Comfort through certification: Limits and opportunities

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CONTENTS

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List of Symbols and Abbreviations

AH	Absolute humidity grams per cubic meter (g/m3)
dB	Decibel
E	Illuminance/light level (lumen/m2) or (lux)
f	Frequency (Hz) or (s–1)
Hz	Hertz
HVAC	Heating, ventilating and air conditioning
IAQ	Indoor air quality
I	Intensity of light (lumen/sr or candela)
I	Sound intensity (W/m2)
K	Kelvin
L	luminance (lux)
L_p	Sound pressure level in decibel (dB)
nm	nanometer
Q	ventilation rate (m3/s)
R	Sound insulation of the wall (dB)
R_a	color rendering index for 8 or 14 Ris
RH	relative humidity in percentage (%)
T_a	Air temperature (°C) or (K)
T_{mrt}	Mean radiant temperature (°C)
T_r	Reverberation time (s)
v_a	Air velocity (m/s)
VOCs	Volatile Organic Compounds
λ	Wavelength of light (nm)

List of Figures

INTRODUCTION

1.1 Context

Today, there are over 600 certifications worldwide, either for products or constructions and buildings *(Guldager Jensen et al. 2018)*. Most of them originate from developed countries and continents like Europe, North America & Asia. However, South America & Africa are slowly beginning to either certify their products, materials and buildings with existing standards or by creating new ones.

Since their apparition in the construction and building field, certifications have taken a notable status and influence on the building industry. Obtaining any kind of certification has become a powerful inclination in most new constructions and renovations, since it increases the value of the property all while providing assurance of a high level of quality during design and construction phases *(Afroz, Burak Gunay, and O'Brien 2020)*. Thus achieving at least one certification has become substantial for different construction projects. Some of these certifications aid architects in creating a comfortable and functional space for the users. However, some certifications with their various criteria and objectives, can become more of a hindrance to the architect's work and design.

The main objective for these building certifications is to guarantee the quality of the building, whether it be a new construction or a renovated building. While some focus on the technical and structural safety of the building, others extend to managing their environmental impact and meeting the occupants' needs. Of these standards, many have one goal: to achieve a degree of sustainability, which is in turn a general and vague term.

Sustainability was first defined by the United Nations Brundtland Commission in 1987 as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" *(Keeble 1988)*. It is composed of three main pillars: the economic aspect, the environmental aspect, and the societal aspect. Since each of these pillars is a complex dimension with its own interpretations, subcategories, interconnection & co-dependance to other pillars, each certification and standard usually focuses on one main aspect or try to combine two of them. Adding to the complexity and growing number of standards, different sustainability aspects of certification like the life cycle of the building, the sustainability of construction materials and the users experience and health inside the building, are additionally expanding and diversifying.

Therefore, green building certifications have multiple benefits: guaranteeing a positive environmental impact, increasing property value while reducing operational costs, and enhancing indoor conditions and health benefits for the users *(Afroz, Burak Gunay, and O'Brien 2020)*. They ensure that a building has met environmental, energy, human health, and other standards and regulations through its design, construction and performance. Choosing the type of certification to achieve helps architects and owners to prioritize the aspirations and goals of their projects *(Simon and Jackson 2020)*.

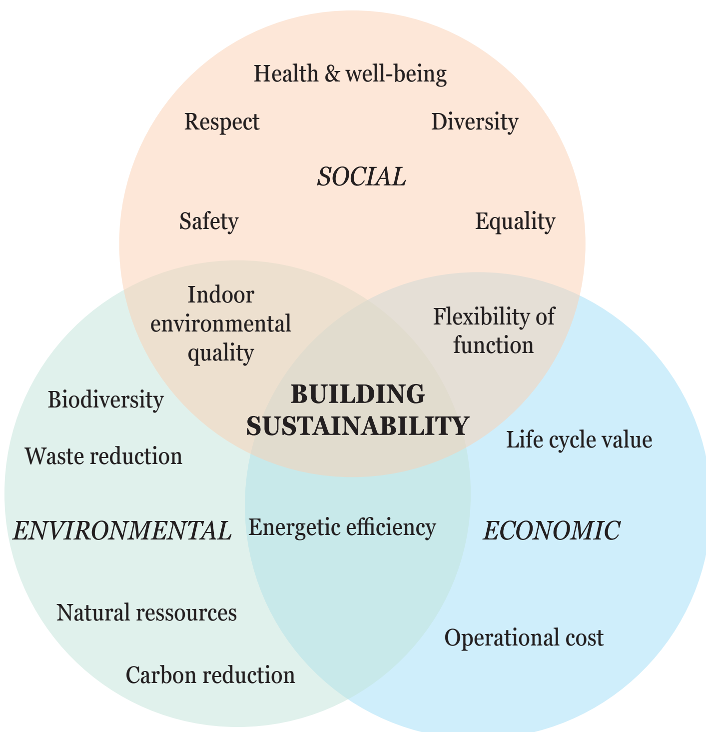


Fig 1: Sustainability pillars

1.2 Types of Certifications

Numerous building and construction certifications focus on one of the three pillars: economical, environmental, and societal aspects, or balancing multiple aspects, or targeting a specific subcategory in one of these pillars. There are other types of certifications outside the scope of this essay that focus on specific systems in a building like fire safety or security and structure. The following certifications were selected based on common use in the building industry as they consider the building as a whole with its different systems, and as a result, impact the indoor environment. These certifications are the most widely used systems today that have a holistic approach that goes beyond individual components of the building. These building certifications were categorized into three main types: Sustainable building certifications, Energy performance certifications, and User focused certifications.

1.2.1 Sustainable building certifications

Since the emergence of the definition of sustainability in the 1990's, the number of certifications related to sustainability is increasing. Sustainable building certifications, widely known as the Green Building Certifications are used to assess and recognise buildings which meet certain sustainability requirements or standards. Most of them are focused on sustainability with its three pillars. However, they generally focus more on the environmental dimension, largely represented by the resources & energetic aspects. The social dimension follows closely, represented by the indoor environment & comfort. And lastly the economic dimension which is generally less represented in all certifications *(Guldager Jensen et al. 2018)*. Thus, some of the most widely used green building certifications will be outlined.

BREEAM

Building Research Establishment
Environmental Assessment Method

Fig 2: BREEAM certification logo

Country of origin

United Kingdom

Foundation year:

1990

Founder and administrator:

Building Research Establishment

It is the first and oldest certification system to assess and rate a building's sustainability. It focuses mainly on the environmental dimension of sustainability with principles focused on resources like water and energy. It has a minor focus on the social and economic dimensions through indoor climate and life cycle cost.

Being the first certification system in the world, it has a worldwide reach with over 600'695 certified projects and around 2'326'192 registered for certification. In Switzerland, there are almost 140 BREEAM certified projects.

Applications

- New buildings
- Interiors
- Renovations
- Existing commercial buildings
- Urban areas

Levels

A score based system with 6 levels

- Outstanding
- Excellent
- Very good
- Good
- Pass
- Acceptable

Principles

- Energy
- Health and Well-being
- Innovation
- Land use
- Materials
- Management
- Pollution
- Transport
- Waste
- Water

BREEAM New construction:
This standard is destined for newly built projects ensuring to deliver high performing, and sustainable buildings including the outdoor facilities.

BREEAM Refurbishment and fit-out:
This standard is destined for refurbishing projects as in the refurbishment of the external envelope, structure, core services, local services, and interior design of existing.

BREEAM In-use:
This standard is destined for operational assets to assess its performance.

BREEAM Communities:
This standard is destined for design in the master planning of new communities and regeneration projects as in sustainable districts.

LEED

Leadership in Energy and Environmental Design

Fig 3: LEED certification logo
© U.S. Green Building Council

Country of origin

United States of America

Foundation year:

1998

Founder and administrator:

U.S. Green Building Council

This certification is one of the oldest and most used internationally. It primarily focuses on the environmental and social aspects of building sustainability through resources and health aspects, with a small focus on the economic aspect through the life cycle cost. LEED was designed to assess sustainability in design, construction, operation and maintenance.

In 2022, almost 150'000 projects are LEED certified including 60 projects in Switzerland.

Applications

- New buildings
- Interiors
- Renovations
- Existing buildings
- Urban areas

Levels

A score based system with 4 levels

- Platinum
- Gold
- Silver
- Certified

Principles

- Location and Transportation
- Sustainable Sites
- Water Efficiency
- Energy and Atmosphere
- Materials and Resources
- Indoor Environmental Quality
- Innovation
- Regional Priority
- Integrative Process

LEED Building Design and Construction (BD+C)
This standard is destined for new construction or major renovations in residential or commercial buildings.

LEED Interior Design and Construction (ID+C)
This standard is destined for complete interior refurbishment in commercial projects.

LEED Building Operations and Maintenance (O+M)
This standard is destined for existing buildings that are undergoing improvement work with little to no construction.

LEED Neighborhood Development (ND)
This standard is destined for new land development or redevelopment projects containing residential and/or non-residential uses. Projects can be at any stage of the development process, from conceptual planning to construction.

LEED Cities and Communities
This standard is destined for cities or communities to measure how they manage their water consumption, energy use, waste, transportation and human experience.

LEED Zero
This is a complementary certification to BD+C & O+M destined for projects with net zero goals in carbon and/or resources.

HQE

Haute Qualité
Environnementale

Fig 4: HQE certification logo

Country of origin

France

Foundation year:

1995

Founder and administrator:

Cerway

This french construction certification was created in 1995 and then established as a non-profit organization in 2004. It is primarily focused on the social dimension of sustainability through health and comfort goals, followed by the environmental dimension with energy principles. It’s a flexible certification that adapts to meet the specific standards and norms of the concerned country.

Over 380’000 projects are HQE certified worldwide.

Applications

- New buildings
- Interiors
- Renovations
- Existing buildings
- Urban areas

Principles

- Energy
- Environment
- Health
- Comfort

Levels

A score based system with 5 levels

- Exceptional
- Excellent
- Very Good
- Good
- Pass

HQE Sustainable Building

This certification is only granted in France for single detached houses, residential or commercial buildings.

HQE Construction

This international certification is destined for the design and construction phases of new-builds and renovated buildings.

HQE Building in Operation

This international certification is destined for non-residential operational buildings to assess the performance of the building and their stakeholders (landlord, property manager & building users)

HQE Sustainable Urban Planning & Development

This international certification is destined for the design and planning of new urban areas like districts while ensuring the application of sustainable systems.

HQE Sustainable Infrastructures

This international certification is destined for infrastructures to assess their impact on the environment.

