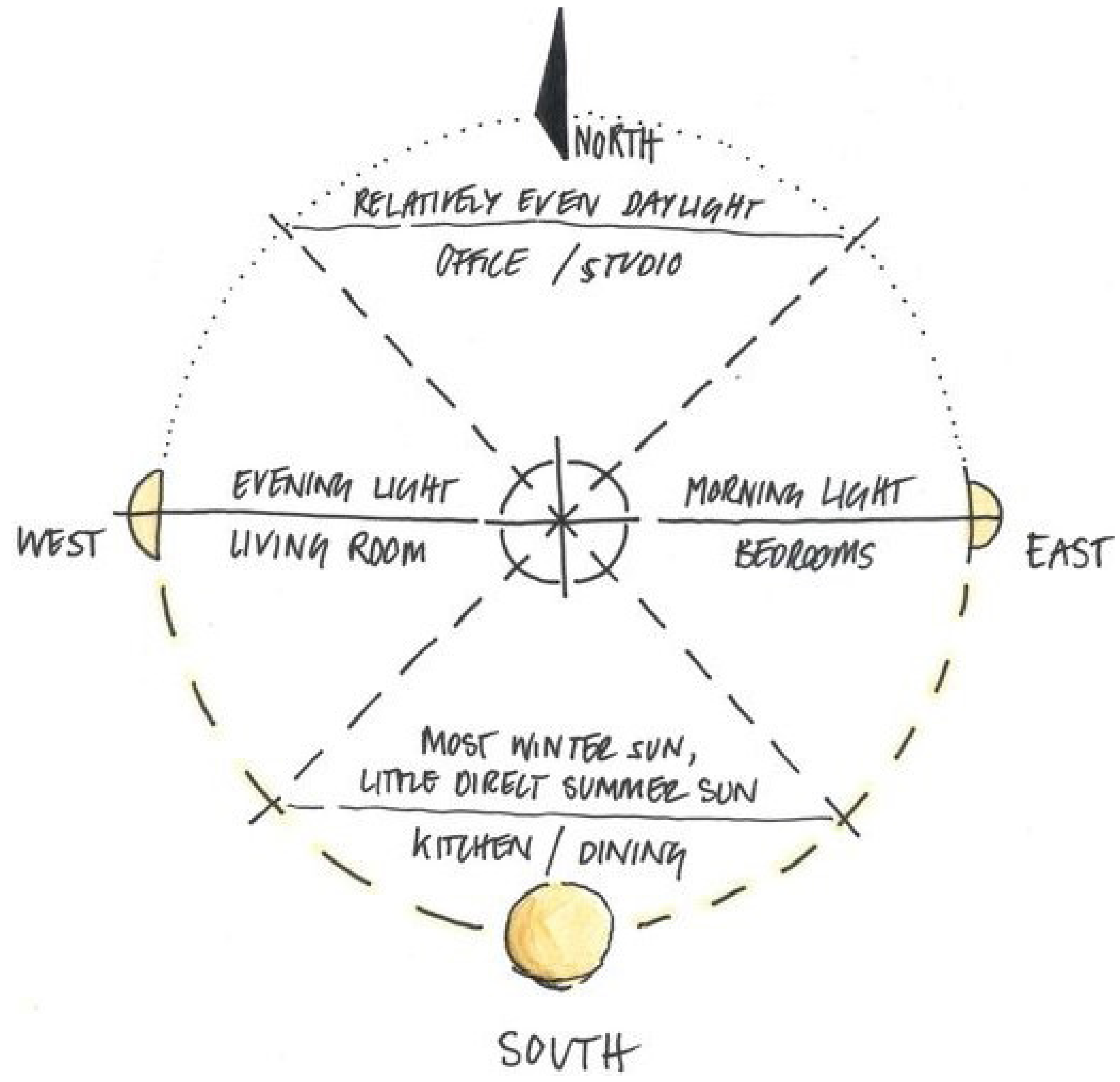

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Fig. 3. Architecture home's program and daylight

To analyze the information, a survey was conducted with 67 participants to map at what periods of the day the dwellers use a space or are it more likely to be used. The survey was done on a digital platform tool, a cloud-based survey that helps users create, send and analyze surveys called "Survey Monkey" to collect data. Even though the essence of this exercise is very straightforward, the complexity behind it was enormous since every person has different traditions and customs depending on their geolocation, status, age, type of home, whether they live by themselves or with more people, social and economic status, or occupations. It is challenging to create a survey that links the space to and specific hour, to name a few factors. To achieve the option was to divide the day not hourly but into the five-time frames "Morning- from 12:01 am to 11:59 am", "Noon- exactly 12:00 pm", Afternoon- from 12:01 pm to 6:00 pm", "Evening- from 6:00 pm to 11:59 pm", and "Midnight- exactly 12:00 am".

The survey was divided into two different questions. In the first part questionnaire, the respondent had to give feedback about the number of people currently living in their household in a multiple-choice format. The respondent only could check a single choice that went from one user to six or more persons.

The second part of the survey was to answer the question in a matrix/ rating scale format. The respondent could see in the left side column a list of all the common spaces that an average domestic dwelling has and the time frame previously mentioned on the top row. The respondent had the liberty to check multiple checkboxes from different time frames, understanding that dwellers may use every residence space throughout the day. However, the focus of the exercise was to understand when the space is more likely to be used by its occupants.

The idea behind it was to create data from which the respondents were given only the essential information to answer the questionnaire but not enough to impose any pre-read and analyzed theory upon them. All the necessary measures were taken to guarantee respondents' anonymity, and no personal data were collected.

In the first question of the survey, most of the participants (23.88%) answer that they share their dwelling with another person.

In the second part of the survey, these are the tendencies found in each aspect of the spaces: Bedroom (morning 74%.63 – evening 65.67% – midnight 44.78%), meaning that the main use of the space covers these three-time frames. Bathroom (morning 98.51% – evening 52.24%) after and before rest. Closet (morning 64.18%) getting ready for the day. Office space (noon 31.34% – afternoon 50.75%). Dining room (afternoon 46.27% – evening 61.19%). Family room (evening 85.07%). Living room (evening 79.10%). Kitchen (morning 67.16% – afternoon 50.76% – evening 68.66%). Laundry (morning 47.76%). Storage (morning 19.40%). Garage (morning 46.27% – evening 37.31%). Outdoor dining (afternoon 28.36% – evening 34.33%). The results and graphs can be reviewed in the appendix section.

With the information gathered and the previous research on the topic was possible to create a chart of each of the residential rooms/ spaces for the periods of occupation and desirable sunlight. *Fig. 4.*

As the home becomes a more multi-functional area, it must accommodate working and learning environments and entertainment, cooking, and rest.
A variety of lighting comfort levels that support these additional functions must be considered throughout the domestic dwelling. Shortly, our homes are likely to remain settings for learning and working, and therefore, we must begin to recognize that these spaces will need to encourage productivity and wellness.

The desired light levels in each space, location, climate, and sociocultural influence inhabitants' light level choices. People are spending more time at home now than ever before; daylighting will become an essential factor in resident satisfaction and be used as a primary design guideline for architects.

A recent study on Hong Kong residents' experience with their kitchen space was conducted. According to the findings of this study, 55% of participants were satisfied with the daylighting conditions in their kitchen but believed unit size to be a more critical design parameter. (Siu-Yu Lau et al., 2010) However, it should be noted that less than half of the participants spent less than 15 minutes per day in this place. In recent years, our reality has changed drastically; it will be interesting to perform the same investigation considering that people will undoubtedly spend more time cooking and dining at home as our kitchens and dinner tables replace restaurants, bars, and coffee shops. Although daylight quality may not have been a priority in the past, it is reasonable to predict that in the post-COVID-19 era, individuals will want optimal light conditions not only in their kitchen but throughout their entire home.

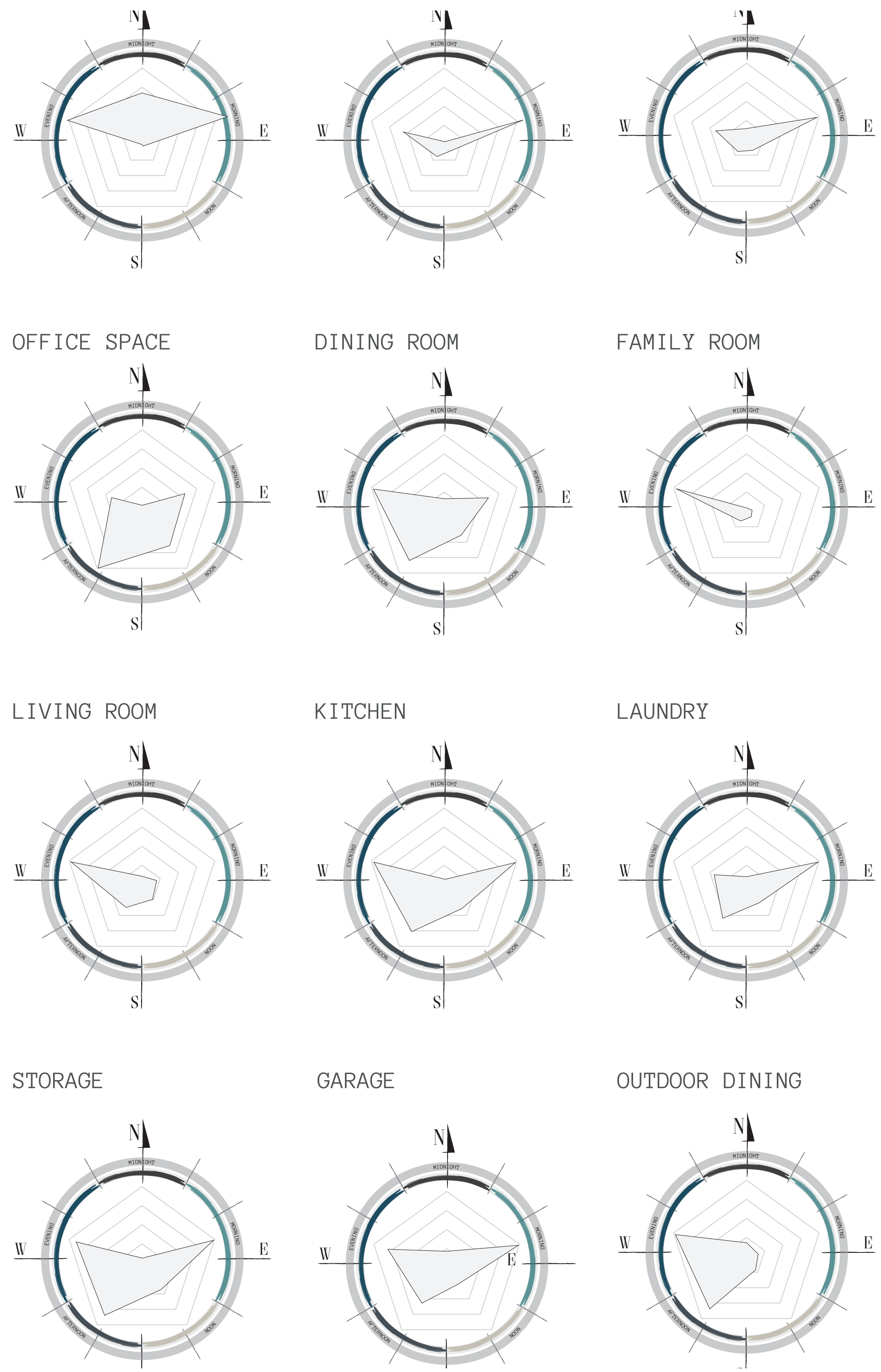

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Fig. 4. Mapping the Domestic Dwelling

POST PANDEMIC

City shutdowns and social distancing regulations implemented around the globe began in early 2020 in many counties on a local and global scale as a response to mitigate, slow down or delay and eventually stop the spread of the virus (Harris M et al., 2020). Since then, people have been forced to spend far more time than ever before in their homes.

The current COVID-19 [3] pandemic lockdowns have changed the meaning, value, and purpose of different rooms in the domestic dwelling, adding entirely new activities that were not considered before, e.g., transforming our homes into a workspace, homeschool or our personal gym—creating a struggle to balance our personal, professional, and social life, creating a "new normal" way of life. "Trying to adopt all those kinds of protective measurements that you can, in situations that you may not have full autonomy and control over" (Bergen, R., 2020). Consequently, we are faced with a big challenge since a vast majority of people do not have the suitable space with the specific characteristics necessary to provide that need, stressing the importance of adequate daylighting for that specific new activity in homes.

As residents are increasingly spending the majority of their time at home, the ability of our homes to support occupants' mental health and wellbeing is becoming more than ever critical in residential design.

1. *SARS-Co-V-2 (severe acute respiratory syndrome) is the virus that causes the disease, COVID-19. This paper will refer to COVID-19 throughout. World Health Organization

On top of that, new issues and negative struggles have been arising, creating an impact on the global public health crisis, such as loneliness, reduced productivity, unhealthy sleeping and eating habits, potential obesity, and loss of various benefits associated with reduced human-human and human-environment interactions (Muñoz-González et al., 2020; Salama, 2020). In relation to this, a survey-based study carried out in several Chinese cities has classified the psychological impact of the pandemic as moderate-severe. **Thus, 54% of those surveyed have shown depression, anxiety, and stress symptoms.** (Wang et al., 2020) This scenario has also deteriorated while social distancing has been in effect, as interaction with the outside has been limited to the windows in many cases, contributing to a worsening of mental and emotional health disorders. (Leone et al., 2020) there has been a rise in physical problems associated with sedentary lifestyles, as well as the changes associated with the shift in circadian rhythms.

As a way to show this in a graphical way based on the literature review, a pinpoint of the keyword commonly found in various articles was allocated in four different categories: 1. Mental health, 2. Social distancing, 3. Well-being and 4. Quality of life. Each category is subdivided into related issues. All this will be considered when designing the solution. *Fig. 5.*

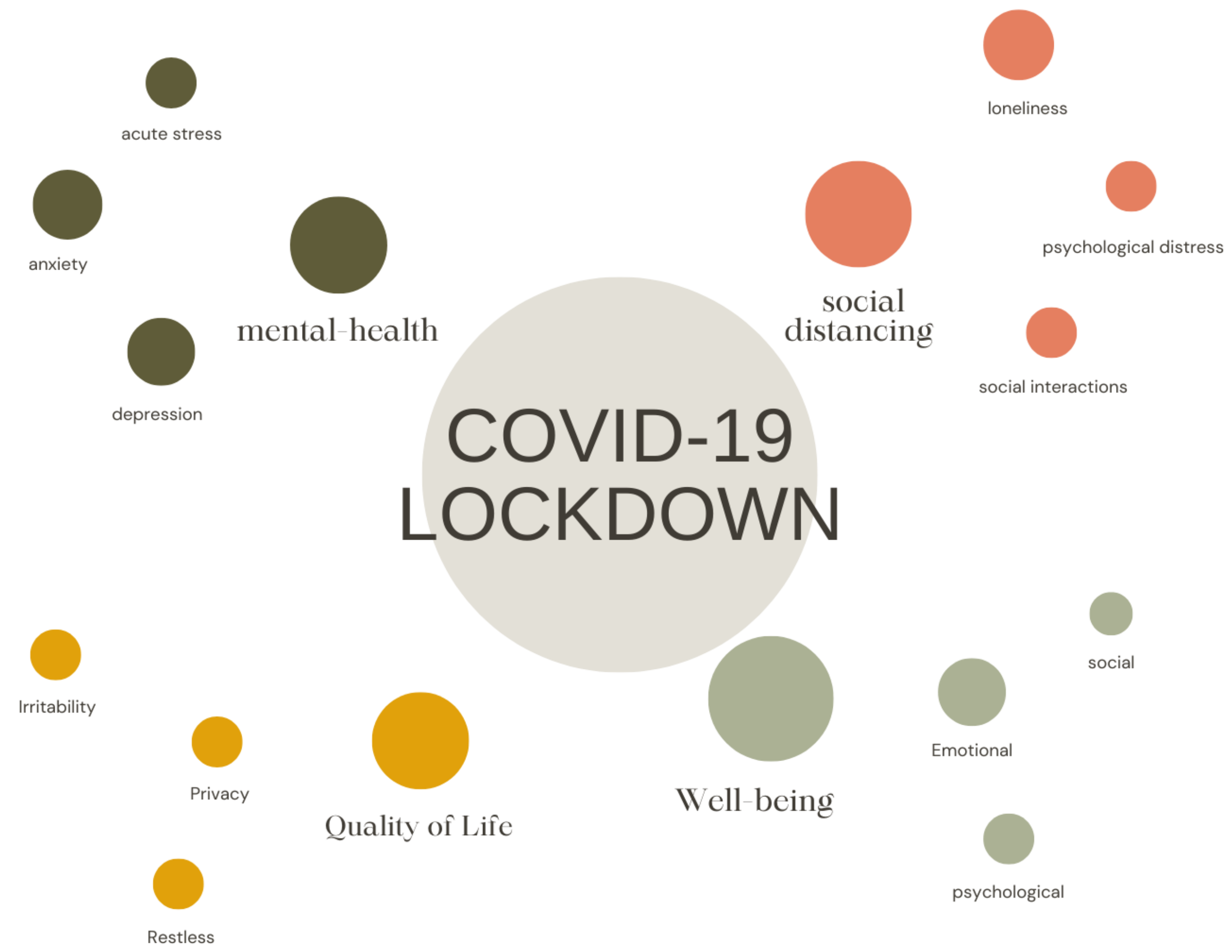

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Fig. 5. COVID-19

BIOPHILIC DESIGN

Biophilic design is known to be a branch of the design that aspires to help mend the existing gap between the modern built environment and the human need for connecting people to nature within the built environments and communities, using natural resources to create a sense of harmony between modern architecture and the natural world around them. (S. R. Kellert et al., 2008) This innovative approach emphasizes the necessity of maintaining, enhancing, and restoring the benefits of experiencing nature within our buildings. The term "biophilic design" originates from the concept of *biophilia*, the idea that humans possess a biological inclination to connect within natural systems and processes instrumental in their health and productivity.