LBC

Living Building Challenge

Fig 5: LBC certification logo © International Living Future Institute

Country of origin

United States of America

Foundation year:

2006

Founder and administrator:

Jason F. McLennan and Bob Berkebile and launched by the Cascadia Green Building Coalition

It is a rigorous sustainability certification launched as a combined effort of the US and Canada. It focuses on both social and environmental dimensions with no mention of the economic dimension as all principles have a strong or partial focus on social sustainability, while only some principles focus on environmental.

It's a really demanding certification in general, that's why only 173 projects are LBC certified with 613 projects under consideration for certification, primarily in the US and Australia. There are only 2 projects certified in Europe.

Applications

- New buildings
- Interiors
- Renovations
- Existing commercial buildings
- Urban areas

Levels

2 levels of certification

- Living certified
- Petal certified

Principles

- Place
- Water
- Energy
- Health and Happiness
- Materials
- Equity
- Beauty

LBC Living Certification
This certification is destined for projects striving for the highest level of sustainability and regenerative design whether they be new or renovation projects.

LBC Petal Certification
This certification is designed for projects focusing on a specific thematic or issue whether they be new or renovation projects, with the condition of fulfilling at least one of these principles Water, Energy, or Materials.

Core Green Building Certification
This certification is destined for projects seeking a high aspiration for sustainability in a more achievable way whether they be new or renovation projects.

Zero Energy Certification
This certification is destined for projects focused on achieving net zero energy through the on-site production of renewable energy whether they be new or renovation projects.

Zero Carbon Certification
This certification is destined for projects focused on impacting climate change through energy and materials whether they be new or renovation projects.

DGNB

Deutsche Gesellschaft
für Nachhaltiges Bauen

Fig 6: DGNB certification logo
© DGNB

Country of origin

Germany

Foundation year:

2008

Founder and administrator:

German Sustainable Building Council

This green building certification considers the entire life cycle of a project: from planning to its construction then its operation and its deconstruction. It comes closest to an equal focus on each sustainable dimension with balanced principles of health, resources and life cycle cost. It's one of the most flexible international certifications since it is usually based on the standards and norms of the country where it's applied.

In 2022, There are currently around 2'000 projects DGNB certified including 14 in Switzerland.

Applications

- New buildings
- Commercial interiors
- Renovations
- Existing buildings
- Urban areas

Principles

- Environmental quality
- Economic quality
- Sociocultural and functional quality
- Process quality
- Technical quality

Levels

A score based system with 4 levels

- Platinum
- Gold
- Silver
- Bronze

DGNB New construction
This certification is destined for new-built projects, it follows the project from its planning phase to its completion and operation. It assesses the construction performance based on six topics with their 37 sub-criteria: ecology, economy, sociocultural and functional aspects, technology, processes & site.

DGNB Existing Buildings and Renovation
This certification is destined for existing buildings renovated or not. It evaluates the performance and use of the building.

DGNB Buildings in-use
This certification is destined for existing buildings in-use to minimize their impact on the environment, especially with a carbon emissions neutrality goal.

DGNB Interiors
This certification is destined for indoor environments to achieve comfort through design and architecture affecting health and Wellbeing.

DGNB Districts
This certification is destined for the development of sustainable districts. It is applied from planning to application.

1.2.2 Energy performance certifications

Energy performance certifications are interested only in the energetic performance of buildings or built environments (neighborhoods). Their main objective is to reduce the energetic consumption all while trying to maintain a comfortable interior for the users. They establish the condition of the building envelope and technical installations to assess the energy efficiency of the building envelope and the amount of energy that the building consumes in standard use. This means energy for heating, domestic hot water and electricity for lighting, ventilation and electrical appliances.

This type of certifications is one of the most used in Switzerland specifically due to the Swiss Energy Strategy 2050 including various programs to promote renewable energies, reduction of energy consumption, waste heat recovery and the optimization of building services technology. This type of certification is encouraged in Switzerland through cantonal financial aid for energy-efficient buildings. Thereafter, the most widely used energy-efficient building certification in Switzerland will be outlined.

Minergie

Fig 7: Minergie certification logo

Country of origin

Switzerland

Foundation year:

1994

Founder and administrator:

Ruedi Kriesi and Heinz Uebersax
the Minergie Association

The Minergie standard is one of the oldest building certifications in Switzerland and probably the most used. It focuses on the topics of climate change and energy consumption and efficiency, based in particular on the Swiss standards & norms (SIA).

There are over 50'000 Minergie certified buildings including up to 300 projects outside of Switzerland

Applications

New buildings
Renovations

Principles

Energy efficiency and sustainability
Comfort and health
Value Preservation and quality

Levels

3 types of certification

Minergie
Minergie-P
Minergie-A

Minergie
This is the basic level of certification that guarantees energy efficiency and a high quality of design. It can valorize both new and renovated buildings.

Minergie-P
Created in 2003, this level of certification pushes the limits of energy efficiency by having a more efficient envelope. It can valorise both new and renovated buildings.

Minergie-A
Created in 2011, this level of certification requires a high level of energetic independence via auto production of energy (solar panels, geothermic energy...etc). It can be given to both new and renovated buildings.

These Minergie standards can have three complementary certifications only obtained in association with a Minergie certification:

SQM Construction
This complementary certification is aimed at building owners and planners who want to ensure compliance with the most regulations during construction.

SQM Exploitation
This complementary certification optimizes the performance of the building's technical installations and their exploitation after construction, thus guaranteeing maximum comfort.

ECO
This complementary certification proposes a component focused on the health and well-being of the users and also the ecological aspects of the building.

1.2.3 User focused certifications

This type of certification addresses the health and safety implications of both the building and its surroundings for the user. It is usually focused mainly on the social dimension of sustainability through human well-being inside and around the building, spaces that encourage good social interactions, and the promotion of healthy transportation to and from the building as well as inside it.

This type of certification that focuses solely on the users, their comfort, health & well-being in the built environment and re-establishes the user as the center point of the built environment is quite rare. Thereafter, the mainly user focused building certification world-widely used will be outlined.

WELL

Fig 8: WELL certification logo

Country of origin

United States of America

Foundation year:

2014

Founder and administrator:

Paul Scialla
the international WELL Building Institute (IWBI)

This standard is considered as the first to focus on the people in the building. It focuses mostly on the social dimension of sustainability as it's a certification that measures the comfort as well as the well-being and health of users in buildings.

In 2022, 22'248 projects are WELL certified with 17'517 projects enrolled. In Switzerland, there are up to 35 projects that are WELL certified and/or in progress of certification.

Applications

- New buildings
- Interiors
- Renovations
- Existing buildings
- Urban areas

Levels

A score based system with 3 levels

- Platinum
- Gold
- Silver

Principles

- Air
- Water
- Nourishment
- Light
- Movement
- Thermal Comfort
- Sound
- Material
- Mind
- Community
- Innovation

Well Building Standard
This certification is destined for new, existing, or renovated buildings whether they are residential or commercial buildings.

WELL Community Standard
This certification is destined for communities that aim to protect health and well-being across all aspects of community life. It is a district-scale rating system promoting human health and well-being.

WELL Rating systems
This is a rating system to help owners and managers assess and improve the environment they provide for their employees and visitors.

The **WELL Health-Safety Rating** is especially created for the pandemic.

The **WELL Performance Rating** is designed to advance health through smarter buildings.

The new **WELL Equity Rating** is created to help diversity, equity and inclusion in company cultures.

1.3 Certifications of focus

The greatest majority of the population spend 80-90% of their time inside buildings *(Sarbu and Sebarchievici 2013)*. Most of their interactions are also with a built environment whether it be a designed outdoor space like a park or an actual building, from their homes to their workplace and service and activity buildings. The users' experience and comfort in these built environments are thus an important aspect in building design.

This essay will focus primarily on certifications that promote the comfort of users in the built environment. The variety of certifications were selected based on either their considerable use in Switzerland and/or worldwide, or due to the level of focus they bring to the social dimension of sustainability, especially health and comfort. Due to the limited number of case studies on some building certifications the selected certifications of focus are narrowed to Minergie (Eco), WELL, and LEED.

Well

As it is the first standard that focuses solely on the users and people in the built environment, it requires attention when assessing the performance of user comfort standards. Its expanding international scope is slowly reaching Switzerland which adds to its importance in this essay.

Minergie (Eco)

As explained before, Minergie is one of the most used certifications in Switzerland. Despite its main focus on energetic efficiency, an additional certification goal is to secure a high level of occupants' comfort through the indoor environmental quality with the compliment Minergie-ECO. The focus will be on the duality of ensuring the users health all while maintaining a good energetic performance of the built environment.

LEED

Even though it puts minor focus on the health aspect, it is so widely applied in Switzerland and in the world that it is necessary to study its influence on the users and their experience in the built environment.

1.4 Research intent

One of the most important considerations when designing a building is the comfortable environment that it can provide for its occupants. Comfort in buildings is affected by a great number of different factors which can, if not addressed properly, lead to not only different levels of discomfort, but can also cause harm and ill health to occupants.

As the impact of green building certifications is constantly growing in the construction and building industry, their influence on user comfort and health is vital. However as seen above, there aren't many certifications that focus on the comfort of the users specifically. Furthermore, the real question is if these certifications do really achieve the users' satisfaction and comfort.

This essay will try to shed some light on the effectiveness of some of these building certifications in guaranteeing user comfort, their advantages and their limits and how can architects employ these certifications to improve the design of the space all while ensuring the user's comfort.

In the pursuit of answering this question, this essay will first briefly explore and define what is known to affect users' comfort. Then, through users' opinions and satisfaction rates in different case studies on certified buildings, their impact on user comfort will be examined as well as identifying their features, advantages and limits. Ultimately, the important role of architects in designing the space and built environment will be addressed to establish how they can contribute to attaining user's comfort whilst obtaining the in-demand building certifications.

The ambition of this essay is to stimulate the architect to understand the impact of these certifications on user comfort as it is the center point of building design. Moreover, identifying their flaws and limitations as well as their benefits can aid in designing better and more comfortable spaces which is a primary objective of the built environment.

DIMENSIONS OF COMFORT

Comfort can be defined as a state of physical ease or relaxation and freedom from pain and distress. Comfort is achieved through physical and psychological well-being. However, during building design, physical comfort is the main focus for architects as it can be integrated and controlled in the design project in contrast to psychological comfort. Furthermore, physical comfort is essential to work productivity, general satisfaction, and physical and psychological well-being.

Physical comfort is a vast concept and term that contains a lot of criteria and dimensions. Most literature and scientific articles address four main dimensions of comfort:
- Thermal comfort
- Air quality
- Visual comfort
- Acoustic comfort

In this section, the main elements and factors of each dimension will be summarized in order to have a global definition of user comfort in the built environment according to scientific literature.