It is a natural emotional bond between humans and other living organisms (plants and animals). (S. Kellert & Wilson, 1993) Our psychological responses to animals and environments demonstrate this connection. This suggests that we have an inbuilt inclination to engage with nature.

Biophilic design can be divided into six design elements. These six elements are then developed in more than 70 biophilic design attributes (see appendix). *Fig. 6.*

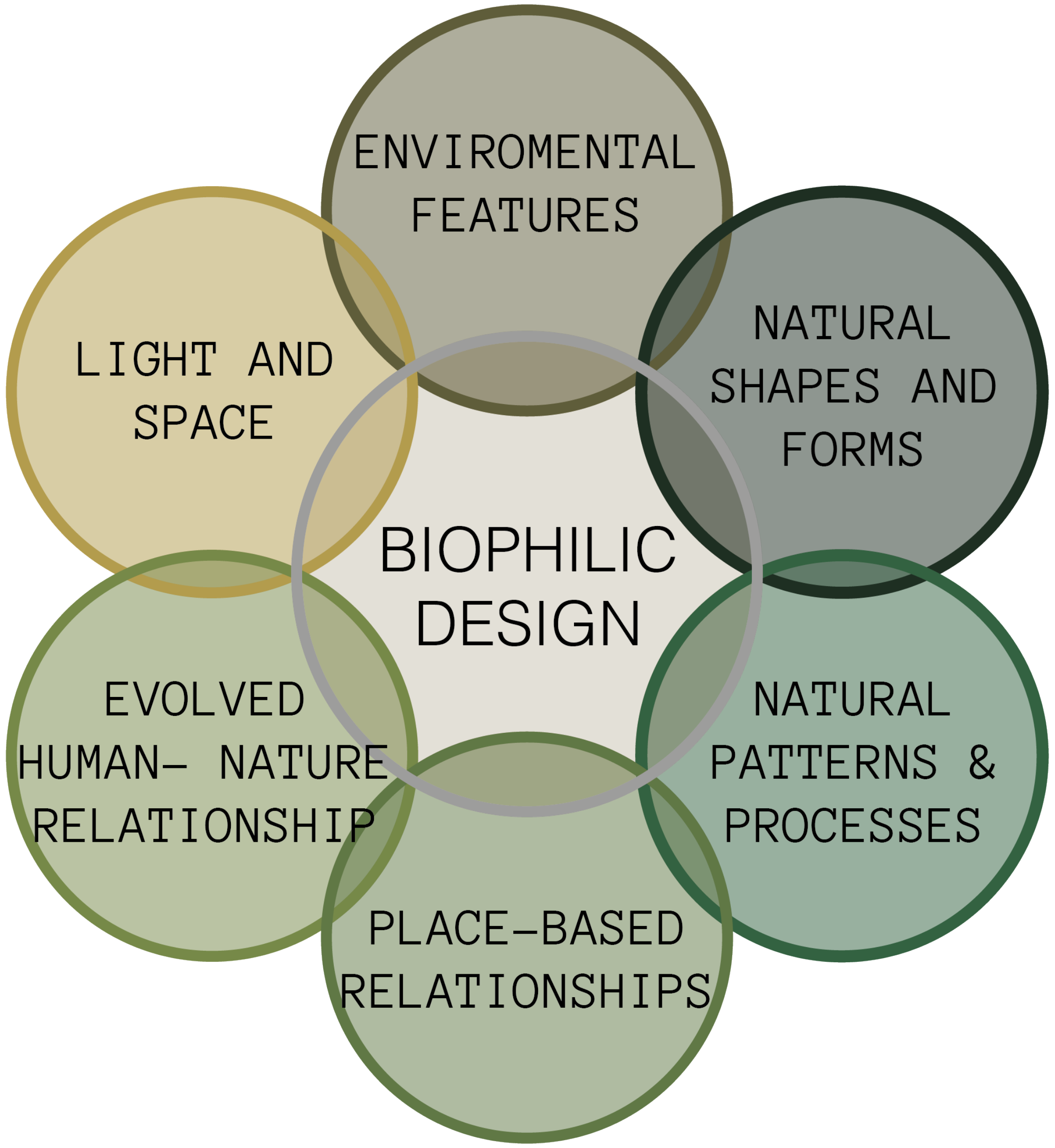

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Fig. 6. Biophilic Design Principals

Using all these design elements principles that link humans with nature plays a role in a restorative environment.

According to (S. Kaplan, 1995), "Restorative environmental design" (RED) is a theory from environmental psychology that argues that the built environment can support recovery and alleviate mental health and wellbeing caused by stress situations by concentration and distractions using nature.
The idea of biophilic design arises from the increasing recognition that the human mind and body evolved in a sensory-rich world, which continues to be critical to people's health, productivity, emotional, intellectual, and even spiritual wellbeing. (S. R. Kellert et al., 2008)

Numerous studies demonstrate that daylight and access to nature have positive impacts on health and wellbeing at home (Veitch & Galasiu, 2012) connections with nature through plants, water, light and views, as well as an indirect connection through natural materials, patterns, colours or images, has been found to improve mood, recovery from stress and concentration (Kant et al., 2003). Daylight contains many characteristics that appeal to human nature and wellbeing, such as its warmth, variation of colour, diurnal and seasonal change, filters and shadows and its fluctuating intensity. Natural light is widely preferred over artificial light for this and other reasons. Changes in the intensity and colour of daylight soothe the eyes and signal the body's rhythms. Different lighting conditions produce different moods, which elicit different psychological responses; the Sun's unique properties produce an especially calming combination that humans innately crave; while some electrical light fixtures can simulate the Sun's patterns, there is no substitute for natural light.

INITIAL RESEARCH QUESTION

“What if our homes could improve people’s health through the integration of daylight to support and serve multiple purposes in a single space?”

6. ANALYSIS

EN 17037, THE DAYLIGHT STANDARD

Daylight varies in a complex and not wholly predictable way; so does human response to daylight. Therefore, design criteria, standards, and guidance required in practice must be objective, straightforward, consistent, and replicable. (Tregenza & Wilson, 2011)

Until recently, there was no specific guideline for building designers to follow to acquire acceptable quantities of daylight in any building. Until 2018 the first coordinated European Standard for daylighting buildings, EN 17037, was published. The goal is to improve occupant comfort and overall energy efficiency by providing glass apertures and evenly distributed daylight to the interior area while lowering electrical lighting usage.

To achieve its multiple aims to daylight and occupants' comfort, the standard covers four focus areas of daylighting: daylight provision, assessment of views, access to sunlight and prevention of glare.

The standards cover all of Europe, and of course, the difference between one site and another is considerable: Different daylight hours and the angle of the Sun. So, calculation results for any of the four aspects of daylight will be unique in every project. Considering national and local conditions through climate-based modelling to give appropriate and specific solutions to each project. (VELUX GROUP, 2020)

There is no way to measure the necessary human light demands. However, individuals require a higher light level in the interior area than what is mentioned in electric lighting standards. Daylight is more stimulating than electric light because it fluctuates in intensity, colour, and direction.

One dilemma is that the amount of light we require for our visual system is far less than we require for our circadian system.

Typical indoor illumination levels of 300-500 lux are adequate for performing most visual tasks but, in most situations, are insufficient to ensure a reasonable regulation of our circadian body clock.

Standards should be used as a baseline to assist the design criteria process. However, they are no substitute for the designer's understanding of the needs and desires of the people who will experience the indoor environment. (Tregenza & Wilson, 2011) The designers' responsibility is to strike a balance between norms and reality.

A minimum amount of natural illumination is obtained when the apertures in a room cover at least 20% of the space's surface (i.e., a window-to-floor ratio of 20%). Furthermore, the depth and width of one-sidedly lighted spaces are limited.

The Illuminating Engineers Society of North America (IES) recommends a minimum light level of 300 lx and a maximum light level of 800 lx for places used for productive work, depending on the climate-based daylight factor. As a result, it is critical to determine whether the windows can also provide the necessary amount of natural light.

EMOTIONAL DAYLIGHTING

Daylight is relevant in architecture design, and it is also to human physiology and behaviour. While daylighting has a significant impact on human health and wellbeing, it is intimately connected to emotional delight and the perceived quality of a space (Ko et al., 2020). It is also very dynamic and varied in nature, depending on the Sun's course and weather patterns. This makes it a necessary and challenging part when considering the performance of a space or particular room in the domestic dwelling. According to environmental psychologists and behaviourists, small changes in lighting can impact building inhabitants' moods and emotional perception state. This concept is based on the idea that the presence or absence of daylight and other environmental factors can evoke a pleasant or negative emotional response. Excitement, attentiveness, and dominance are all feelings that come with good daylighting. On the other hand, poor daylighting causes dullness, monotony, and submissiveness. The paradigm says that these affective states, in turn, govern the occupants' social, emotional and behavioural responses. (Mehrabian & Russell, 1974) The light has a powerful capacity to trigger an emotional response in the people experiencing it. It is no wonder why the American artist James Turrell uses it as its primary medium.

Emotions are the physical reactions of the human body to various situations that can be beneficial and harmful consequences for our health. Physical and emotional wellness are intertwined. e.g., long-term exposure to high levels of stress and negative emotions can lead to various health issues.

The spectrum properties of daylight and its dynamic aspect may stimulate hormonal and physiological processes, which affect our psychological wellbeing.

"Emotion is defined as an episode of interrelated, synchronized changes in the state of all or most of the five organismic subsystems in response to the evaluation of an external or internal stimulus event as relevant to major concerns of the organism"

– Emotion Researcher, 2015

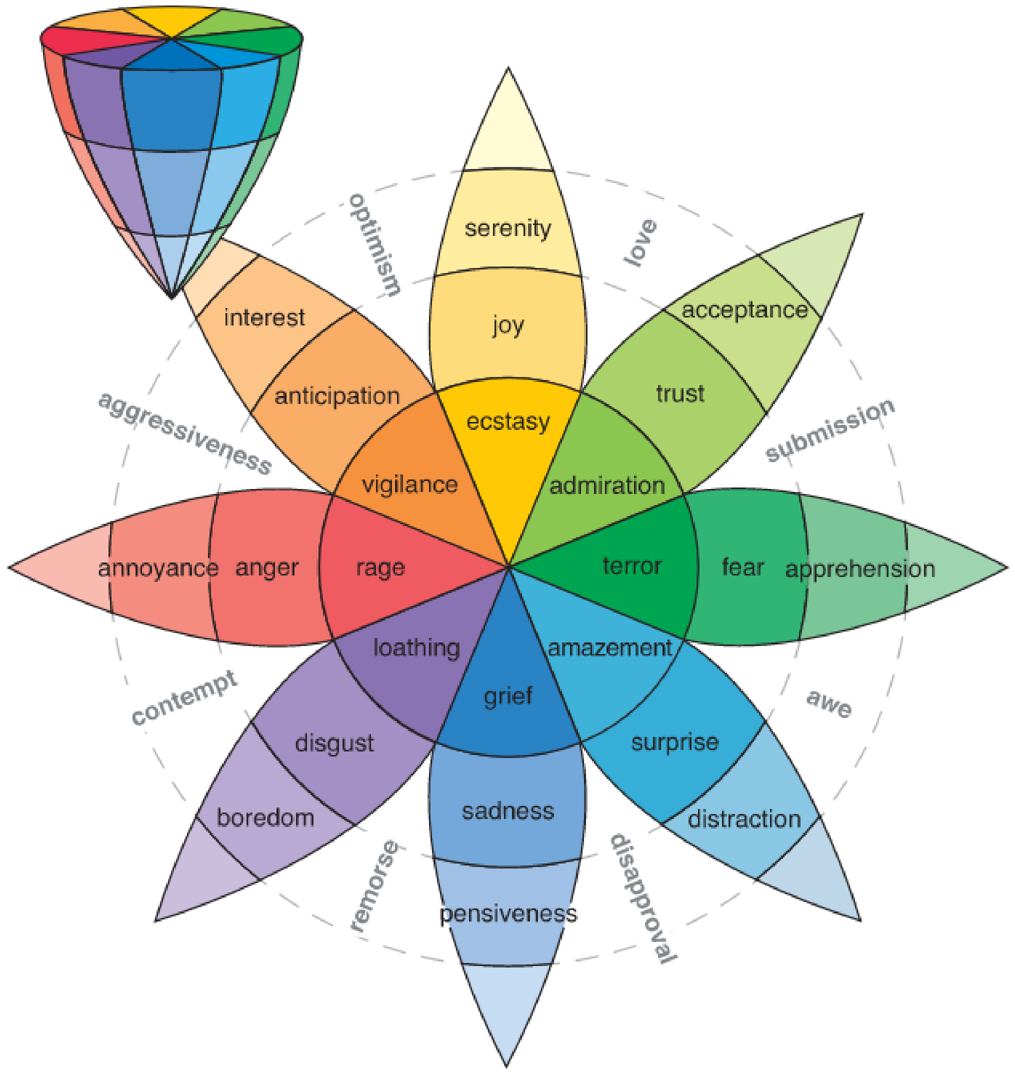

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Fig. 7. Plutchik's wheel of emotions

Joy, trust, fear, surprise, sadness, anticipation, anger, and disgust are the eight primary emotions, according to psychologist Robert Plutchik. He established the wheel of emotions, which displays relationships among them. This approach groups emotions according to how they interact with one another. The eight basic emotions place each at the opposite end of the spectrum. While the entire wheel folds in a 3D shape, adjacency describes how similar the emotions are. The concept is that the closer we get to the centre, the stronger the emotions become. *Fig. 7.*

RESEARCH QUESTION

“How can we create a better living environment in the domestic dwelling through daylight, benefiting human wellbeing and enhancing the dweller’s experience to evoke emotions that mitigate negative aspects in a post-pandemic context?”…

7. SUCCESS CRITERIA

To sum up, the research and analysis of the main concerns of the thesis are crucial to developing a design success criteria to interconnect all the aspects of the multidisciplinary concepts.

The diagram below shows the three main fronts of the research in the outer ring: *Residential Daylighting, Post Pandemic* and *Biophilic Design*. In the second ring is another layer developed from the first one; the three topics introduced here: *The daylight Standard, Emotional daylighting,* and *Healthy Domestic Dwellings* are at the centre of the gravitational point of the research on the domestic dwelling.

This diagram represents the order of importance of each of these elements to guide the readers on how this thesis has been developed. From understanding the importance of architectural daylight planning, environmental integration to architecture, the health struggles from the pandemic left, the guidelines for integrating daylight, the emotional attachment we have to it and finally, how architecture has been used as a tool for our wellbeing. As a result, making it possible to create recommendations on the daylight strategies and emotions that will substantially elevate human mental health in our dwellings. *Fig. 8.*

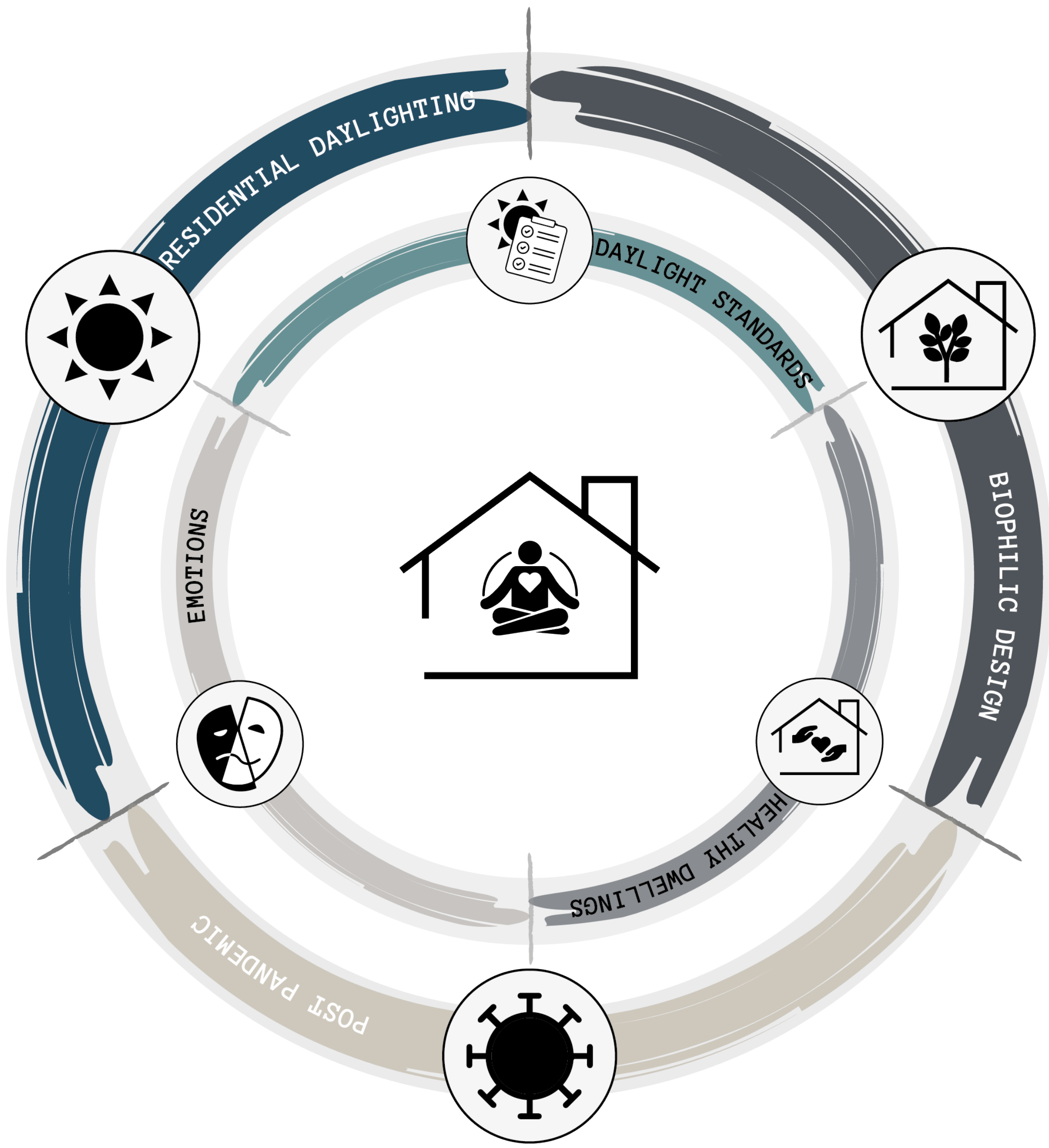

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Fig. 8. Thesis mind map


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8. DESIGN FRAMEWORK

DESIGN GOALS

As found in the analysis, the current domestic dwelling has been transformed from a specific purpose to a multipurpose/ dynamic space responsible for allocating all aspects of our lives (personal, professional, and social life). Each of these aspects requires a specific light need that the appropriate use of daylight could provide; unfortunately, the vast majority of spaces in our homes fail to offer this adequate illumination and lack variation in the atmospheres for the intended use and new use of the space. The objective of this master thesis is to Identify synergies between passive design strategies and health-promoting residential architecture or "restorative environmental design" principles by combining daylight with biophilia as a tool to enhance emotions to contra rest/ fight the struggles of the human wellbeing after the post-pandemic context while maximizing the use of the daylight.

The proposal of the design goals is associated with each of the EN 17037 daylight standards, meaning that the design framework has been developed according to the four features commonly deficient in the domestic dwellings identified through the research. It can positively be transformed into new design opportunities. *Fig. 9.*

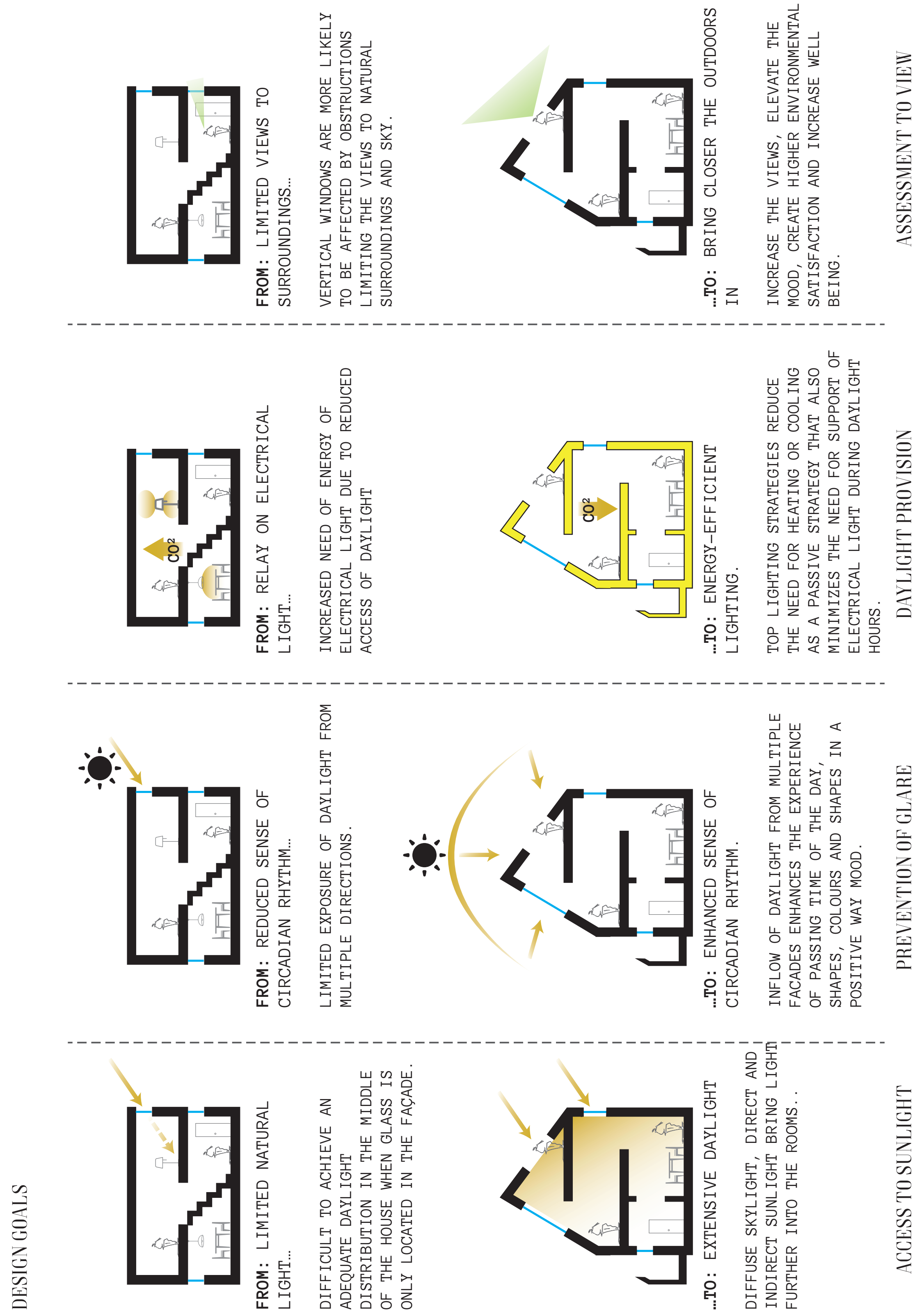

Fig. 9. Design Goals
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FUTURE LIVING ENVIRONMENTS

It will be naïve to think that COVID-19 will not be the last sanitary pandemic to disrupt our way of life. Thus, the domestic dwelling's design must be more resilient. Accomplishing this means that our future living environments must consider the biggest lections learned over the almost two years from the "impacts on stay-at-home protocols" due to the sanitary lockdowns. *Fig. 10.*

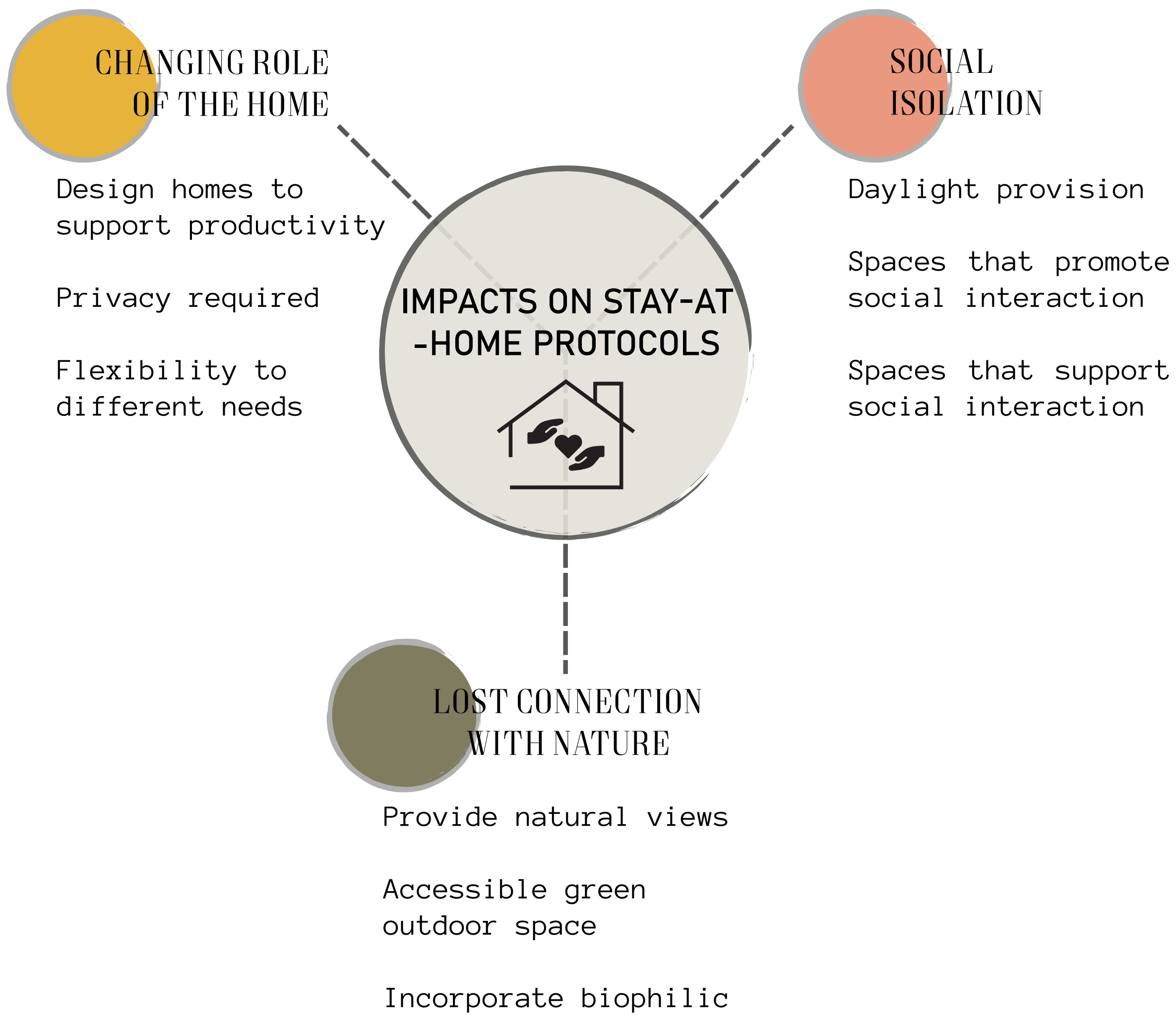

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Fig. 10. Impacts on stay-at-home protocols

"Changing the role of the home": multi-functional spaces that serve as their primary purpose, but they offer the flexibility to adjust to the different dwellers' needs.

- *Designing homes that support productivity*: Remarking that our homes have evolved into places for learning and working.
- *Privacy required*: The extended period at home requires a sense of refuge, offering space within the home and the immediate outer environment.
- *Flexibility to different needs*: homes are multi-functional spaces that provide the right conditions to perform different activities within the same space.

"Lost connection with nature": daylight, views, and fresh air are three essential factors in our homes; lack of these three can negatively affect human health.

- *Provide natural views*: Views of greenery landscape and a good portion of the sky positively affect physiological activity levels, positive emotional state, and mental and physical health.
- *Accessible green outdoor space*: Considering the easy access and connection to a natural environment, this could be provided by the integration of balconies and courtyards that could be used all year round; these spaces should be used as a tool to support the inflow of daylight into the residence.
- *Incorporate biophilic design principles*: Use and enhance the dynamism of the natural world to connect man-made environments with nature and visual engagement while playing a crucial role as a restorative environment.

"Social Isolation": Homes that allow self-isolation within the dwelling to contain and minimize the risk of spreading disease.

- *Daylight provision*: Daylight exposure within and outside the dwelling for circadian regulations and environmental design promotes wellbeing and comfort.
- *Spaces that promote social interactions:* open and flexible spaces to create community among the residents
- *Spaces that support social interactions:* Dwelling design provides safe spaces for passive and active social interactions and supports restoration in communal spaces.

It is challenging to transform an existing physical place, but it is possible to adequate design the inflow of daylight. This could offer versatility to various needs that engage us with the natural and the man-made environment while offering a natural health promoting solution. That improves living conditions that enhance residents' health and wellbeing by using restorative environmental design principles.

9. HYPOTHESIS

Various hypotheses were evaluated from different angles where the research could be approached, such as…

"If the orientation of the rooms in a domestic dwelling is placed according to the Daily Sun's path, then the light quality will be appropriate and dynamic to the room's intended use."

Or

"If we allow the inflow of daylight into the domestic dwelling, then we could benefit the dweller's wellbeing."