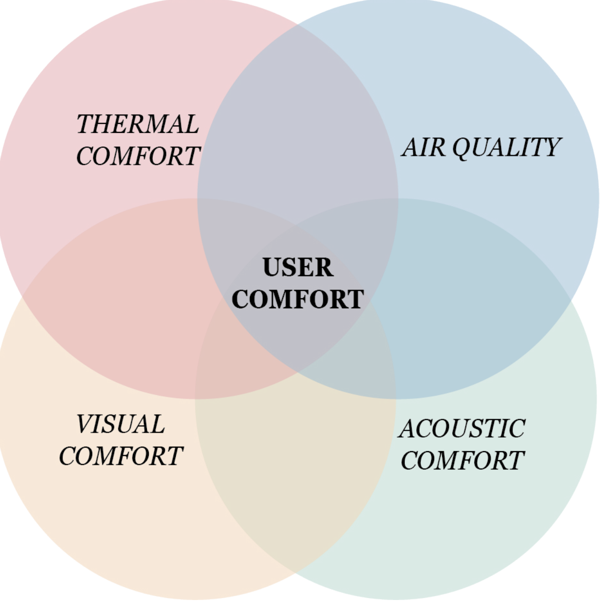
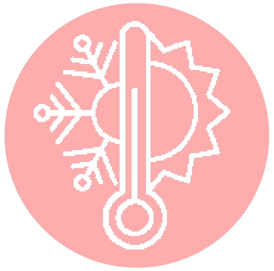


Fig 9: Diagram of physical comfort dimensions

THERMAL COMFORT

2.1 Thermal comfort

According to multiple studies and scientific articles, Thermal comfort is ranked by users as the most important parameter in achieving comfort *(Frontczak and Wargocki 2011)*. The direct influence of thermal comfort and discomfort on users' performance and productivity has even been scientifically proved *(Wargocki and Wyon 2017)*.



2.1.1 General definition of thermal comfort

Thermal comfort is scientifically defined as the equilibrium between the metabolic emission of the person, meaning his heat production, and the energy outflow, i.e. the heat loss through heat transfer between the body and the ambient air *(Karmann, Schiavon, and Bauman 2017)*. This heat transfer between a person and his surroundings occurs under three forms: Conduction, Convection, and radiation. A person normally loses heat by convection with surrounding air, by radiation with surrounding surfaces, and by conduction through clothing *(P. Bluyssen 2009)*. A person also loses heat through breathing and skin diffusion. They can also feel discomfort due to high temperatures and sweating *(P. Bluyssen 2009)*.

2.1.2 Factors affecting thermal comfort

To limit all these transmissions and heat loss, there are some factors that can be controlled. Here are the most prominent aspects affecting one's thermal comfort:

Temperature

Several temperatures should be measured and controlled to achieve a person's thermal comfort. There is the indoor air temperature T_a that should follow changes of outdoor temperature: increase in summer and decrease in winter and taking into consideration the local climate conditions *(Frontczak and Wargocki 2011)*. There is also the mean radiant temperature T_{mrt} with bordering surfaces that should be monitored. This quantifies the exchange of radiant heat between a human and their surrounding environment, specifically neighboring surfaces. It can be controlled by ensuring that there are no cold objects and surfaces in the space which can influence the indoor air temperature and thus the person's thermal comfort.

Humidity

It is the amount of water that exists in the air in the form of vapor *(P. Bluyssen 2009)*. There are both absolute humidity *AH* and relative humidity *RH*. However, relative humidity particularly affects a person's thermal comfort. *RH* is the ratio between the amount of water vapor in the air and the amount that would be present in saturated air at a given temperature. *RH* ideally should be between 30%-70% *(Taleghani et al. 2013)*. The greater the air humidity the higher the perceived air temperature. This is due to the human bodies' reaction to high humidity through reducing transpiration, which usually helps regulate the body temperature.

Air Velocity

Air velocity v_a is the speed of air, traveling a certain distance in a certain direction. The greater the air velocity, the greater the heat loss and exchange between people in a space and the air around them through convection. Sometimes, it is desirable to have high air velocity, for example air from a fan in hot weather. However, it can also cause discomfort in colder conditions when higher air velocities may be noticeable as a draught due to turbulence intensity representing the fluctuation of the air velocity. Thus, air velocity should be adjusted to the local climate conditions.

Human factor

The human factor contains two main aspects, the activity performed by the person and the thermal resistance of clothing *(Sarbu and Sebarchievici 2013)*. Depending on the activity a person is accomplishing, there is a different effect on their metabolic rate and thus their heat production. The more strenuous the activity is, the faster their metabolic rate gets and the harder the person breathes and sweats. These are the two main forms a person loses and transfers heat with his surroundings. As for clothing, their ability to transfer heat or to maintain it affects the thermal perception of the user. The more resistant they are, the better they retain heat and limit the transfer of heat between the body and its surroundings.

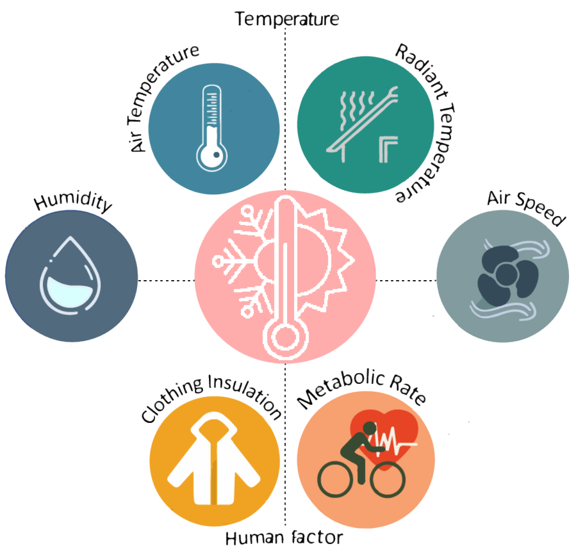


Fig 10: Measurable factors influencing user thermal comfort

In summary there are two ways to control these aspects depending on their type. Either control the human related factors (Clothing and activity) or control the air related factors (Temperatures T_i & T_{mrt}, Relative Humidity *RH*, Air Velocity v_a and turbulence). The human related factors can't be controlled while developing a project and are variable depending on the person in question. However, the air related factors can be controlled via the cooling, heating, and air conditioning systems. These systems are always associated with a ventilation system whether it be mechanical, hybrid or natural ventilation.

2.1.3 Non measurable factors affecting thermal comfort

There are other non-physical factors that influence thermal comfort. These factors depend on the users and their differences but also on the space in question.

Studies indicated that according to the activity done in the space or what it represents to the users, the degree of thermal comfort can vary. For example, residential occupants are less sensitive to temperature variations and accept a wider range of fluctuation than students in school or workers in offices *(Rupp et al. 2019)*. This can be related to the different activities done in the space such as stationary desk work in offices and school for a long period of time. Or it can be due to the more personal control in residential buildings.

As for the other factors depending on the users, they vary from age to climate zone of origin and gender. Studies exhibited that younger users are more sensitive to temperature changes, the same for female users who are more sensitive than their male counterparts *(Rupp et al. 2019)*. Also, the climate zone of the origin of the user is relevant since it was demonstrated that people from dynamic climate zones like tropical zones, are more tolerant to thermal comfort. However, this is only a temporary tolerance since it diminishes with time spent in the same conditions *(Pastore and Andersen 2019)*.

2.1.4 Sources of discomfort

Although the different systems have a high control on these factors, there are still some phenomena that cause user thermal discomfort, mainly the non-uniformity temperatures.

For instance, a big difference of temperature between distinct areas of the ambient air like vertical temperature gradients (perceiving different temperatures near the user's head and feet causing discomfort) or radiant asymmetries (the difference between the radiant temperature of two opposite sides of a small plane element) can cause discomfort. Studies have revealed that local thermal discomfort influences the whole-body thermal sensation *(Schellen et al. 2013)*.

2.1.5 Design measures for thermal comfort

Air related factors such as air temperature, humidity and velocity are the ones that can be controlled by the architect during the building's design. It depends on the HVAC system, which is the heating/cooling systems put in place coupled with a mechanical or natural ventilation system. This system uses water or air as a transportation medium of temperature from one location to the other. Each system has a considerable space needed in a building that must be integrated in the design of the building. Whether it be heated and cooling radiant ceilings or floors.

However, this system must also be associated with a tight air envelope to limit air infiltration and a higher control of indoor air temperature. This can be achieved in newer buildings although it can be quite problematic while renovating buildings. While renovating, architects try to limit the interventions in the existing structure and facades which can be problematic when trying to increase the air tightness of the building by adding insulation layers. For heritage renovation the added insulation layers can change the image and essence of the historical building. Furthermore, in some historical buildings, there might not be enough space to add a conventional HVAC system. That's when the architect's role is most important, by choosing the best HVAC system and insulation for each specific case to balance between the preservation of the historical character while improving the indoor environmental quality.

There is also a huge influence of solar radiation on the indoor temperature that must be considered while designing the façade. Direct sunlight affects the heat sensation, depending on its intensity and duration, it can influence positively or negatively the indoor temperature. For example, in summer a transparent façade without shading and materials with high inertia can result in overheating the indoor environment. However, using the solar gain in winter can be beneficial for indoor temperatures.

In conclusion, there are many factors that can guarantee thermal comfort. Some are easy to manipulate while others can't be controlled during project design. Since thermal comfort varies from one user to the other, it is irrational to have the same criteria for ensuring thermal comfort all over the world. Outdoor climate zone must be considered while defining the criteria for indoor thermal comfort as well as the variability of a user's comfort zone. There is also the influence of daylight on thermal comfort and the substantial link between thermal comfort and air quality.

AIR QUALITY

2.2 Air quality

This is the only dimension that isn't used with the term comfort since it's usually linked to the absence of discomfort or lack of foul odor or stifling feeling in the air *(Frontczak and Wargocki 2011)*. This dimension is usually heavily affiliated with thermal comfort, as both are influenced by similar aspects and have an impact on each other. Hence Xue et al. defined those two dimensions as having the greatest influence on the users' comfort *(Xue, Mak, and Ai 2016)*.

2.2.1 General definition of air quality

The main source of discomfort due to air quality is the diverse pollutants that exist in the ambient air, specifically the concentration of these pollutants over time. Especially since most of these pollutants are unidentifiable by the human senses (odorless). To control the concentration of these pollutants, there are some parameters and aspects that have to be regulated *(P. M. Bluyssen 2010)*.

2.2.2 Factors affecting air quality

To limit all the concentration of these pollutants in the air, there are some factors that can be controlled *(P. M. Bluyssen, 2010)*. Here are some controllable aspects affecting air quality:

Source control

There are two main types of pollutants in indoor air, biological and chemical pollutants. The biological pollutants consist mostly of micro-organisms as in molds, bacteria... etc. and their discharges like dust particles. The chemical pollutants are either gases and vapors or a particulate matter like fibers. The main gaseous pollutants are CO, CO_2, O_3...etc. and all forms of VOCs (Volatile organic compounds) like benzene and toluene. There are various sources of these pollutants, and they exist abundantly in our surroundings. They can vary from furniture and building materials, to machines like printers, and even our own activities like breathing and sweating.