However, the hypothesis needed to tie up all the edges that gave shape to this thesis…

"If the emotional responses are linked to the inflow of daylight in the domestic dwelling, then these emotional responses can be used to mitigate the harmful effects of the pandemic, enhancing and strengthening the mental health and wellbeing of its habitants."

This hypothesis is a development starting from the idea that the appropriate arrangement of the spaces in the domestic dwelling according to the Sun's transition and integration of biophilic design daylighting can enhance and strengthen its habitants' mental health and wellbeing.

TESTING

A. METHODOLOGY

The test has been developed into two phases. In the first part, the subject will be exposed to a few 3D animation videos of the same room, but with a different treatment on the ceiling; this will allow a variation in the inflow of daylight. While this is happening, the subject's electrical brain activity will be recorded using EEG. After showing the videos, the EEG will be taken off, indicating the end of the first phase of the test.

The second phase of the test consists of a survey, where the subject will be presented with an image of the different scenarios previously shown in the videos of the first phase. On each image, the subject will have to choose from a list of what emotion they relate to the most when seeing that specific image.

By analyzing the data collected, it will be possible to relate the emotion triggered by the first phase's brain activity to those selected in the second part of the test. After collecting and comparing the data, it is expected that it will be possible to select the necessary emotion that could soothe and boost the wellbeing of a domestic dwelling.

B. TEST PROCEDURE

The test will be conducted in a low-light room to enhance the immersive experience and avoid external distractions. In this room, the subject will perform a test with an electroencephalogram (EEG); the model used will be a Unicorn Brain Interface Hybrid Black. This technology consumer grade biosignal amplifier kit allows the collection of data on a computer for non-medical applications by performing a diagnostic test that uses electrodes placed over the scalp to record the electrical activity of neurons in the cerebral cortex. The subject will be stimulated by exposing them to a projection of simple room videos where they will experience a time-lapse of the movement of the daylight, shadows, reflection, refractions and the changeability of the light quality and dynamism throughout a day.

The videos consist of 15 seconds of a 3D animation of 6 different scenarios of the same room. The sequences are divided into three different categories that allow the inflow of daylight into the room. *Diffuse, Direct and Filtered*; each category contains two different proposals. *Fig. 11*

DIFFUSED LIGHT

LOUVERS
https://api2.enscape3d.com/v3/view/d7e7ea39-7aa8-4169-8563-124b9240f26c

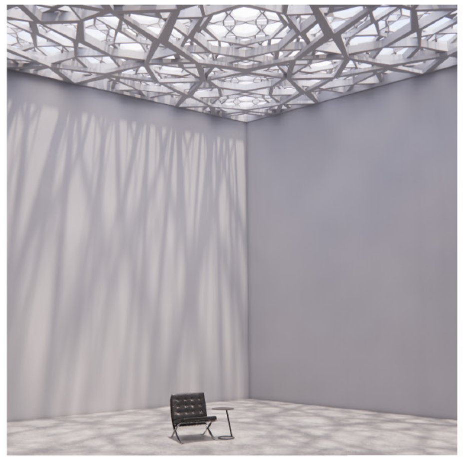
HOLES
https://api2.enscape3d.com/v3/view/b5faafe8-eee2-4523-bdbc-f93bfa2fff26

DIRECT LIGHT

SQUARES
https://api2.enscape3d.com/v3/view/d276435a-a487-46d4-a434-7cd6f2968b7a

OCULUS
https://api2.enscape3d.com/v3/view/25e2237f-73be-44de-a830-27b4d80c7176

FILTERED LIGHT



ABU Dhabi
https://api2.enscape3d.com/v3/view/f11d0452-0fc5-48d2-9f9b-c4c2e9aae9f5

Tree Line
https://api2.enscape3d.com/v3/view/7a841ac1-16d7-45a8-8f39-fb449c594663

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Fig. 11. Test scenarios

The first 5 seconds of the video will consist of a black screen with a small white cross in the centre, followed by a 15-second video; this is to be more precise with the measurements when the scene pops out. It is worth mentioning that these six videos will be shown to the participants in a random order to offset any bias possibilities and be able to find patterns in the data collected.

The second part of the test (behavioural/ subjective) is like the first phase. However, the EEG will not be used since the participants will have to answer a survey, in which they will be presented with an image of each of the scenarios. The participants will have some time to see the image and be presented with a list of different human emotions afterwards. They will have to select the emotion evoked according to each image presented.
The emotions shown are sorted from the eight basic emotions from the first level of Plutchik's wheel of emotions (Plutchik, 1988).

By analyzing this data collected, it will be possible to relate the emotional response trigged in the brain activity with the selected in the second phase of the test.

C. PROCEDURE OF DATA COLLECTION

To properly compare the data from the EEG test and the behavioural/ subjective test, it is necessary to create a common language so we can analyze data that make sense. The first step is to work with the behavioural/ subjective test. Each of the emotions listed on the survey will be categorized into two different groups; positive emotions (+) and negative emotions (-). *Fig. 12.*

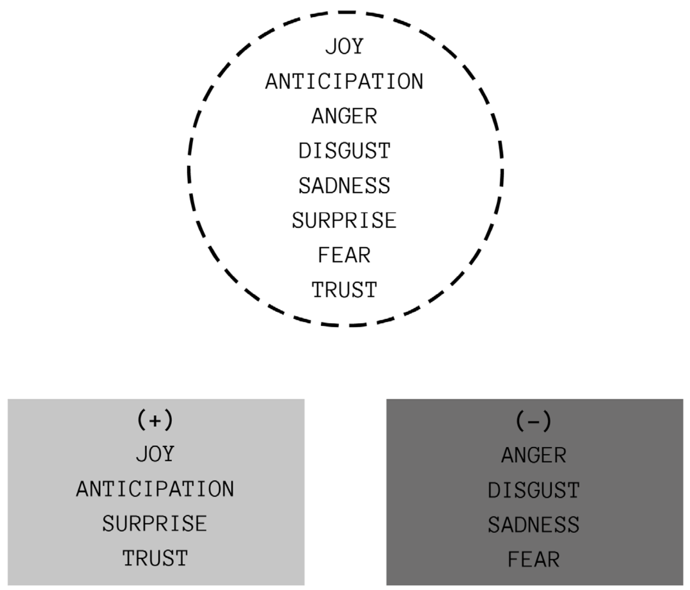

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Fig. 12. Filtering Emotions

The following step will consist of analyzing the behavioural/ subjective test responses to determine the percentage of + and – emotions in each of the scenarios; Afterwards, the scenarios are going to be divided into the three categories *Diffuse, Direct and Filtered,* allowing the possibility to see the + and – emotions percentage of each category.

Timestamp		Participant #	ANSWER		ANSWER		ANSWER		ANSWER		ANSWER		ANSWER	
5/14/2022 16:23:15		P1	Fear	B	Disgust	B	Trust	A	Joy	A	Anticipation	A	Joy	A
5/14/2022 18:14:21		P2	Anticipation	A	Anticipation	A	Anticipation	A	Surprise	A	Trust	A	Joy	A
5/16/2022 12:17:51		P3	Boredom	B	Surprise	A	Joy	A	Anticipation	A	Surprise	A	Fear	B
5/16/2022 13:03:23		P4	Boredom	B	Surprise	A	Joy	A	Surprise	A	Trust	A	Surprise	A
5/16/2022 17:04:22		P5	Trust	A	Disgust	B	Surprise	A	Joy	A	Disgust	B	Joy	A
5/16/2022 17:18:16		P6	Calmnees, relax	A	Fun	A	Sadness	B	Anger	B	Sadness	B	Trust	A
5/16/2022 17:30:36		P7	Trust	A	Joy	A	Surprise	A	Surprise	A	Anticipation	A	Surprise	A
5/16/2022 17:43:11		P8	Serenity	A	Disgust	B	Disgust	B	Joy	A	Disgust	B	Joy	A
5/16/2022 17:55:44		P9	Boredom	B	Joy	A	Joy	A	Surprise	A	Serenity	A	Surprise	A
Category			Diffuse		Diffuse		Direct		Filtered		Direct		Filtered	
Name			Louvers		Holes		Squeres		Tree lines		Oculus		Abu Dhabi	
Positive	/	A		5		6		7		8		6		8
Negative	/	B		4		3		2		1		3		1

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Table 1. Subjective test answers: emotions

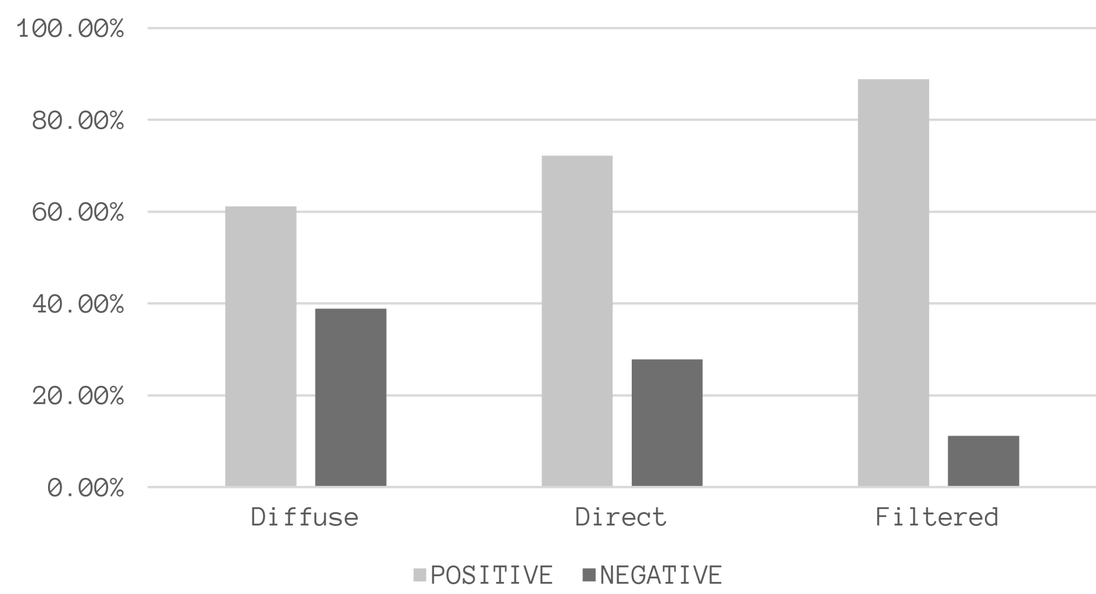

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Table 2. Positive and Negative responses by category

From the EEG recordings, the average of each of the seven frequency bands will be extracted (Delta, Theta, Alpha, Beta Low, Beta Medium, Beta High, and Gamma) for each video (6) and each participant (9). In this way, it will be possible to graphically sort out the percentage of the frequency bands recurrent in each of them. The following step in this analysis will be to average out the videos. Table 3 is an overall view of the average data of the frequency bands produced by each category (for the individual data see appendix). The three different video categories will appear on the left side. The next column to the right shows the two videos that make up the category. Meanwhile, the top row shows the frequency band.

Having this information made it possible to average the result of each participant of every single frequency band and have one number for each. Making it possible to show the participants' emotional responses to each video graphically. In this way, a common language is made realizable to compare the EEG test with the behavioural/ subjective test. Allowing to compare the percentages of responses and allowing to find patterns. *Table 3. Grf. 2.*

ALL	Frequency bands AVG. in %						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	99.51%	71.70%	58.60%	44.00%	34.38%	50.61%	36.50%
Direct	92.13%	65.78%	55.42%	41.44%	29.97%	46.42%	34.38%
Filtered	95.76%	68.99%	57.22%	42.79%	30.86%	47.49%	35.12%

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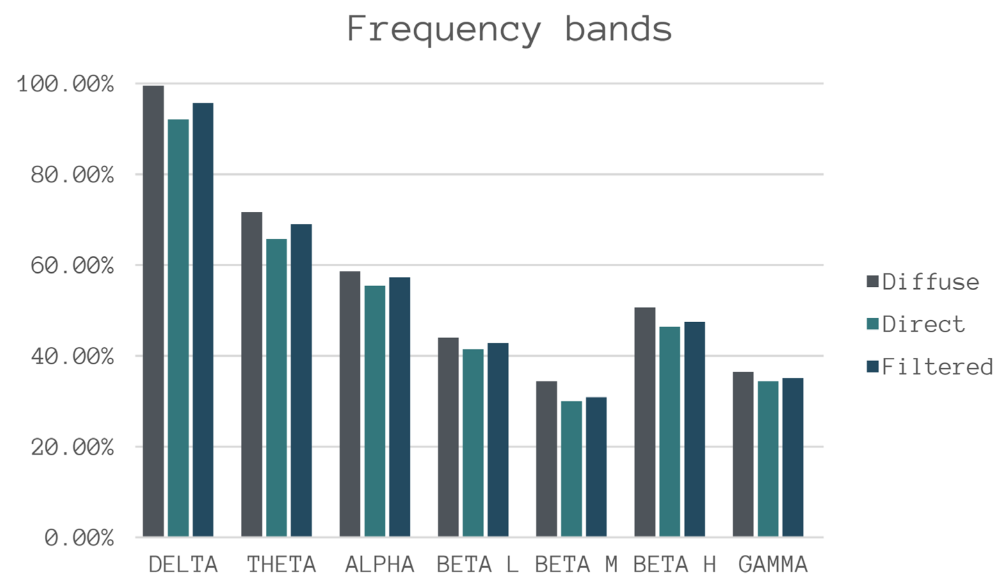
Table 3. Overall Frequency Band pct.



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Grf. 2. Overall Frequency Bands pct.

D. RESULTS AND OBSERVATIONS

When analyzing the behavioural/ subjective test results, it is clear the tendency of the participants to relate the six scenarios with positive emotions; the overall responses indicate 74% inclined toward the positive and 26% related to the negative. By using this information and allocating it to their corresponding category, the results look as fallowed: *Table 4.*

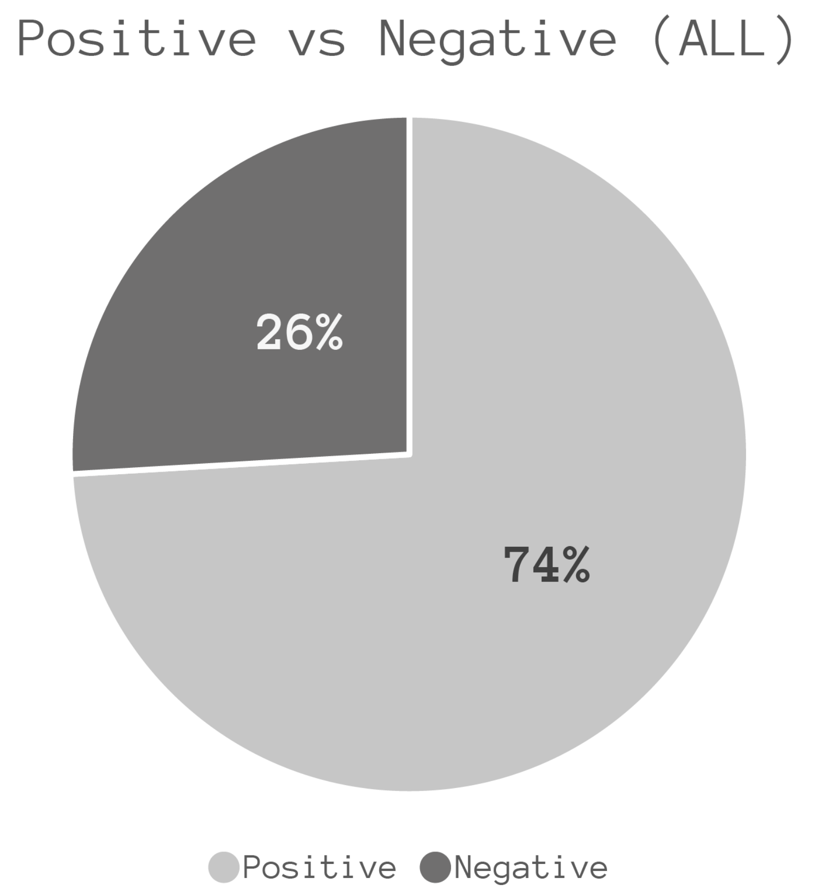

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Table 4. Overall Positive and Negative avg. pct.

By examining the Data is safe to say that the *Filtered light* had an outstanding impact on the subjects since from the 18 possible points available in each category, 88.89% were positive while 11.11% were negative. We could find "Joy" and "Surprise" among the participants' most recurrent emotions selected. The second ranked scenario was the *Directed light*, with 72.22% of the responses having been linked with positive emotion vs 27.78% with negative emotions. Associating it to the emotions "Joy" and "Trust." Lastly, the least ranked of the three was the *Diffuse light* category. It had a response of 61.11% in the positive emotions and 38.89% in the negative emotions meaning that the gap between the positive and negative emotions is very close. The two primary emotions indicated by the participants were "Boredom" and "Serenity".

Contrary to these results, the EEG test shows different data. The sum of all averages of each category ranked the *Diffuse light* scenarios to have the most positive responses, *Filtered light* scenarios in second and third the *Direct light* scenarios. The Diffuse light scenario has the overall preference, but each frequency band shows the highest percentage compared to the other categories. Another interesting observation is that Delta has the highest percentages, followed by Theta, Alpha, Beta low, Beta high, Gamma and Beta medium, respectively, in that order. *Table 5.*

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ALL	Frequency bands AVG.						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	51746.01	37285.71	30474.12	22878.64	17879.3	26314.89	18979.77
Direct	47906.71	34205.33	28819.33	21550.83	15584.68	24137.37	17878.65
Filtered	49795.74	35873.39	29755.03	22252.73	16046.11	24695.77	18264.2

Table 5. Categories agv. responses sum

The author of this thesis is aware of the limitations of the test since to accurate trigger brain responses is necessary to expose the subject to real-life daylight conditions. Under this logic, the original test was designed to be the most immersive experience possible while performing it; this was going to be achieved by the use of Virtual Reality (VR), creating 3D videos that were not only the participant were allowed to move freely in this virtual reality but to experience the dynamism and interaction of the daylight within the virtual world. Unfortunately, a series of challenges were presented; of course, the complexity and the time available play a crucial role in the decision to use another approach to the test. However, enhancing the feeling and getting the subject closer to the real-world conditions were still the primary concern of the performance of the test, so to expose the subject to an immersive experience, the experiment used a projection in a dark room to avoid external distractions. At the same time, the EEG monitored them and recorded their brain waves.

RECOMMENDATIONS

As has been discussed throughout the paper, the way the inflow of light gets into the indoor environment has a major impact on the way we feel and perceive the space. The Data positively suggest that small exposure to a changing environment can generate a response in the brain activity. Each frequency band is associated with different states of the mind that can enhance certain conditions and be linked to positive emotions. This is vital to comprehend so that the domestic dwelling can be designed to accommodate various light intakes thought the day.

The ability of our brain to become flexible and transitional among multiple brain wave frequencies has a significant impact on our ability to manage stress, focus on tasks, and obtain a good night's sleep. However, being exposed to only one condition or not at all is not the solution since focusing on one frequency band could trigger too much or too few brain waves; It can cause health problems if one of the frequency waves is either overproduced or underproduced in our brain. It is critical to recognize that no particular brain wave is "better" or "ideal" than the others; a mixed generation of frequency bands can substantially alleviate the mind. Based on the research and test results, design recommendations for health-promoting housing in a post-pandemic could be introduced. Dwelling design must prioritize the following to create living settings that support people's health and wellness.

Spatial flexibility: Window views could be accomplished by providing unobstructed sky views and natural surroundings through vertical and horizontal windows. Multiple windows from different directions provide the dwelling with the necessary flexibility to allow different qualities of the daylight to enter from different directions at different times of the day; thereby improving wellbeing, physiological calmness, improved focus, elevating mood, assisting in the recovery from mental or physical disorders, and increasing resident satisfaction.

Residential versatility: Home layouts could be changed to accommodate and adapt to the increasing role of the home as a multi-functional area for learning, working, exercising, cooking, resting, and socializing.

Retroactive design: Filtered, diffuse and direct inflow of light setups that adapt to the necessity of the activity of the dwellers and boost human circadian clock regulation. Designing with the sun path: Use daylight as the primary illumination source in all the rooms occupied during the daytime. Allowing the right daylight quality to get into different spaces when needed is a passive design strategy.

10

10. DISCUSSION AND FUTURE WORKS

This research acts as a starting point to further develop recommendations and hopefully concrete design solutions; there has indeed been a glance at some design solutions at some level. The test presented fascinating data that opened the opportunity for further testing, such as recreating the same test but with the original idea of using VR and making the video length bigger so the subject could experience the dynamism of the time at a slower pace. Comparing those results with the ones obtained in this master thesis could be very beneficial to start designing scalable solutions that could be implemented in the domestic dwelling context.

Human emotional responses are incredibly complex, and the need for more profound attention should be considered. As seen in the test, a minimal variation is just enough to trigger an emotional response, which makes it more important to be aware of this to limit the emotional responses and correctly target the ones needed to offset post-pandemic disorders and dweller's needs.

11. CONCLUSION

Residential design and daylight requirements have already begun to adapt to post COVID-19. It is expected that these changes will have an increasing impact on our homes and how we live.

The remedy to our growing detachment from nature is daylight. Different and shifting materials and atmospheric effects treated by different inflows of daylight can stimulate our senses and help us better understand and relate to our surroundings and the seasonal and atmospheric conditions of every day.

Including multiple openings in the domestic dwelling for morning and evening sunlight arguably adds a higher quality to the indoor space, rather than the ones that only receive direct sunlight at a specific time of the day from a limited location.

As designers, we can build places with solutions that impact the human body and impact the dweller's life. The environments in which we live and interact daily profoundly affect our health and wellbeing.

A healthy building is designed, built, and maintained to improve the users' health, happiness, needs, and productivity.

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13

13. TABLE OF FIGURES

All the images of the covers of the chapters come from www.pexels.com

14. APPENDIX

70 BIOPHILIC DESIGN ATTRIBUTES

"fractals," and these patterns are found in some of our most successful buildings and landscapes. These structures frequently include repeated but varying patterns of a basic design, such as ornamentation in parallel or closely linked rows that differ slightly from one another.

14. *Hierarchically organized ratios and scales.* Successful natural and built forms often occur in hierarchically connected ways, sometimes arithmetically or geometrically related. This thematic congruence can facilitate the assimilation of highly complex patterns that otherwise might be experienced as overwhelmingly detailed or even chaotic. Arithmetic and geometric expressions of this tendency in both natural and built settings include the golden proportion and the Fibonacci ratio (Portoghesi 2000).

Light and Space

A fourth biophilic design element is *light and space.* Twelve design attributes of this element follow, seven focusing on qualities of light and five focusing on spatial relationships:

1. *Natural light.* This attribute includes the effects of daylighting as previously described, as well as inclusion of the full color spectrum of natural light. Chapters by Loftness and Frumkin note studies showing that natural light is both physically and psychologically rewarding to people, frequently contributing to their health, productivity, and well-being in the built environment.
2. *Filtered and diffused light.* The benefits of natural light are often enhanced by modulating daylight, particularly by mitigating the effects of glare. Filtered or diffused sunlight can also stimulate observation and feelings of connection by providing a variable and mediated connection between spaces, particularly inside and outside areas such as described in the chapter by Bloomer.
3. *Light and shadow.* The complementary contrast of light and dark spaces can produce significant satisfaction in both buildings and landscapes. The creative manipulation of light and shadow can foster curiosity mystery, and stimulation. This attribute likely evolutionarily enhanced human movement and the ability to discern objects over long distances, particularly from a protected refuge.
4. *Reflected light.* Lighting designs are frequently enhanced by light reflecting off surfaces such as light-colored walls, ceilings, and reflective bodies like water. Functional benefits include mitigation of glare, enhanced penetration of light into interior spaces, and spying resources at a distance.
5. *Light pools.* People are often drawn into and through interior spaces by the presence of pools of connected light. Light pools can assist movement and way-finding by providing lighted patches across shadowed or obscured areas such as a forest or darkened halls and passageways. Light pools can also foster feelings of security and protection, such as a lighted hearth.
6. *Warm light.* The perception of warmly lit areas, often islands of modulated sunlight surrounded by darker spaces, can enhance the feeling of a nested, secure, and inviting interior.
7. *Light as shape and form*. The manipulation of natural light can create stimulating, dynamic, and sculptural forms. Beyond the aesthetic pleasure, these shapes facilitate mobility, curiosity, imagination, exploration, and discovery.
8. *Spaciousness.* People prefer feelings of openness in natural and built environments, especially when it occurs in complementary relation to sheltered protected refuges at the surrounding edges. Effective designs often include spacious settings in close alliance with smaller spaces, which in contemporary architecture can often be encountered in airports, train stations, and some commercial and educational buildings.
9. *Spatial variability.* Spatial variability fosters emotional and intellectual stimulation. Spatial diversity is often most effective when in complementary relation to organized and united spaces.
10. *Space as shape and form.* Space can be creatively manipulated to convey shapes and forms. This effect can add beauty to the built environment, which stimulates interest, curiosity, exploration, and discovery.
11. *Spatial harmony.* The manipulation of space in the built environment tends to be most effective when it blends light, mass, and scale within a bounded context. This achievement evokes a sense of harmony, which fosters a sense of security and facilitates movement within diverse settings.
12. *Inside-outside spaces.* Appealing interior spaces in the built environment often appear connected to the outside environment. These areas also mark the transition of nature with culture. Important design forms in the built environment that evoke this quality include colonnades, porches, foyers, atriums, and interior gardens.

Place-Based Relationships

A fifth biophilic design element is *place-based relationships.* This element refers to the successful marriage of culture with ecology in a geographical context. The connection of people to places reflects an inherent human need to establish territorial control, which during the long course of our species' evolution facilitated control over resources, attaining safety, and achieving security. Locational familiarity—the yearning for home—remains a deeply held need for most people. Eleven attributes of place-based relationships are described, the last (placelessness) being the antithesis of the others rather than a stand-alone attribute.

1. *Geographic connection to place.* Secure feelings of connection to the geography of an area often foster feelings of familiarity and predictability. This can be achieved by emphasizing prominent geological features associated with the siting, orientation, and views of buildings and landscapes.
2. *Historic connection to place.* Meaningful relation to place often marks the passage of time, which fosters a sense of participation and awareness of an area's culture and collective memory. Buildings and landscapes that elicit this continuity with the past encourage the belief that the present and future are meaningfully linked to the history of a place.
3. *Ecological connection to place.* Places are sustained by an affirmative connection to ecology, particularly prominent ecosystems such as watersheds and dominant biogeographical

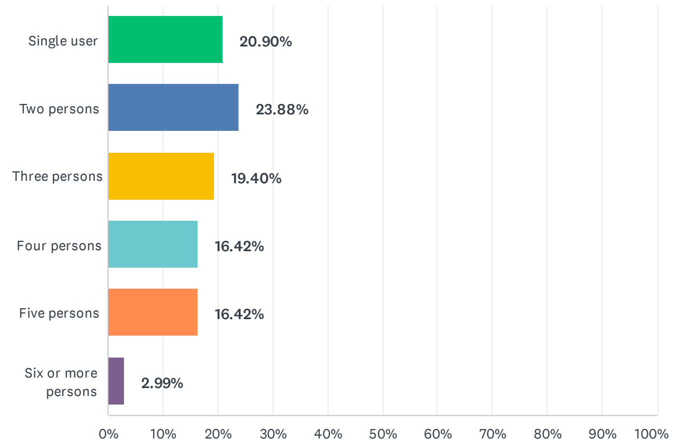
TABLE 1-1 Elements and Attributes of Biophilic Design

Environmental features	Natural shapes and forms	Natural patterns and processes
Color	Botanical motifs	Sensory variability
Water	Tree and columnar supports	Information richness
Air	Animal (mainly vertebrate) motifs	Age, change, and the patina of time
Sunlight	Shells and spirals	Growth and efflorescence
Plants	Egg, oval, and tubular forms	Central focal point
Animals	Arches, vaults, domes	Patterned wholes
Natural materials	Shapes resisting straight lines and right angles	Bounded spaces
Views and vistas	Simulation of natural features	Transitional spaces
Façade greening	Biomorphy	Linked series and chains
Geology and landscape	Geomorphology	Integration of parts to wholes
Habitats and ecosystems	Biomimicry	Complementary contrasts
Fire		Dynamic balance and tension
		Fractals
		Hierarchically organized ratios and scales
Light and space	**Place-based relationships**	**Evolved human-nature relationships**
Natural light	Geographic connection to place	Prospect and refuge
Filtered and diffused light	Historic connection to place	Order and complexity
Light and shadow	Ecological connection to place	Curiosity and enticement
Reflected light	Cultural connection to place	Change and metamorphosis
Light pools	Indigenous materials	Security and protection
Warm light	Landscape orientation	Mastery and control
Light as shape and form	Landscape features that define building form	Affection and attachment
Spaciousness	Landscape ecology	Attraction and beauty
Spatial variability	Integration of culture and ecology	Exploration and discovery
Space as shape and form	Spirit of place	Information and cognition
Spatial harmony	Avoiding placelessness	Fear and awe
Inside-outside spaces		Reverence and spirituality

Kellert, S., & Wilson, E. (1993). The biophilia Hypothesis. Island Press/Shearwater Books.

Q1 How many people currently live in your household?