The different pollutants have different methods of emission, and they circulate over different time periods depending on conditions in the indoor space like temperature and humidity. It is impossible to eliminate all types of pollutants from our surroundings, it is only possible to control the known sources of some of these pollutants all while regularly analyzing the air for new pollutants.

Some of the main sources of pollutants are human activity: whether it be natural breathing emitting CO_2, smoking, or cooking emitting odors or using machines like printers and photocopiers emitting O_3. These activities are essential in our daily lives. Therefore, the only way is to control the emissions either by having specific areas for these activities to limit the spreading of these pollutants like smoking areas, or to have a good ventilation system to renew the air and reduce the amount of these pollutants in the surrounding air.

Another main source of pollutants is cleaning and chemical products, furniture and building materials like carpets or paint. The solution is to reduce the number of objects and chemicals in our surroundings that emit pollutants. There is also the option of storing all chemicals in an isolated space. The regular analysis of air particles and the regular inspection for micro-organisms like molds or fungus are highly recommended.

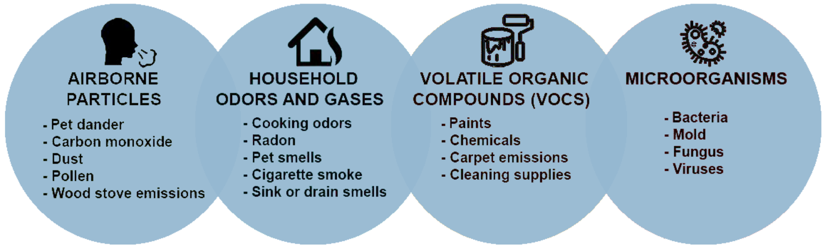


Fig 11: Types of air pollutants

Ventilation

This is the process of removing the different pollutants from the surrounding air by extracting the air and introducing new fresh air. This process reduces the concentration of the pollutants and limits the duration of exposure to it. The higher the ventilation rate Q, the higher the performance and comfort of the users *(Wargocki and Wyon 2017)*. However, this happens only when the introduced new air is clean and supplied to the right places. This implies that new fresh air reaches the user's head as closely and as quickly as possible while the extracted air is evacuated with the same speed. That's where air velocity influences air quality, the balance between the necessary speed to introduce new air while avoiding thermal discomfort must be found.

Air cleaning and freshness

This strategy requires the removal of most pollutants whether they are gaseous, airborne particles or micro-organisms. This can be done through the filter integrated in the ventilation system for the introduced air or through electronic air cleaners like air purifying machines. These options need regular maintenance by changing filters and to always maintain the space clean and clear of all known sources of pollutants. There is also the solution of adding indoor plants, that have a positive effect on air freshness.

In summary there are two ways to control these aspects either control the content of the air by eliminating all sources of pollutants or renew the air to reduce the concentration of the pollutants. The pollutant sources can partially be controlled while developing a project through the choice of non-polluting materials or through the space design. For air renewal, it is mainly achieved through the design of the ventilation system whether it be mechanical, hybrid or natural.

2.2.3 Design measures for air quality

As discussed above, ventilation systems are the main course of action to ensure air quality indoors. There are three general ventilation systems: natural, mechanical and hybrid systems. The natural ventilation system is a passive way to exchange indoor and outdoor air via openings like ventilation ducts and openings or windows and doors. Mechanical ventilation is an energy-based system that not only conditions the air but also moves it. The hybrid system combines both systems, favoring natural ventilation as much as possible except in instances with poor outdoor conditions like noise or pollution.

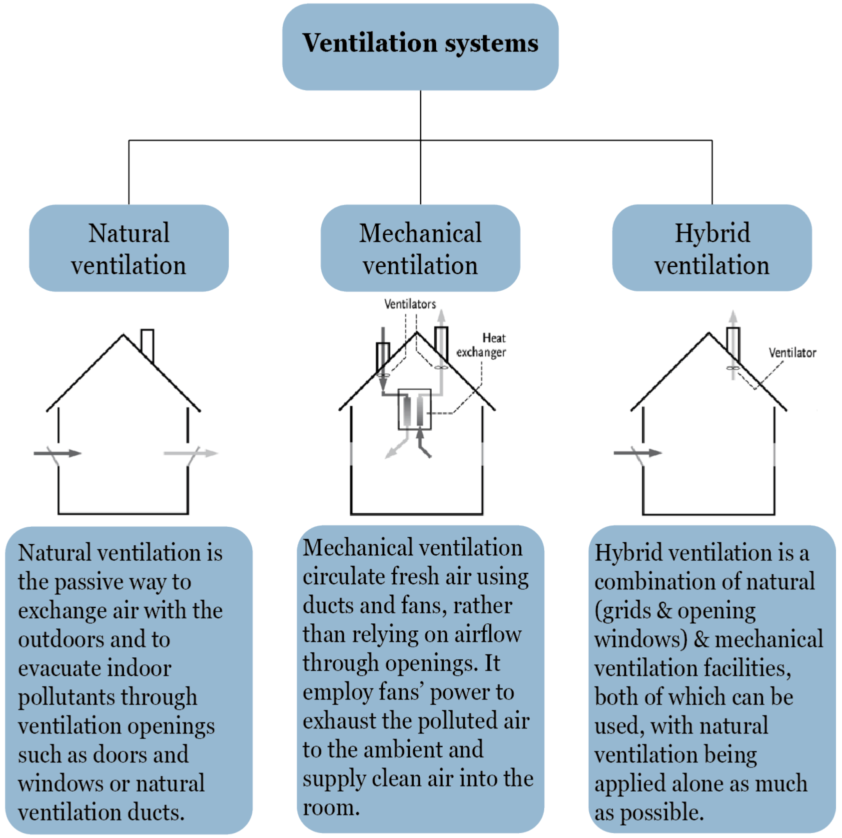


Fig 12: Types of ventilation systems

Several scientific articles declared, following case studies and users' opinions, that better air quality and thermal comfort is offered by natural ventilation *(Rupp et al. 2019) (Teitelbaum and Meggers 2017)*. This may be the result of a higher degree of users' personal control in natural ventilated buildings, offering the user a vaster adaptability to the indoor environment. There is also the freshness of air that eliminates the feeling of stuffiness in the indoor environment. This can be achieved through air filters as mentioned above or through the integration of plants indoors that contribute to air purification *(Grzegorzewska and Kirschke 2021)*.

Fig 13: Use of plants combined with ventilation system

In summary, there are a lot of pollutants sources that can't be all eliminated. The only solution is to work with these sources and to have a regular new and fresh air supply to reduce the concentration of these pollutants. That's why the ventilation system in a building is essential in ensuring users' comfort. However, the speed and temperature of the introduced air must be well monitored for it greatly affects users' thermal comfort. If the introduced air is too cold or has a very high speed, it can cause discomfort and have a negative effect on the users' general comfort.

VISUAL COMFORT

2.3 Visual comfort

This dimension might not be ranked as the most influential on users' comfort. However, it is fundamental for the normal functioning of a person and to accomplish any kind of activity, without health problems like eye strain and headaches. It is crucial for the occupant's health, physical capabilities, memory, and attention. This dimension is a complex one with multiple definitions possible and different criteria and factors affecting it *(Thuillier 2017)*.

2.3.1 General definition of visual comfort

Visual comfort depends solely on light and its perception. Light is a form of energy that allows us to perceive our surroundings. This radiation that reflects on objects and surfaces can then be seen by the human eye and can be interpreted in our brains, thus allowing us to perceive and understand the world around us. Light has multiple characteristics and factors that need to be adjusted or controlled to ensure a comfortable vision of the user *(P. Bluyssen 2009)*.

2.3.2 Factors affecting visual comfort

To ensure a comfortable amount of light for the normal functioning of a person, here are some controllable and adjustable factors that affect visual comfort *(P. Bluyssen 2009)*:

Sources of light

Sources of light, whether natural or artificial, require having a certain intensity and to be composed of certain radiations for users to be able to recognize their environment.

Natural and artificial light

Natural light is mostly called daylight. It is a combination of direct sunlight and atmospheric light which is the sunlight refracted and reflected by the air and the surrounding objects. It is the main source of light known to humankind. However, as its name suggests, this light is variable, it changes intensity through the day, and it diminishes at night. It also lasts for different time intervals throughout the year.

Therefore, contemporary society depends on artificial light to perceive their surroundings when daylight isn't available during hours beyond daytime or due to architectural design such as deep floor plates, lack of daylighting entry in the space, or poor daylighting design in which the blinds are constantly pulled. Thus, balancing natural lighting and complementing it with artificial lighting is crucial for the visual comfort of indoor environments.

Light intensity

The intensity of light I is the amount of light flux emitted by the source within a certain space. It is the perceived power of light. The higher the intensity of light is, the brighter the light will be, and the space can be well lit and easily perceived.

Light color

Light is composed of a spectrum of radiation with specific wavelength λ, the visible part ranges from 380 nm (violet) to 780 nm (red). All colors of the spectrum are needed for people to see all present colors in the indoor environment. Since daylight contains all the spectrum, even the non-visible part, the artificial light tries to replicate as much as possible the visible part of daylight's spectrum.

To quantify this, color temperature is used and its measurement unit is Kelvin K. Light has a different color temperature which gives a different impression of colors. A white light's color temperature can range from 3'300 K (warm white) to 7'000 K (cool white). Daylight has a color temperature of approximately 6'500 K.

However, the use of both cool and warm white depends on the activity. The higher color temperature boosts alertness which helps improve activities necessitating higher concentration. It was proved scientifically that users prefer cool white light in work or education environments since it demands a higher concentration and alertness. And lower color temperatures (warm white) are more associated with relaxing spaces *(Shamsul et al. 2013)*.

Distribution of light

Since light is a form of energy that disperses in the surroundings, there are some factors that are related to these surroundings that affect the distribution of light like the lights' illuminance and luminance.

Light level

Illuminance E is defined as the amount of light falling and spreading on a certain area or surface, it is measured with the unit lux. Depending on the task at hand, a different amount of light is necessary for the user to see an object comfortably. In general, it varies from 20 lux (identifying features of a face) to 5'000 lux (unrecommended since it can cause light blindness). The normal level of light for an inhabited space is between 200 & 300 lux. However, for concentration and work in offices, a 500 lux threshold is recommended. This limit can go up to 750 lux for fine detail work in workshops.