Answered: 67 Skipped: 0



ANSWER CHOICES	RESPONSES	
Single user (1)	20.90%	14
Two persons (2)	23.88%	16
Three persons (3)	19.40%	13
Four persons (4)	16.42%	11
Five persons (5)	16.42%	11
Six or more persons (6)	2.99%	2
TOTAL		67

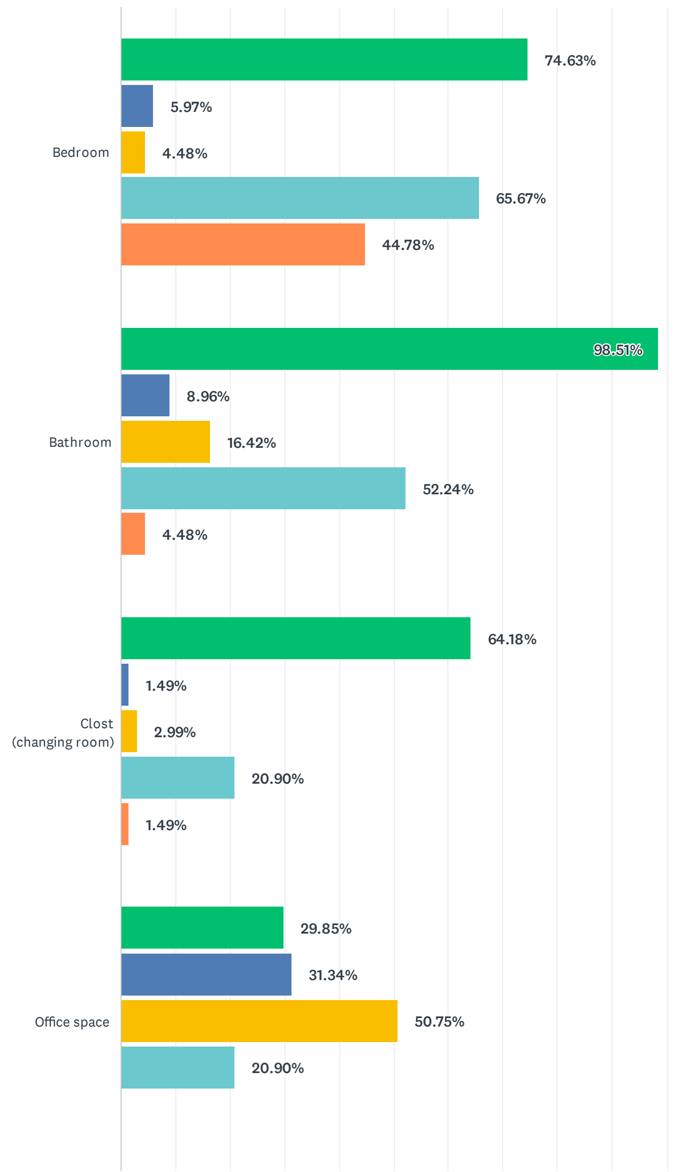
BASIC STATISTICS				
Minimum	Maximum	Median	Mean	Standard Deviation
1.00	6.00	3.00	2.93	1.47

PERIODS OF SPACES OCCUPATION
IN THE DOMESTIC DWELLING

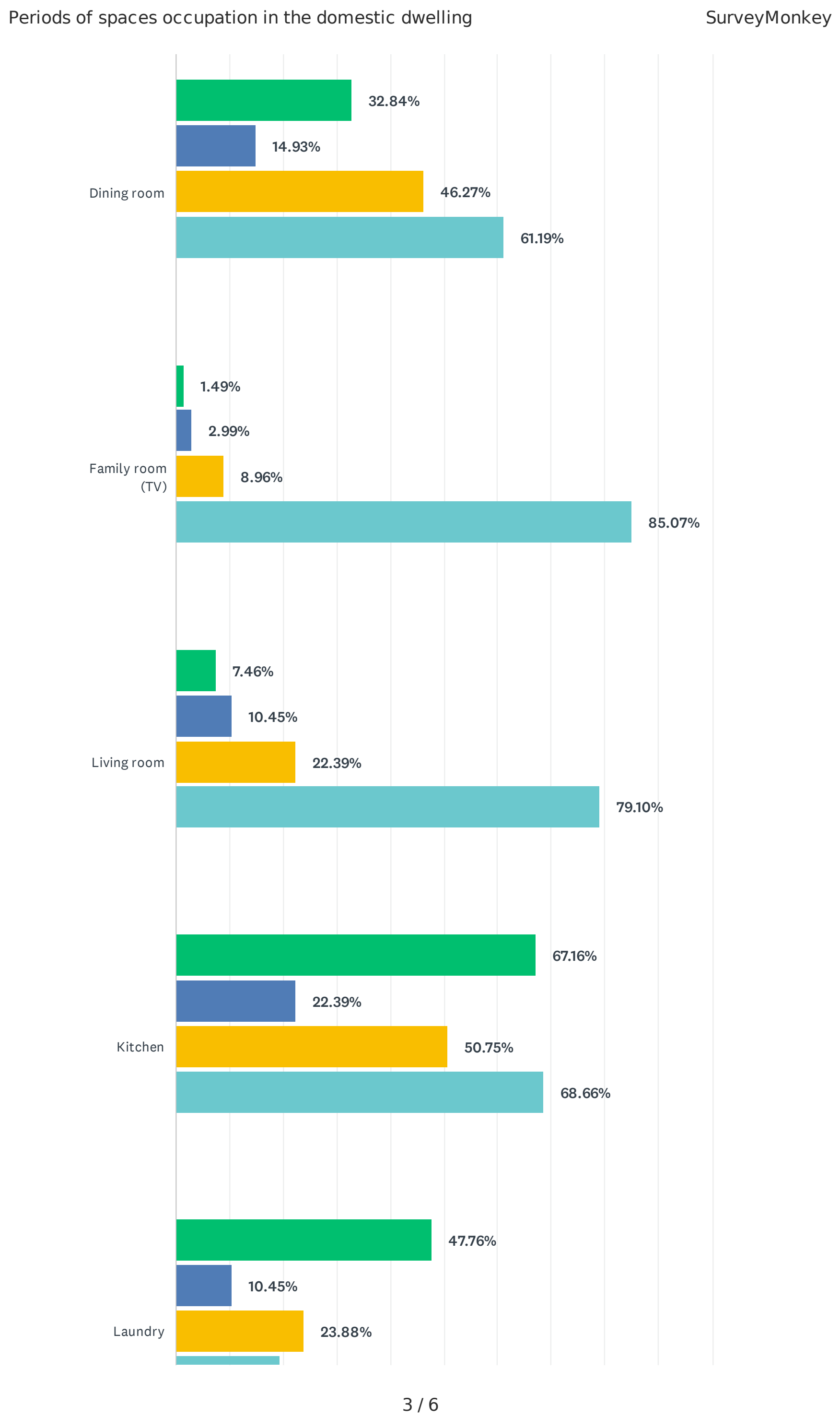
Periods of spaces occupation in the domestic dwelling SurveyMonkey

Q2 In what period of the day are you most likely to occupy the following spaces in your home?

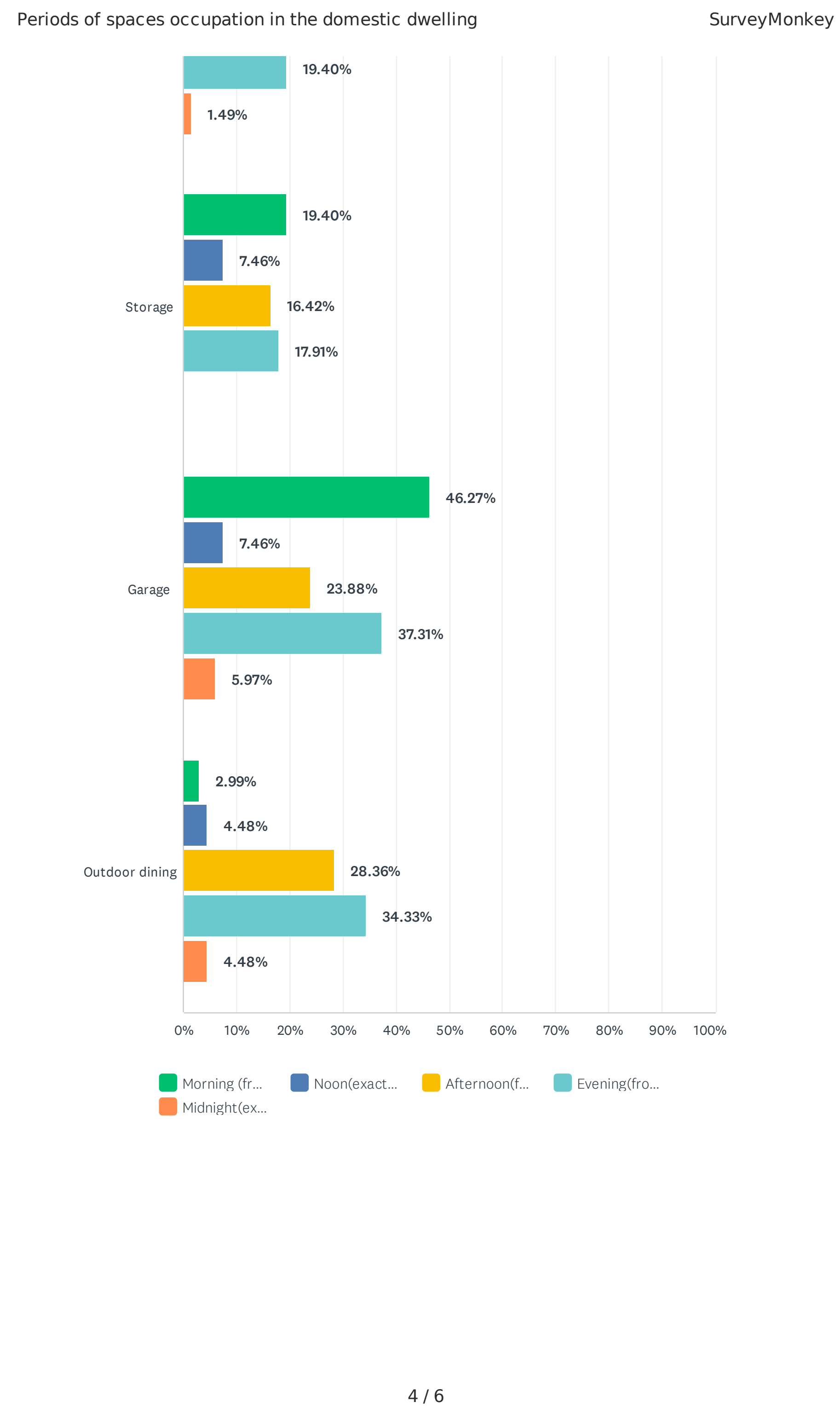
Answered: 67 Skipped: 0



PERIODS OF SPACES OCCUPATION IN THE DOMESTIC DWELLING



PERIODS OF SPACES OCCUPATION IN THE DOMESTIC DWELLING



PERIODS OF SPACES OCCUPATION IN THE DOMESTIC DWELLING

Periods of spaces occupation in the domestic dwelling — SurveyMonkey

	MORNING (FROM 12:01 AM TO 11:59 AM)	NOON(EXACTLY 12:00 PM)	AFTERNOON(FROM 12:01 PM TO 6:00 PM)	EVENING(FROM 6:00 PM TO 11:59 PM)	MIDNIGHT(EXACTLY 12:00 AM)	TOTAL RESPONDENTS
Bedroom	74.63% 50	5.97% 4	4.48% 3	65.67% 44	44.78% 30	67
Bathroom	98.51% 66	8.96% 6	16.42% 11	52.24% 35	4.48% 3	67
Clost (changing room)	64.18% 43	1.49% 1	2.99% 2	20.90% 14	1.49% 1	67
Office space	29.85% 20	31.34% 21	50.75% 34	20.90% 14	0.00% 0	67
Dining room	32.84% 22	14.93% 10	46.27% 31	61.19% 41	0.00% 0	67
Family room (TV)	1.49% 1	2.99% 2	8.96% 6	85.07% 57	0.00% 0	67
Living room	7.46% 5	10.45% 7	22.39% 15	79.10% 53	0.00% 0	67
Kitchen	67.16% 45	22.39% 15	50.75% 34	68.66% 46	0.00% 0	67
Laundry	47.76% 32	10.45% 7	23.88% 16	19.40% 13	1.49% 1	67
Storage	19.40% 13	7.46% 5	16.42% 11	17.91% 12	0.00% 0	67
Garage	46.27% 31	7.46% 5	23.88% 16	37.31% 25	5.97% 4	67
Outdoor dining	2.99% 2	4.48% 3	28.36% 19	34.33% 23	4.48% 3	67

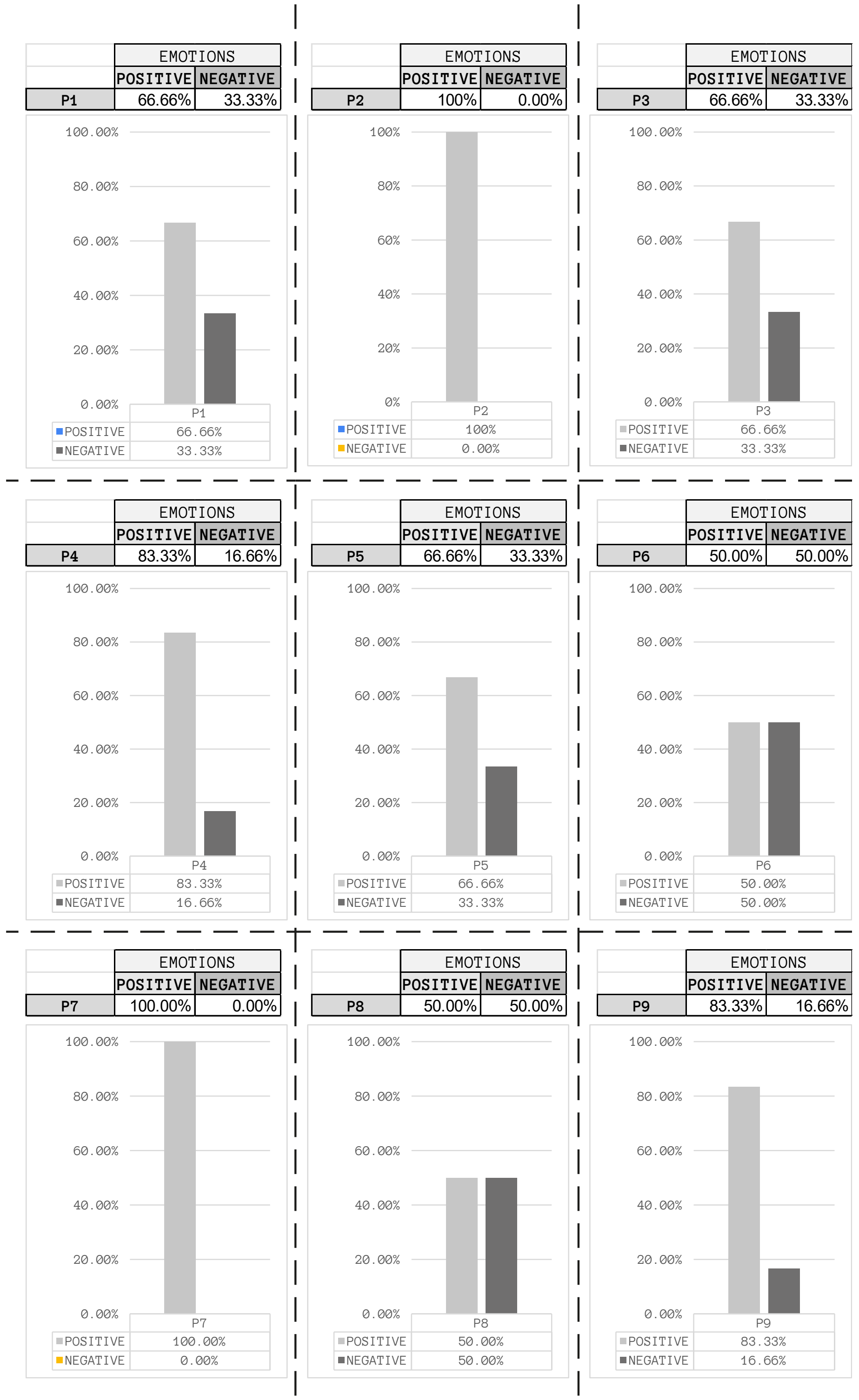
PERIODS OF SPACES OCCUPATION IN THE DOMESTIC DWELLING

Periods of spaces occupation in the domestic dwelling — SurveyMonkey

BASIC STATISTICS

	MINIMUM	MAXIMUM	MEDIAN	MEAN	STANDARD DEVIATION
Bedroom	1.00	5.00	4.00	3.00	1.68
Bathroom	1.00	5.00	1.00	2.20	1.41
Clost (changing room)	1.00	6.00	1.00	3.01	2.19
Office space	1.00	6.00	3.00	3.20	1.68
Dining room	1.00	6.00	3.00	3.07	1.35
Family room (TV)	1.00	6.00	4.00	4.07	0.88
Living room	1.00	6.00	4.00	3.60	1.05
Kitchen	1.00	4.00	3.00	2.58	1.24
Laundry	1.00	6.00	3.00	2.67	1.72
Storage	1.00	6.00	4.00	4.08	1.94
Garage	1.00	6.00	4.00	3.44	1.91
Outdoor dining	1.00	6.00	4.00	4.42	1.41

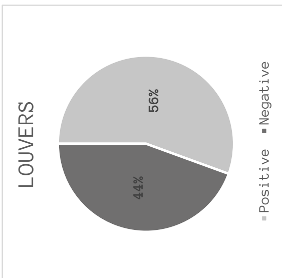
TEST RESULTS

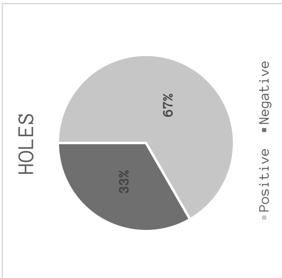


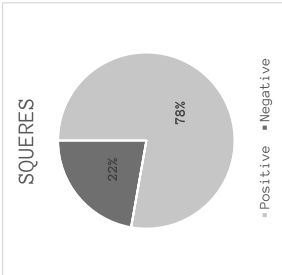
	Category	Setups		EMOTIONS POSITIVE	EMOTIONS NEGATIVE
ALL	Diffuse		Louvers	5	4
			Holes	6	3
	Direct		Squeres	7	2
			Oculus	6	3
	Filtered		Tree Lines	8	1
			Abu Dhabi	8	1