Luminance distribution

Luminance L is the ratio of light illuminating a space depending on the angle of incidence and the contrast between what is illuminated and what is not. The difference of lighting between the foreground and background of the visual field can cause discomfort. This is the phenomenon of Glare. There is also the flicker rate that can cause discomfort. It is defined by the frequency and speed of change in luminance or color over time in the same illuminated area.

Glare and flicker rate are some of the main problems causing visual discomfort since the human eye must adjust to the contrast of light repeatedly the whole time. These phenomena can affect user's health causing eye illnesses in the long term.

Light perception

Light perception depends on how the object is finally perceived by the user. It depends on the light signal received by the user and how they interpret it.

Color rendering

It is the ability of a light source to accurately give the right impression of the colors of the objects. Each light source reproduces the colors of the objects differently. Thus, a color rendering index R_a was created to measure this feature. The higher the index the better since the colors are accurately perceived.

In summary, most of the measurable factors influencing visual comfort are related to the light source and its different characteristics. Certain thresholds and minimal values are crucial for not only a comfortable vision but also a visible environment for the functioning of a person. Daylight should always be promoted since natural light is better for user's health as the eye can adapt to lower levels of illuminance for natural light rather than artificial light.

2.3.3 Non-measurable factors affecting visual comfort

There are other factors related to the user that affect their visual comfort. The main factor is the sharpness of their eyesight. If the eyesight is not properly corrected by glasses or contact lenses, it can affect the visual comfort of the person. This can be visible with older users who have non-corrected bad eyesight due to eye degeneration with age and how it influences their visual comfort for simple tasks. There is also the influence of the activity on visual comfort. Since a correlation between the level of light needed and the activity done by the user is essential to ensure visual comfort.

2.3.4 Other aspects of visual comfort

Visual comfort doesn't solely revolve around light exposure and access. There is also the direct visual connection possible due to the multiple functions of windows. Windows and other transparent openings are essential for both daylight entry and for visual contact with the outdoors. The direct visual contact with opposite buildings that can occur due to proximity between buildings, or the out proportioned windows can cause discomfort depending on the type of activity done in the space. It was demonstrated that most users prefer having a visible skyline with greenery for the outdoor view, especially in office buildings.

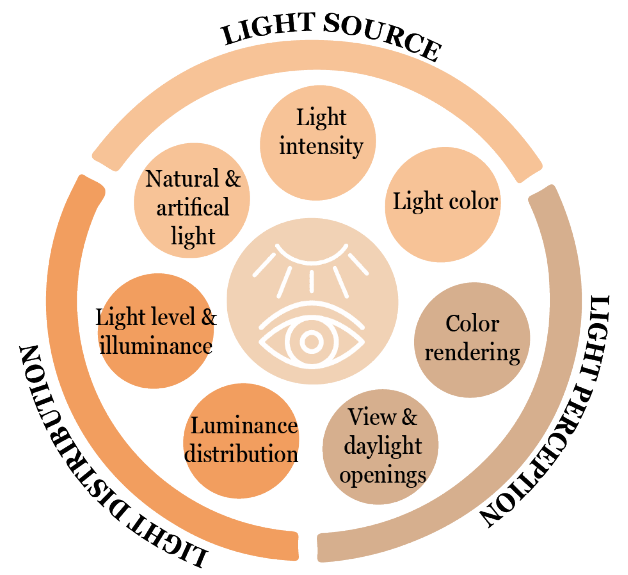
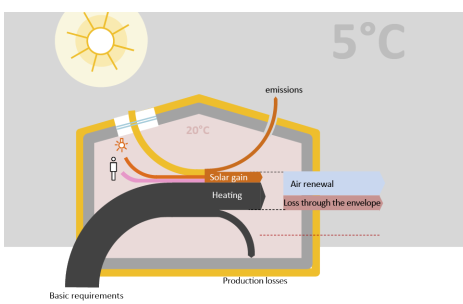


Fig 14: Measurable factors influencing user visual comfort

2.3.5 Influence of light on thermal comfort

Light being an energy wave, it also influences users' thermal comfort. Depending on the amount of direct daylight entry, due to orientation and façade design, it can poorly influence the users' sensation of comfort. For thermal comfort, direct sunlight increases the sensation of heat and can be either pleasant or it can cause discomfort even if the temperature of the indoor air is acceptable.

However, this direct sunlight can be used to increase thermal energy and temperature in a building, heating the space in cooler climates. And thus, reducing the energy needed for heating systems. But in warmer climates or during extremely hot seasons, solar gain can be problematic and can cause discomfort for occupants. All these problems, whether it be direct vision between buildings or heat waves and overheating due to sunlight, can be prevented by solar screens or shading that can be personally controlled by the users.



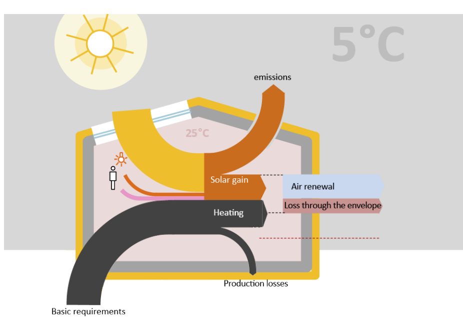


Fig 15: Influence of sunlight on thermal comfort

2.3.6 Design measures for visual comfort

To ensure visual comfort in a building, an architect must guarantee sufficient amount of light whether it be natural and/or artificial, and to provide an adequate outdoor view with the possibility to control visual privacy. For a sufficient amount of light, it starts with the orientation of the building if it's a new construction. Orientation can be one of the obstacles in ensuring visual comfort while renovating buildings. Controlling orientation and windows dimensions offers management of the entry of sunlight in the indoor space which is essential for the user circadian cycle. which is a natural cycle of physical, mental, and behavior changes that the body goes through in a 24-hour cycle, and it is mostly affected by light and darkness.

Afterward, the intensity and color temperature of artificial lighting needs to be regulated and adequate for the specific activity performed in each space. The position of the lighting system in the building and the degree of its control and regulation by the users is also essential to ensure comfort and ought to be considered during design. Personal control can also extend to solar shadings and screens that play a role in adjusting the influence of sunlight on indoor temperatures and offer a certain degree of visual privacy from the outdoor.

Visual comfort is extremely important and depends on a lot of factors whether they are related to light and its characteristics or how the users perceive and interpret the view around them. The amount of daylight entry is one of the foundations in project design: how to regulate this necessary entry and how to limit it when needed to avoid its negative effects on users' comfort.

ACOUSTIC COMFORT

2.4 Acoustic comfort

The acoustical environment is often given little attention during project planning in comparison with the other comfort dimensions. However, noise levels may be detrimental to concentration, communication, rest or health which affects users' health and comfort.

2.4.1 General definition of acoustic comfort

This dimension of comfort depends solely on sound and noise. Sound is produced through the transmission of energy through air particles. When surrounding sounds become too intense, it causes discomfort and is considered as pollution. Noise pollution is another form of air pollution since sound transmission is only possible through air particles. To avoid noise and the discomfort it can bring users, there are some factors that need to be controlled.

2.4.2 Factors affecting acoustic comfort

To limit sound pollution in the indoor environment, there are some factors that can be controlled *(P. M. Bluyssen 2010)*. Here are some controllable aspects affecting acoustic comfort:

Sound sources

This factor includes the intensity & frequency of the sound emitted. These two parameters are the most important for the sound source as they define how much sound is created and how harmful (too loud or too high and low pitched) it is to the human ear.

Intensity level

Sound or acoustic intensity I is the power carried by sound waves in a defined area. However, the way our ears perceive sound can be more accurately described through the sound pressure level L_p which is the level of the intensity of a sound relative to a reference value. This aspect is measured in dB. The human ear can perceive sound in a range from 0 dB to 140 dB which is the maximum level of pain caused by a sound. Normal conversation and traffic range from 60 to 75 dB while loud music can go up to 110 dB.

Frequency

Sound frequency f is the pitch of the sound, it varies depending on the number of repetitions of sound waves per second. The human ear has a range from 20 to 20'000 Hz, however it is most sensitive to 3'000- 5'000 Hz. Multiple scientific articles analyzed the influence of different sound frequencies on health. It was determined that exposure to low and high frequency noise can cause irritability and annoyance as well as sleep disturbance and negatively affect the variation in heart rate *(Araújo Alves et al. 2020)*.

Sound distribution

This is related to how the sound is distributed in a certain space. It depends on reverberation time, sound insolation and sound absorption.

Reverberation time

Reverberation time T_r is the time needed for a sound to diminish in the environment and become imperceptible. Reverberation time depends

on the size of the space, and on the capacity of the surfaces and elements inside it to reflect or absorb the sound waves. When reverberation time is very long, the sound level diminishes slowly, resulting in words and sounds overlapping. On the other hand, when the reverberation time is too short, all types of sound lose quality and nuances. To ensure acoustic comfort, reverberation time should be corrected through sound absorption materials limiting the propagation of sound.

Sound insulation and absorption

Sound insulation R is the materials' ability to transfer the sound, since materials can transfer, reflect, and absorb sound waves, thus stopping its spreading. This materials' ability is then used to mitigate sound transfer from one space to another.

This transmission can be between outdoor and indoor spaces, or between two indoor spaces. The outdoor-indoor transmission is usually through air sound transmission which depends on the vibration of the building's façade. Thus, according to the type of façade, its vibrating response to sound waves is different, transmitting the sound differently. For the indoor-indoor transmission, it occurs through both air and contact sound transmissions. Either a sound source vibrates air that vibrates a separating wall which then vibrates air on the other side, or the sound source directly vibrates the wall through contact which then transfers sound into the other space.

In indoor spaces, the volume of the space has a big influence on the distribution of sound. The bigger the volume, the longer it takes for sound waves to reach a surface that can either absorb it, reflect it, or transfer it. In bigger volumes like offices, absorbent materials are essential to absorb most of the reverberating sound waves in the air. There are porous materials that maintain the sound wave inside like carpets, curtains, and fabric, while resonating panels transform absorbed sound waves into heat. Then there are resonators and perforated panels which dampen sound through small channels, behind which a porous material can absorb the sound.

There are also materials that reflect sound waves like concrete and plaster which can cause an echo effect. Echo is the reflection of sound due to hard or hollow surfaces causing the repetition of the sound waves on different time intervals. It can be prevented or reduced through absorbing materials on these surfaces.

Sound perception & interpretation

This is the human factor influencing sound. It depends on the users' concentration during an activity and their speech intelligibility.

Speech intelligibility

Speech intelligibility depends on the background noise and the difference between the two sources of sound. Reverberation time has an influence on clarity of speech hence the use of sound absorbing and dampening materials to shorten that reverberation time.