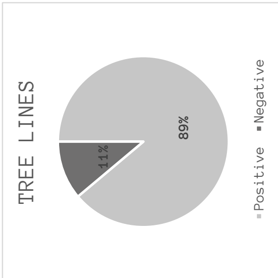
BEHAVIOURAL/ SUBJECTIVE
TEST RESULTS

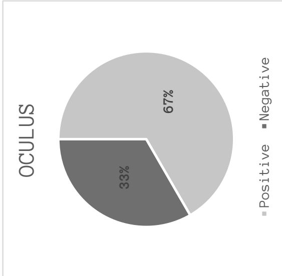
Timestamp	Participant #	ANSWER		ANSWER		ANSWER		ANSWER		ANSWER		ANSWER	
5/14/2022 16:23:15	P1	Fear	B	Disgust	B	Trust	A	Joy	A	Anticipation	A	Joy	A
5/14/2022 18:14:21	P2	Anticipation	A	Anticipation	A	Anticipation	A	Surprise	A	Trust	A	Joy	A
5/16/2022 12:17:51	P3	Boredom	B	Surprise	A	Joy	A	Anticipation	A	Surprise	A	Fear	B
5/16/2022 13:03:23	P4	Boredom	B	Surprise	A	Joy	A	Surprise	A	Trust	A	Surprise	A
5/16/2022 17:04:22	P5	Trust	A	Disgust	B	Surprise	A	Joy	A	Disgust	B	Joy	A
5/16/2022 17:18:16	P6	Calmnees, relax	A	Fun	A	Sadness	B	Anger	B	Sadness	B	Trust	A
5/16/2022 17:30:36	P7	Trust	A	Joy	A	Surprise	A	Surprise	A	Anticipation	A	Surprise	A
5/16/2022 17:43:11	P8	Serenity	A	Disgust	B	Disgust	B	Joy	A	Disgust	B	Joy	A
5/16/2022 17:55:44	P9	Boredom	B	Joy	A	Joy	A	Surprise	A	Serenity	A	Surprise	A
Category		Diffuse		Diffuse		Direct		Filtered		Direct		Filtered	
Name		Louvers		Holes		Squeres		Tree lines		Oculus		Abu Dhabi	
Positive	/ A		5		6		7		8		6		8
Negative	/ B		4		3		2		1		3		1

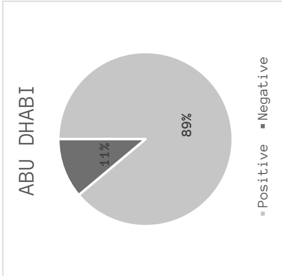








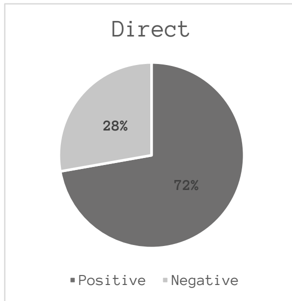


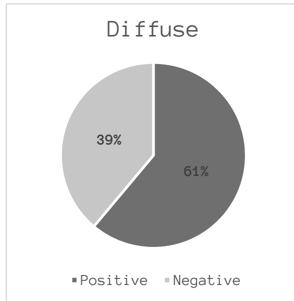


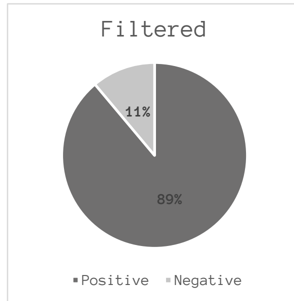
BEHAVIOURAL/ SUBJECTIVE
TEST RESULTS

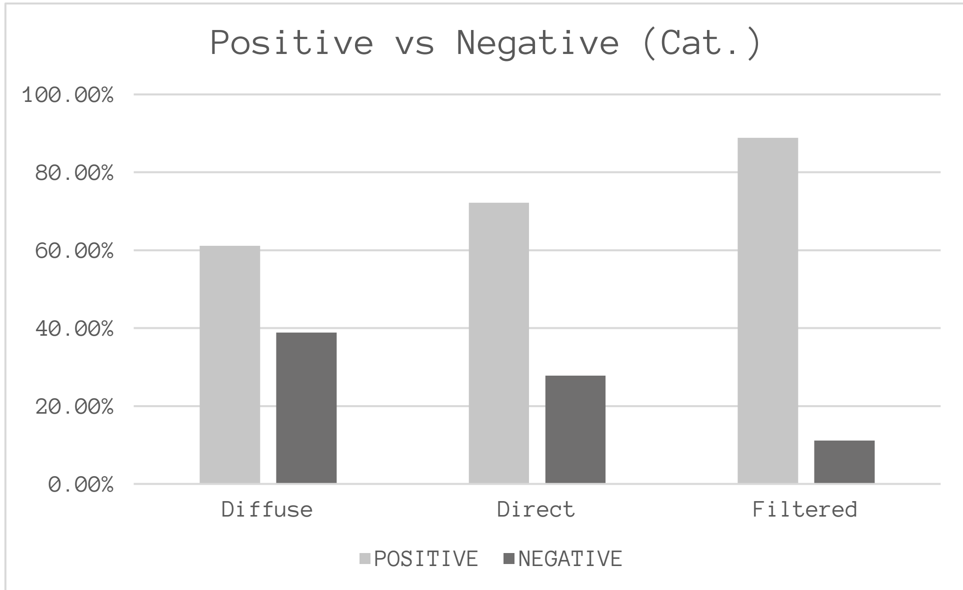
	Category			Total
	Diffuse	Direct	Filtered	
Positive	11	13	16	40
Negative	7	5	2	14

	EMOTIONS	
	POSITIVE	NEGATIVE
Diffuse	61.11%	38.89%
Direct	72.22%	27.78%
Filtered	88.89%	11.11%







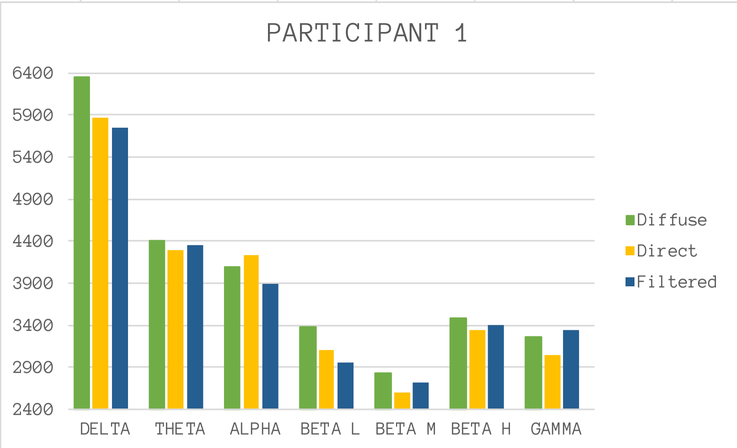


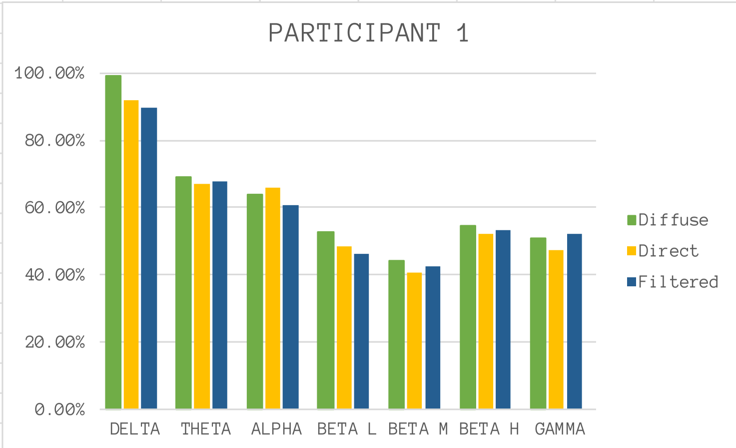
#01

EEG TEST RESULTS PARTICIPANT

	Frequency bands AVG.						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	6350.814	4407.952	4094.515	3382.459	2832.375	3483.736	3264.306
Direct	5869.406	4292.162	4226.772	3102.49	2596.591	3346.403	3039.877
Filtered	5746.296	4345.939	3895.578	2964.085	2725.228	3408.723	3335.978

	Frequency bands AVG. in %						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	**99.23%**	**68.87%**	63.98%	**52.85%**	**44.26%**	**54.43%**	51.00%
Direct	91.71%	67.07%	**66.04%**	48.48%	40.57%	52.29%	47.50%
Filtered	89.79%	67.91%	60.87%	46.31%	42.58%	53.26%	**52.12%**



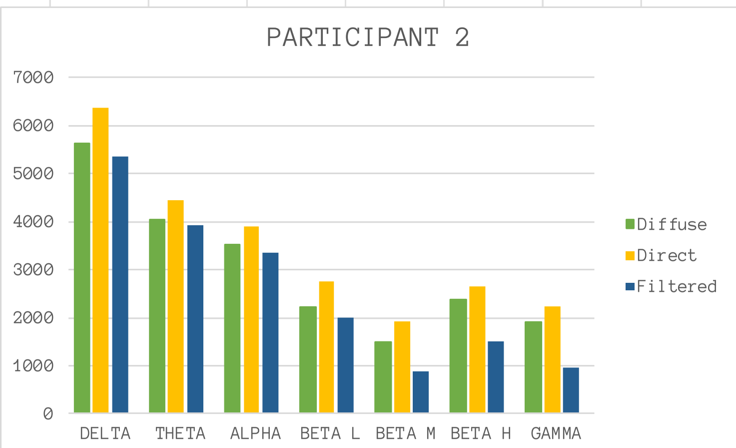


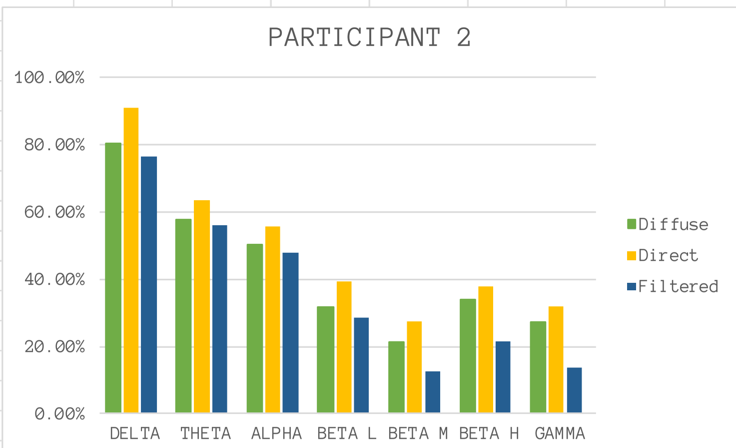
#02

EEG TEST RESULTS PARTICIPANT

	Frequency bands AVG.						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	5624.847	4037.458	3509.367	2234.64	1498.552	2376.773	1916.312
Direct	6365.023	4457.132	3891.693	2766.684	1931.444	2644.27	2235.504
Filtered	5355.684	3935.22	3344.771	1999.199	882.526	1499.683	959.111

	Frequency bands AVG.						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	80.35%	57.68%	50.13%	31.92%	21.41%	33.95%	27.38%
Direct	**90.93%**	**63.67%**	**55.60%**	**39.52%**	**27.59%**	**37.78%**	**31.94%**
Filtered	76.51%	56.22%	47.78%	28.56%	12.61%	21.42%	13.70%



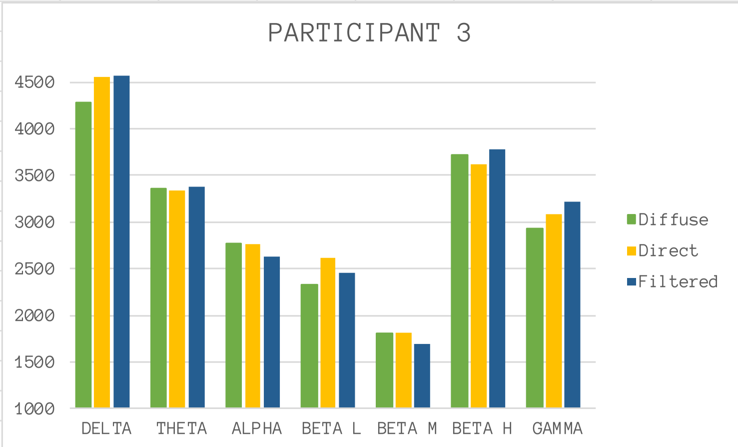


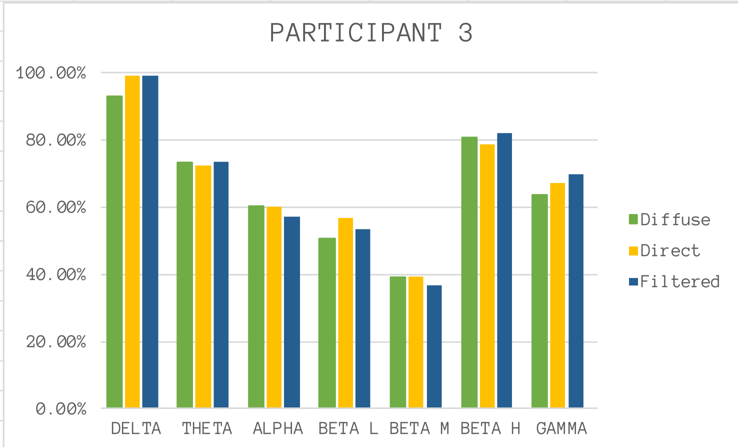
#03

EEG TEST RESULTS
PARTICIPANT

	Frequency bands AVG.						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	4277.087	3364.676	2776.769	2334.845	1808.403	3716.637	2929.532
Direct	4553.535	3335.209	2767.236	2614.119	1809.162	3617.836	3084.253
Filtered	4564.04	3383.184	2632.665	2452.577	1690.593	3774.903	3217.345

	Frequency bands AVG. in %						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	92.98%	73.15%	**60.36%**	50.76%	39.31%	80.80%	63.69%
Direct	98.99%	72.50%	60.16%	**56.83%**	**39.33%**	78.65%	67.05%
Filtered	**99.22%**	**73.55%**	57.23%	53.32%	36.75%	**82.06%**	**69.94%**



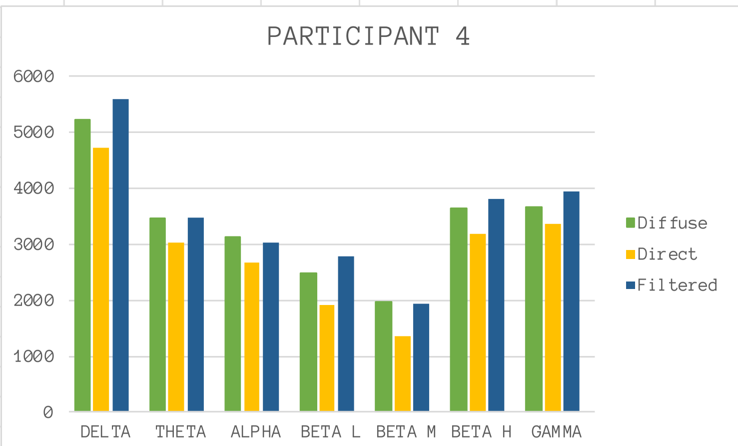


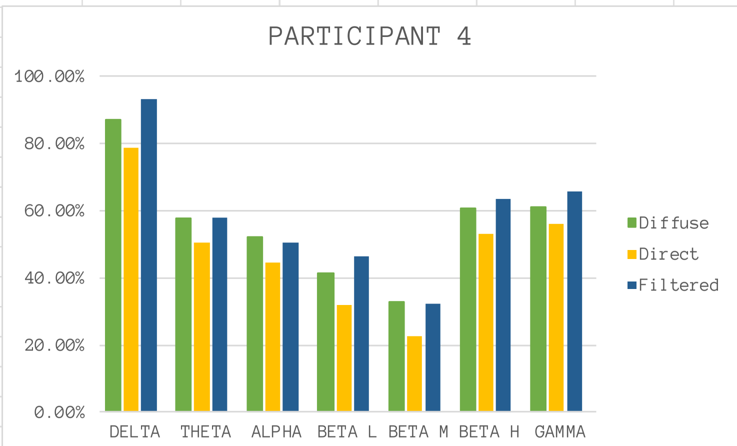
#04

EEG TEST RESULTS
PARTICIPANT

	Frequency bands AVG.						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	5226.685	3469.846	3125.86	2483.71	1976.528	3644.896	3663.595
Direct	4712.454	3035.123	2680.027	1923.418	1358.198	3194.841	3374.006
Filtered	5594.25	3477.859	3019.201	2784.653	1946.305	3803.183	3941.404

	Frequency bands AVG.						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	87.11%	57.83%	**52.10%**	41.40%	**32.94%**	60.75%	61.06%
Direct	78.54%	50.59%	44.67%	32.06%	22.64%	53.25%	56.23%
Filtered	**93.24%**	**57.96%**	50.32%	**46.41%**	32.44%	**63.39%**	**65.69%**



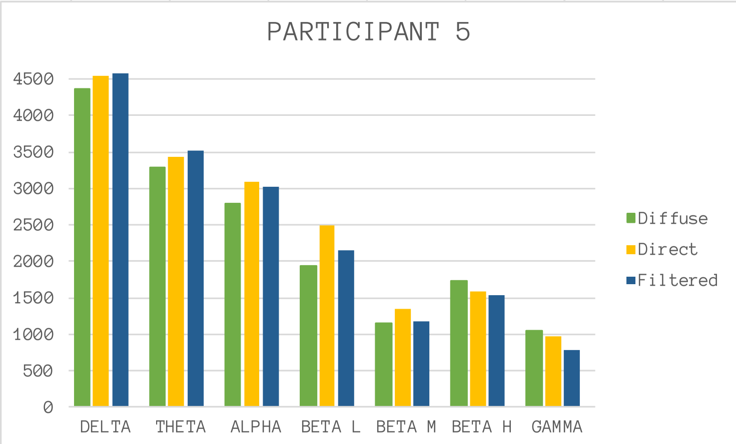


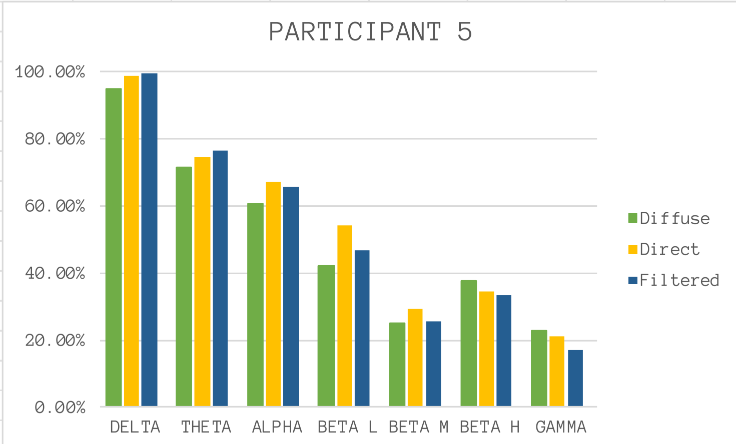
#05

EEG TEST RESULTS
PARTICIPANT

	Frequency bands AVG.						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	4369.004	3294.3	2798.352	1945.715	1155.086	1732.986	1053.997
Direct	4545.925	3429.077	3097.087	2485.59	1341.202	1584.813	969.7645
Filtered	4583.623	3523.524	3017.572	2148.448	1175.445	1531.776	777.5535

	Frequency bands AVG. IN %						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	94.98%	71.62%	60.83%	42.30%	25.11%	37.67%	22.91%
Direct	98.82%	74.55%	67.33%	54.03%	29.16%	34.45%	21.08%
Filtered	99.64%	76.60%	65.60%	46.71%	25.55%	33.30%	16.90%



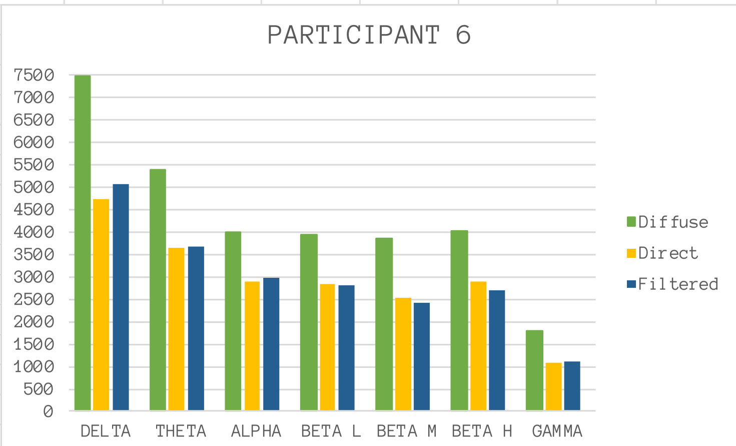


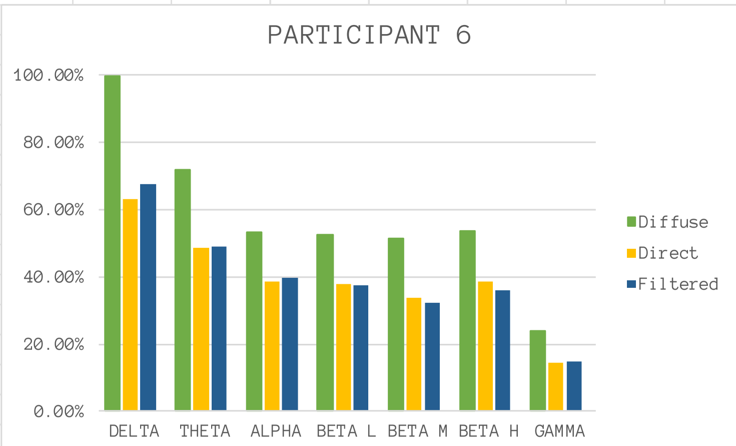
#06

EEG TEST RESULTS
PARTICIPANT

	Frequency bands AVG.						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	7474.459	5390.763	3982.743	3949.648	3843.683	4030.828	1801.989
Direct	4737.95	3653.323	2891.34	2828.258	2545.951	2888.084	1094.251
Filtered	5068.932	3684.323	2966.136	2815.923	2432.955	2712.809	1115.254

	Frequency bands AVG. IN %						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	99.66%	71.88%	53.10%	52.66%	51.25%	53.74%	24.03%
Direct	63.17%	48.71%	38.55%	37.71%	33.95%	38.51%	14.59%
Filtered	67.59%	49.12%	39.55%	37.55%	32.44%	36.17%	14.87%

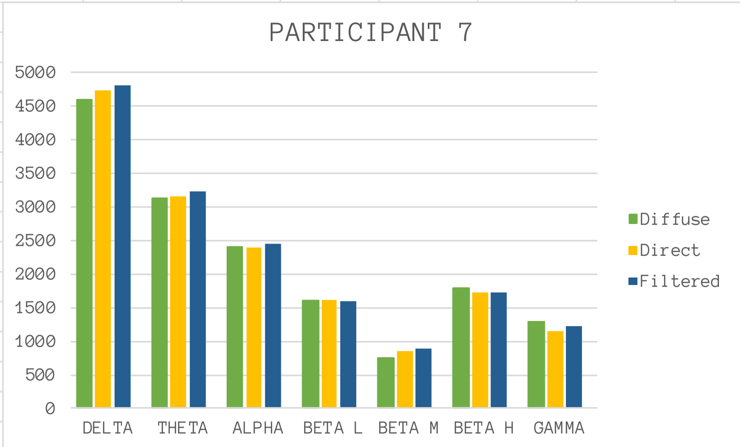


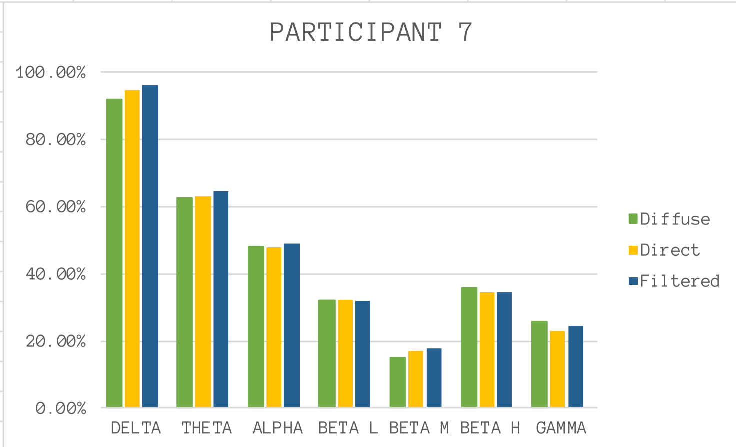


EEG TEST RESULTS PARTICIPANT #07

	Frequency bands AVG.						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	4585.646	3134.448	2409.859	1607.845	755.465	1787.039	1299.129
Direct	4731.19	3162.345	2396.378	1614.588	846.191	1729.407	1151.901
Filtered	4808.795	3223.687	2458.238	1604.632	888.813	1726.363	1219.652

	Frequency bands AVG.IN %						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	91.71%	62.69%	48.20%	32.16%	15.11%	35.74%	25.98%
Direct	94.62%	63.25%	47.93%	32.29%	16.92%	34.59%	23.04%
Filtered	96.18%	64.47%	49.16%	32.09%	17.78%	34.53%	24.39%

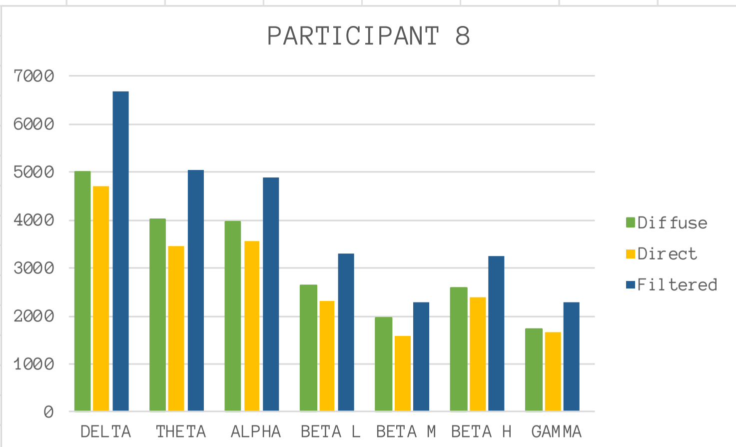


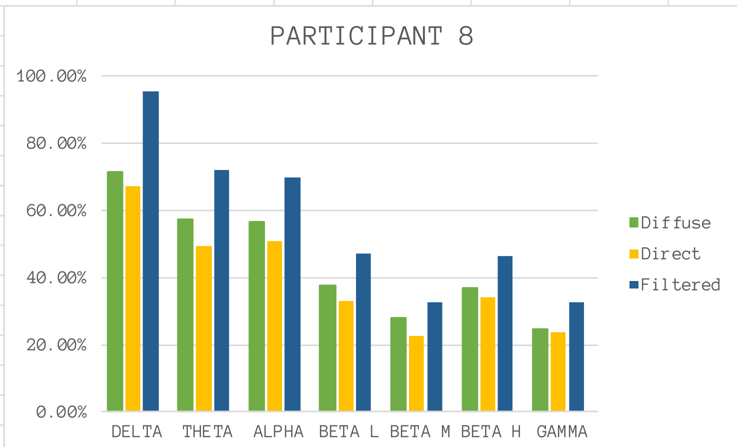


EEG TEST RESULTS PARTICIPANT #08

	Frequency bands AVG.						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	4991.896	4008.73	3954.066	2632.55	1967.533	2579.457	1731.449
Direct	4709.712	3461.656	3560.48	2305.41	1573.275	2395.505	1668.183
Filtered	6667.57	5046.96	4888.465	3292.473	2291.429	3248.357	2289.901

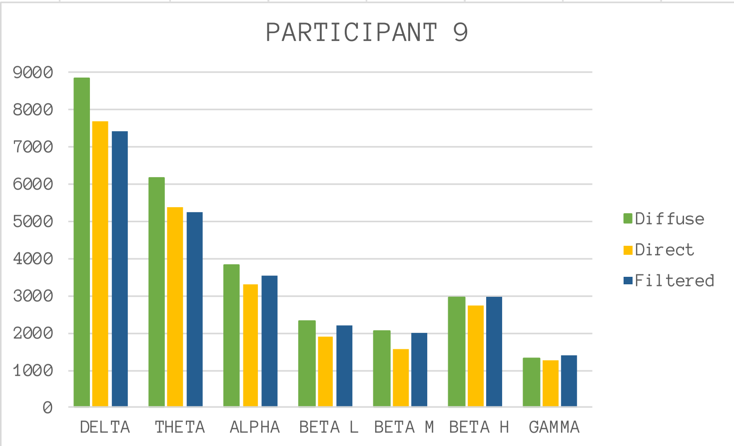
	Frequency bands AVG. IN %						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	71.31%	57.27%	56.49%	37.61%	28.11%	36.85%	24.73%
Direct	67.28%	49.45%	50.86%	32.93%	22.48%	34.22%	23.83%
Filtered	95.25%	72.10%	69.84%	47.04%	32.73%	46.41%	32.71%



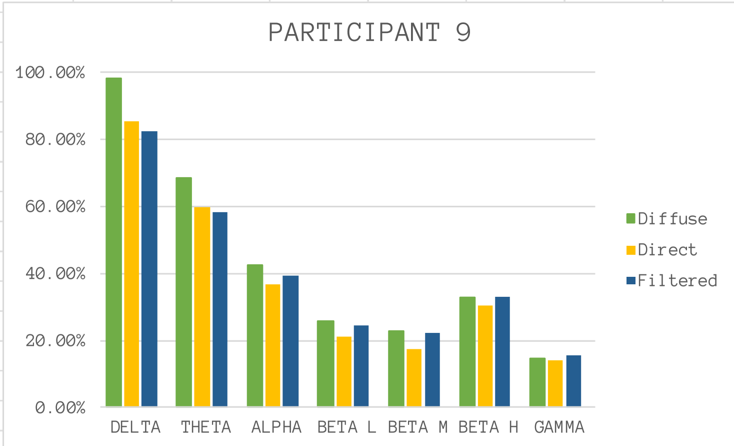


EEG TEST RESULTS PARTICIPANT #09

	Frequency bands AVG.						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	8845.5755	6177.537	3822.587	2307.23	2041.68	2962.536	1319.461
Direct	7681.5115	5379.302	3308.318	1910.278	1582.673	2736.217	1260.915
Filtered	7406.5465	5252.694	3532.41	2190.738	2012.822	2989.971	1408.004



	Frequency bands AVG.IN %						
	DELTA	THETA	ALPHA	BETA L	BETA M	BETA H	GAMMA
Diffuse	**98.28%**	68.64%	42.47%	25.64%	22.69%	32.92%	14.66%
Direct	**85.35%**	59.77%	36.76%	21.23%	17.59%	30.40%	14.01%
Filtered	**82.29%**	58.36%	39.25%	24.34%	22.36%	33.22%	15.64%



Domestic Dwelling Daylighting | Rodrigo Lagüera Pérez

Aalborg University Copenhagen | Project Period: February - May 2022