Concentration

Concentration depends on surrounding sounds and the degree of their uncomfortable influence on the user. It can be done by removing higher and lower frequencies that can be uncomfortable.

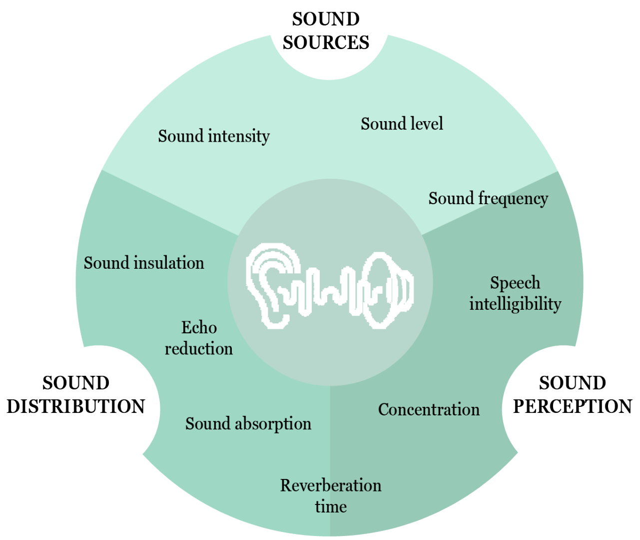


Fig 16: Measurable factors influencing user acoustic comfort

In summary there are two ways to control these aspects either control the characteristics of the sound source like intensity and frequency or correct sound distribution that can cause discomfort through absorbing materials. Limiting noise transfer between outdoor-indoor spaces or indoor rooms through sound insulation is also essential to reduce acoustic discomfort and its negative effect on human productiveness and psychological state.

2.4.3 Non measurable factors affecting acoustic comfort

In some studies, it was determined that the users' background of origin and their habits had an influence on their tolerance and sensitivity towards noise and acoustic discomfort. For users who have lived most of their lives in noisy neighborhoods or big cities have a higher tolerance towards noise than those who lived in calmer regions *(Frontczak and Wargocki 2011)*.

2.4.4 Design measures for acoustic comfort

There are many factors influencing sound and how users perceive it. There are two main sources of noise, outdoor noise for example from traffic noise outside, which cannot be completely controlled, only mitigated, and reduced by highly insulating the outdoor and the indoor environment.

However, for indoor noise produced from mechanical equipment in adjacent spaces or machines and voices in the space, there are multiple design aspects that can be controlled. For instance, the ratio between the volume of the space and the insulating materials used in said space has a great effect on acoustic comfort. Likewise, reducing vibrations and noise transmitted through contact or air, due to sanitary appliances, ventilation systems and other machinery in buildings, must be a priority while designing spaces for these elements.

This dimension might have a lesser influence on other comfort dimensions, but it has a great influence on user comfort. It affects both the health and well-being of the user since it can cause anything from just mild irritation to serious psychological health risks.

2.5 General Conclusion

In this section, the main dimensions of comfort were explored, what factors affect each of them, and how these factors can be controlled to ensure better users' comfort. Some of these factors influence multiple dimensions and in almost all dimensions, the users' personal control on their surroundings had a huge influence on their comfort. The interactions and influences of the four dimensions on each other is briefly explained and illustrated with the figure below.

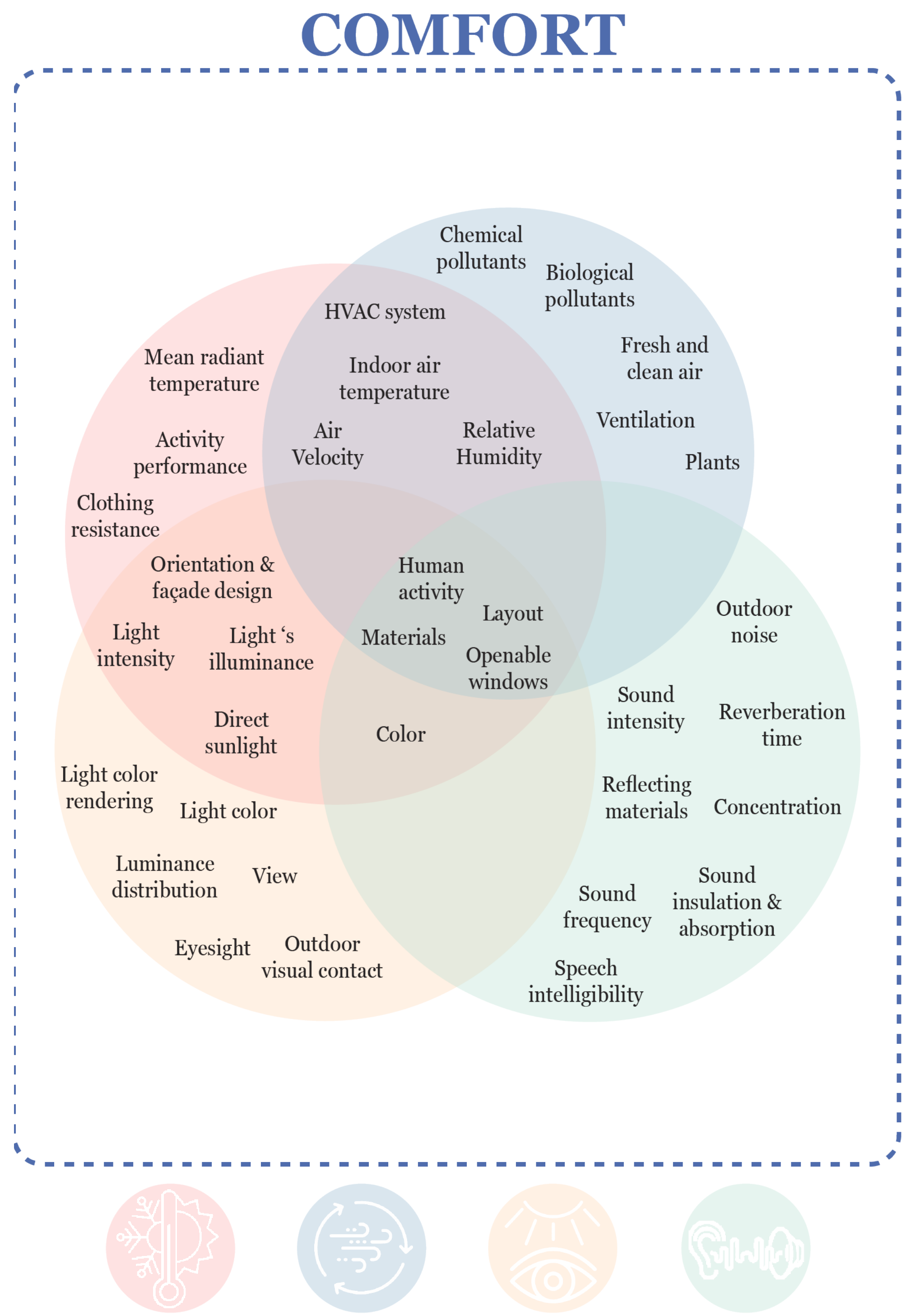


Fig 17: Relationship between physical dimensions of comfort

COMPARISON OF CERTIFICATIONS AND USER COMFORT

After this summary of the main dimensions of users' comfort in a building and how to control them, the core of this section will be how they are integrated in the certifications of focus, and where are the limits and discrepancies.

In order to identify those inconsistencies, multiple case studies on occupant comfort and the quality of indoor environment in certified buildings are considered. However, there were some limits to these case studies. Most of them examined the indoor environment of office buildings, particularly comparing conventional buildings without certifications with newer or renovated green-certified buildings. Another hindrance was the limited number of case studies done on some of the studied certifications like Minergie ECO.

3.1 WELL certified buildings effect on user's comfort

This standard is considered the first to focus on the people in the building. It is composed of 11 main principles with a score-basis system. These principles are Air, Water, Nourishment, Light, Movement, Thermal comfort, Sound, Material, Mind, Community & Innovation. Thus, this certification considers the four comfort dimensions discussed above and approaches other non-measurable dimensions that affect the users' comfort.

3.1.1 Concepts and principles of WELL certification

Each of the 11 principles has its own list of preconditions and optional criteria. Projects must achieve all preconditions which are not allocated points. In order to achieve different levels of WELL certification a certain number of points should be obtained through optional criteria called optimizations.

To discover this certification and its criteria, the 11 principles will be inspected and outlined.

Air

This principle considers air quality in the indoor environment. It is composed of 4 preconditions and 10 optimizations. The 4 preconditions deal with ventilation systems and pollutants control whether it be gaseous or organic pollutants and their sources from human activity like smoking to construction materials.

As for the optimizations, they range from the user control through openable windows, to air supply, filtration, and monitoring, and also source control through source separation and minimization.

Water

This principle considers the access to clean water inside the building. It is composed of 3 preconditions and 6 optimizations. The 3 preconditions deal with water management, distribution, and quality in the building to avoid any negative effect on human health.

As for the optimizations, they consider the promotion and importance of hydration for human health, as well as the high quality of drinking water. They also ensure hygiene support through bathroom availability in addition to the re-use of water to avoid water waste.

Nourishment

This principle considers the healthy nutrition substances and their availability in the building. It is composed of 2 preconditions and 12 optimizations. The 2 preconditions deal with the consumption and accessibility to healthy and diverse food like fruits and vegetables.

As for the optimizations, they range from the quality and sources of offered nutrition as well as its variability, to providing spaces for food preparation and production on site, as well as nutrition awareness and education for users.

Light

This principle considers visual comfort in the indoor environment. It is composed of 2 preconditions and 7 optimizations. The 2 preconditions deal with the necessary amount of light inside the building through both natural and artificial lighting.

As for the optimizations, they range from promoting user control to the lighting design to aid the circadian cycle and increase daylight exposure, as well as the quality of artificial light and avoidance of discomfort sources.

Movement

This principle considers physical activity in the indoor environment. It is composed of 2 preconditions and 9 optimizations. The 2 preconditions deal with the ergonomic furniture and design of the space to facilitate physical activity.

As for the optimizations, they range from promoting physical activities through space design, equipment and circulation, as well as encouraging cycling and use of public transport with the site planning and selection.

Thermal comfort

This principle considers thermal comfort in the indoor environment. It is composed of 1 precondition and 8 optimizations. The precondition ensures an acceptable thermal environment for most users.

As for the optimizations, they consider user control through openable windows or thermal zoning, as well as the monitoring and control of humidity and ventilation rates affecting thermal comfort.

Sound

This principle considers acoustic comfort in the indoor environment. It is composed of 1 precondition and 8 optimizations. The precondition considers noise control through planning and space design.

As for the optimizations, they range from acoustic conditioning through sound isolation and absorbing materials, as well as high-performance audio technology and promoting awareness of risk of hearing loss.

Materials

This principle considers used materials in the indoor environment. It is composed of 3 preconditions and 9 optimizations. The 3 preconditions deal with the quality and management of construction materials in the building to avoid any health risks to users.

As for the optimizations, they range from the control of all types of materials and chemicals on site, as well as waste management and exposure reduction to hazardous materials.

Mind

This principle considers psychological and mental health. It is composed of 2 preconditions and 9 optimizations. The 2 preconditions deal with mental health promotion as well as connection to nature.

As for the optimizations, they range from mental health education and aid through support programs and promotions as well as a higher connection to nature in the interior design.

Community

This principle considers the influence of community on user's health. It is composed of 4 preconditions and 16 optimizations. The 4 preconditions deal with the well-being and health of users as well as their safety and their integration in the design, in addition to the importance of users' opinions through surveys.

As for the optimizations, they range from the well-being of the users and their family through different support groups and programs as well as health benefits, to diversity and accessibility both in design and community. They also promote emergency resources and plans for users.

Innovation

This principle is composed of only 6 optimizations with no preconditions. The 6 optimizations deal with the evolution of the Well certification by proposing new interventions and the promotion of well-being education and importance of sustainability and green certifications.

Following this small summary of the Well certification aspects, the diversity of their goals can be observed. This certification considers the 4 dimensions of comfort: thermal, visual, acoustic comforts as well as air quality, as well as a unique attention to non-measurable aspects like physical activity and healthy nourishment that influence not only users' physical health but also their psychological and mental health.

3.1.2 Case studies' analysis of WELL certified buildings

To discover the effectiveness of the WELL certification with its multiple principles inguaranteeing user comfort, health and WELL-being, multiple case studies of users' opinions and satisfaction in WELL certified buildings are analised in this section.

In the majority of the case studies, the WELL certified buildings had a higher satisfaction rate with non-environmental parameters like furnishings, colors and textures *(Licina and Yildirim 2021)*. The higher satisfaction with maintenance and cleanliness was also noted in the WELL certified buildings than conventional ones. Nevertheless, that higher satisfaction was insignificant in comparison with other certified buildings like BREEAM *(Ildiri et al. 2022*).

However, for the physical and measurable dimensions, there were some discrepancies. Generally, most WELL certified buildings have a higher satisfaction rate than conventional buildings, particularly with air quality despite the occasional higher concentration of VOCs and the measurements of some factors out of requirement zones *(Licina and Langer 2021)*. Noise and acoustic comfort were the most problematic physical dimension in all case studies followed by temperature and thermal comfort.

For the acoustic comfort, the reason might be due to the plan and layout of offices that are predominantly open plans with low separations and partitions between workstations. As for thermal comfort, there was an increase in satisfaction than in non-certified buildings, although the dissatisfaction with temperature might be in some cases due to the absence of personal control or temperature fluctuations *(Licina and Yildirim 2021)*. For light and visual comfort, satisfaction levels varied from one project to the other. Some had a higher visual and privacy satisfaction, while others had a non-significant or sometimes negative difference between WELL-certified and non-certified buildings.

In some of the case studies, there was an analysis of time's influence on satisfaction in certified buildings. For this study, there was a time gap of 7-8 months between two surveys done in the same WELL certified buildings to identify if there is a difference in occupant's satisfaction. In most cases there were not any remarkable differences except some seasonal influence on temperature and light *(Licina and Yildirim 2021)* or a better air quality measurement in the later survey due to fresh paint produced particles present in the air after relocation *(Licina and Langer 2021)*.

Despite the insignificant time effect on satisfaction proven, a regular occupant satisfaction survey and maintenance is necessary to guarantee the certification status of a building. This act is necessary due to the occasional out of recommended standard limits of some physical factors like the relative humidity in the case study done by Licina and Langer *(Licina and Langer 2021)*. In this case study the relative humidity measures were out of the recommended values which are between 30%-60%. It was also observed that the higher level of certification doesn't necessarily guarantee a higher level of comfort, as a decrease in satisfaction can be noted in one of the buildings with a platinum WELL certification in the case study done by Licina and Yildirim *(Licina and Yildirim 2021)*.

3.1.3 Limits and opportunities of WELL certification

Despite WELL certification being solely focused on the well-being and health of the user inside the built environment, it isn't able to completely guarantee their comfort.

This certification has its advantages related to the non-environmental aspects which are not always considered in other certifications, like the importance given to mental and psychological health through different awareness programs or even physical and physiological health through nourishment quality and the promotion of physical activity. It is one of the few certifications that include the importance of accessibility, diversity and comfortable furniture which boosts the user's mindset and performance.

However, there are still problematic physical dimensions like acoustic and thermal comfort to be improved. Although the four physical dimensions

of comfort are the usual components of comfort in most scientific studies *(Sarbu and Sebarchievici 2013),* these dimensions have the least number of preconditions and optimizations in the Well certification. Some even having only one precondition with a global definition and criteria to guarantee comfort.

WELL certification has a major focus on non-environmental and non-physical dimensions of comfort although these are the more accessible dimensions to control during the design of the building, while most of the other principles can only be managed by the owners and management of the building after its completion. Thus a distribution of these principles into design-dependent and service-management-dependent categories might aid both the architects and the developers to better understand and apply this certification *(Potrč Obrecht et al. 2019)*.

WELL has a comprehensive insight on users' well-being and comfort, but it can be time-consuming and demands effort from the designing team on specific topics unrelated to design *(Potrč Obrecht et al. 2019)*.

3.2 Minergie certified buildings effect on user's comfort

Minergie is the oldest and most used building certification in Switzerland. It focuses mainly on climate change and the energetic efficiency of buildings. It isn't really considered a user focused certification, nevertheless there is a complimentary certification that can be added to the Minergie label called ECO. This complementary certification proposes a component focused on the health and well-being of the users as well as the ecological aspects of the building.

3.2.1 Concepts and requirements of Minergie certification

Minergie is established to attest the high energy efficiency and comfort of new and refurbished buildings in Switzerland, associated with the annual energy consumption of the buildings for space heating, hot water and electrical ventilation. Despite having occupants' comfort as one of their main goals, there are no specific requirements to attain that goal except for thermal comfort and air ventilation which is one of the outcomes of the required energetic efficiency.

This certification isn't score-based like most of the green building certifications, nor does it have different levels. However, there are 3 different Minergie certifications that have various degrees of energy efficiency and production.

The main requirements for all Minergie certifications are:
- envelope airtightness and insulation
- use of energy-efficient ventilation system
- a large proportion of renewable energy supply and production.

As for the other two degree of certifications, Minergie-P pushes the limits of the energy efficiency by having a more efficient envelope in order to lower energy consumption while increasing thermal comfort all year long. Minergie-A requires a high level of energetic independence via auto production of energy (solar panels, load management, geothermic energy… etc).

The complementary certification Minergie-ECO includes aspects related to health and ecology of the construction. Indoor air quality (IAQ), natural lighting, noise protection and sound insulation are taken into consideration in the upgraded Minergie-ECO label. This complementary label also considers the design of the building, its flexibility and life cycle as well as the construction materials and their impact on the environment.

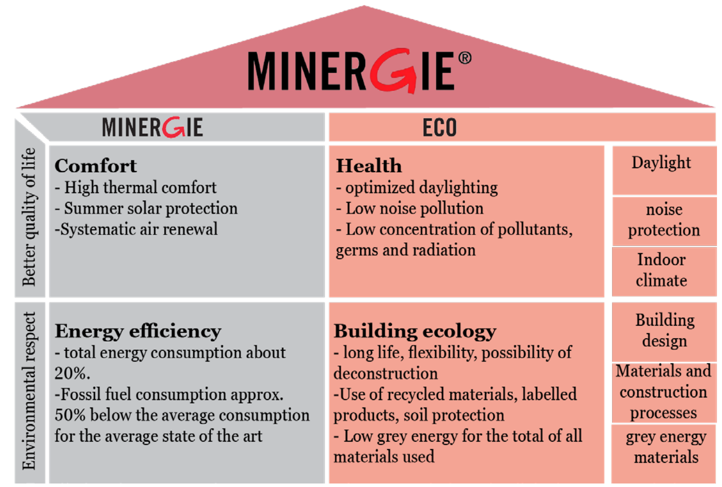


Fig 18: Criteria of Minergie & Minergie-ECO

All buildings with a surface greater than 2'000 m2 must be equipped with energy monitoring systems as well as all Minergi-A certified buildings regardless of their size. Random controls can be effectuated on Minergie-Eco buildings to verify the regularity of the requirements and the quality of the indoor environment.

The different Minergie certifications have one main goal: high energy efficiency, with the user comfort as a complementary goal. However, sometimes this high energetic efficiency of buildings can become a hindrance to user comfort.

3.2.2 Case studies' analysis of Minergie certified buildings

As this certification doesn't necessarily focus on user comfort, the goal was to focus on the complementary certification Minergie-ECO. However, since this certification is primarily used in Switzerland with no wide international reach, case studies on Minergie certified buildings were limited. There are two case studies considered in this essay: the first compares between four offices with different Minergie certifications *(Pastore and Andersen 2019)*, while the second compares Minergie housing with energy-renovated dwellings *(Yang et al. 2020)*.

There is a consensus that green-certified buildings are perceived as more comfortable than conventional ones, even if they are energy-renovated. Nevertheless, there is still discomfort in these certified dwellings due to air quality. To achieve the Minergie standard, the building must be airtight with low air infiltration which can result in poor air quality if not sufficiently compensated with a proper ventilation system *(Yang et al. 2020)*. This can also be perceived in the office building with the ECO certification having no openable windows. This lack of control of occupants had a huge influence on their level of discomfort and complaints about "stuffy" or "smelly" air *(Pastore and Andersen 2019)*.

Other problematic dimensions noticed in the office building with the ECO certification regarding the other Minergie certified offices are acoustic and thermal comfort. The main source of the noise complaints was the HVAC and building systems, probably not properly insulated. As for thermal comfort, temperature was perceived as too cold even in summer, probably due to the central air conditioning system without any personal control which was one of the main reasons of discomfort *(Pastore and Andersen 2019)*.

As for visual comfort, it was overall acceptable with some episodes below the acceptable range. However, concerning the outside view, the ECO-certified building was poorly evaluated due to "bad view" but with no high influence on the overall comfort of the building. Despite having the complementary ECO certification, users' comfort in this building was lower than in a building with a basic Minergie certification, with a similar ceiling radiant system. The difference between the two lies in the openable windows and the automated shading system.

It was proved that despite the compliance of multiple factors with the norms and the recommended values, the users' comfort was not achieved or guaranteed in any of the Minergie-certified buildings. None of the studied buildings reached the 80% satisfaction threshold which confirms the inadequacy of this certification in ensuring users' comfort.

3.2.3 Limits and opportunities of Minergie certification

Minergie certification is solely focused on energy efficiency with exact values and norms for energy consumption, production, and the use of renewable energy sources with airtight buildings. Even though user comfort is one of their declared objectives, there are no specific criteria in their requirements so as to achieve that goal.

This certification has a positive influence on the environmental aspect through the promotion of renewable energy use and the reduction of the use of fossil and polluting sources of energy and materials. This attention to renewable energy and reduction of pollution also benefits user comfort even if indirectly, as the decrease of general pollution improves user general health and well-being.

All types of Minergie certifications supposedly ensure user thermal comfort & air quality through the HVAC system that is also energy efficient. However, this high energy-efficiency and airtightness required in Minergie certification occasionally negatively influence user satisfaction & comfort in the indoor environment due to the lack of user control on their surroundings; as well as the fact that other comfort dimensions such as visual and acoustic comfort are not even addressed.

Even in the complimentary certification Minergie-ECO, that supposedly focuses on user comfort, comfort dimensions are not well addressed with only general requirements. For instance, for visual comfort, only the amount of natural daylight is considered with no mention of the quality of artificial lighting nor the importance of external view which are major factors in guaranteeing user visual and general comfort. This also applies to acoustic comfort as well as air quality, as this certification considers only some of the factors affecting these comfort dimensions, which doesn't ensure user comfort.

In summary, this certification with a major focus on energy efficiency doesn't really contribute to user comfort even though it is normally one of its main goals. This certification can even negatively affect user comfort with its high energetic and airtightness standards. In spite of the existence of the complementary certification Minergie-Eco focusing on user comfort, this certification can't guarantee nor achieve user comfort.

3.3 LEED certified buildings effect on user's comfort

This certification is one of the oldest and most used green building certification internationally. It was designed to assess the environmental and social sustainability of a building through its life cycle, from its design to its use and maintenance. Even though it puts minor focus on the health aspect, it is so widely applied all around the world that it is necessary to study its influence on the users and their experience in the built environment.

3.3.1 Concepts and principles of LEED certification

LEED provides a framework for healthy, energy-efficient, carbon and cost-saving green buildings, it became a symbol of sustainability achievement. This score-based certification has 4 levels depending on the number of points earned by adhering to prerequisites and credits that address its main principles. Their score system considers multiple factors from energy to water resources. These factors are divided under 9 principles, yet the distribution of the score depending on their relevance to general sustainability aspects are represented in the figure below.

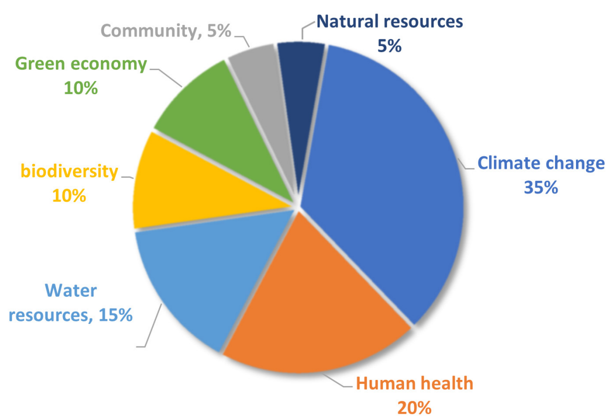


Fig 19: Distribution of LEED credits

To discover this certification and its criteria, its 9 principles will be inspected and outlined.

Location and Transportation

This principle is composed of 7 criteria. Half of the points are allocated to the conservation of ecosystems and resilience of the community culturally and economically through the site choice of the building. Whilst the other half of the points cover access to transportation mediums with a positive environmental footprint and the reduction of motor vehicle use.

Sustainable sites

This principle is composed of 1 pre-requirement and 6 criteria. This principle promotes the reduction of all forms of pollution from construction materials and operation to light pollution, as well as the protection of surrounding ecosystems and their interaction with the users through building design.

Water efficiency

This principle is composed of 3 pre-requirements and 4 criteria. This principle considers water consumption in order to reduce it as well as optimize its use and management to conserve this vital natural resource.

Energy and Atmosphere

This principle is composed of 4 pre-requirements and 6 criteria. This principle considers the energetic efficiency of the project all while reducing all related pollution sources and guaranteeing the quality of indoor environment. It also promotes the use of renewable energy and reducing greenhouse gas emissions.

Materials and Resources

This principle is composed of 1 pre-requirement and 5 criteria. This principle considers the project's life cycle impact on the environment through waste management as well as the use of more eco-friendly and less hazardous materials.

Indoor environmental quality

This principle is composed of 2 pre-requirements and 9 criteria. This principle mainly focuses on the indoor air quality and pollutants control and elimination, with a minor consideration for thermal and acoustic comfort, as well as visual comfort through external view and the balance of natural and artificial lighting.

Innovation

This principle is composed of 2 criteria that encourage innovative solutions that benefit human and environmental health and equity.

Regional priority

This principle is composed of 1 criterion that promotes addressing any particular concern based on the regional or geographical location.

Integrative process

This principle is composed of 1 criterion that considers the high-performance, cost-effective, and equitable aspects of the project.

Following this small summary of the LEED certification principles, the diversity of their goals can be observed. This certification considers the environmental impact of the building and its construction and operation. In addition, it is also attentive to the user comfort in the indoor environment.

3.3.2 Case studies' analysis of LEED certified buildings

There are a lot of case studies done on LEED certified buildings due to its international reach. However, most of them exhibit their flaws and limitations.

In general, all LEED certified buildings had a better satisfaction rate for the overall building, furnishings, maintenance and cleanliness in office buildings *(Altomonte and Schiavon 2013)*. However, for the physical comfort dimension as visual and acoustic comfort, LEED certified buildings have a lower satisfaction rate in offices or no significant differences with non-certified buildings *(Vosoughkhosravi, Dixon-Grasso, and Jafari 2022)*. As for air quality and thermal comfort, there was a general higher satisfaction than non-certified buildings though still an overall low satisfaction for thermal comfort.

Considering that LEED certification doesn't necessarily focus on the users' comfort, Vosoughkhosravi et al. attempted to investigate the benefits of being LEED certified by comparing the energetic performance and the user comfort in LEED and non-LEED certified campus buildings. It revealed that despite the higher energy consumption of the LEED certified building, the indoor environment quality and the users' comfort didn't exceptionally improve compared to its non-certified counterparts. In some cases, it even had lower satisfaction rate like with water pressure and temperature.

In summary, despite its widespread and use around the world, many studies demonstrated LEED's many flaws and limitations not only in achieving users' comfort in the built environment, but also in having a better environmental impact than non-certified buildings.

3.3.3 Limits and opportunities of LEED certification

LEED certification addresses the sustainability of its projects through multiple principles ranging from energy efficiency to user health and well-being. Being LEED certified grants the project and its owners sustainability credentials and increases its value and their public image while reducing operating and maintenance costs.

It has a major focus on the environmental impact of materials, construction and operation phases. Nonetheless, following the different LEED criteria and principles doesn't guarantee the sustainability of the project as some projects could still get LEED-certified despite the unsustainability of its surrounding area or by achieving criteria with minor impact on the environment as they are easy to achieve.

Despite the multiplicity of its principles, this certification is not comprehensive in its assessment of health and well-being, as it only has a major focus on certain aspects of health, such as air quality while not properly addressing other comfort dimensions like acoustic or thermal comfort.

Additionally, the energetic efficiency was proved to be problematic in some projects where LEED certified buildings were consuming more energy than their conventional non-certified counterparts without any improvement in comfort dimensions or other environmental aspects.

In conclusion, this section established a homogenous conclusion between the different certification schemes through multiple case studies. The different green-buildings' certifications don't necessarily achieve users' comfort. Although there is a general unanimity that green-certified buildings have a higher satisfaction rate than conventional buildings, this is probably due to an improvement in "soft" non-environmental dimensions like furnishings, colors, maintenance, and cleanliness.

Most of the environmental dimensions were slightly better or with no significant difference between certified and non-certified buildings. Although some dimensions like acoustic comfort are still problematic in most cases. Certifications are therefore necessary for the overall comfort of users as well as the environmental impact of the building, but there are still some limitations and flaws that must be improved and strengthened *(Potrč Obrecht et al. 2019)*.

ARCHITECTURAL IMPACT ON COMFORT

As we have seen, most certifications are focused on the measurable physical dimensions of comfort like thermal comfort, visual comfort, acoustic comfort & air quality. Some standards and certifications treat other non-environmental dimensions like maintenance and furnishings which improve user satisfaction with the overall building. However even by following the criteria of these certifications, there are still some limitations and discomfort in some physical dimensions like thermal and acoustic comfort in general.

Thus, green building certifications do have a positive impact on users' comfort, but they are not sufficient. That's where architects have more impact since they ensure the functionality of the measurable physical dimensions but also can use the non-environmental dimension to improve user comfort through design.

4.1 The architect's impact on comfort

When searching for synonyms of the noun architect, there are many results ranging from designer, artist and creator to planner and engineer. This diversity of synonyms stems from the numerous roles the architect usually plays in a project.

They are usually the decision makers from the spatial setting and relation of the object to its context, spatial functionality, structure and aesthetic aspects, its environmental, social and cultural impact to its use, maintenance and end of life *(Majerska-Palubicka 2019)*.

Therefore, there is a role of architects that combines their knowledge of technical systems as well as their social connection to users allowing them to conceive and design spaces, directly affecting the users comfort; particularly in renovation projects.

4.1.1 Architects’ position on technical systems

Some of the dimensions as discussed above must be considered while designing the building, from the HVAC system ensuring thermal comfort, to the proportions of windows and transparent surfaces in the façade influencing visual and thermal comfort. These elements are usually restricted and regulated by the standards’ values and criteria from the indoor air temperature to the intensity of light indoors. However, it was proved that following norms and being in the recommended values for the physical dimensions don’t necessarily ensure the users’ comfort.

The different technical systems, whether it be the HVAC and ventilation system or the artificial lighting systems, must be integrated in the built project. In the 20th century, when these technical systems became more and more prominent and necessary in the built environment to ensure a higher indoor comfort, architects began to invent new ways to integrate them in their design. This integration was done by adapting these technical systems to the architectural form like in the Guggenheim Museum building in New York. In this building, Frank Lloyd Wright adapted the HVAC system to follow the natural spiral form of the ramp while creating certain vertical points for the connection between floors.

In other cases, these technical systems created the aesthetic language of the building like in the Rinascente Department Store in Rome. The architects Franco Albini and Franca Helg exploited the technical air conditioning systems to create the building’s unique architecture. The air supply and evacuation ducts in this dual duct system created the façade’s rhythm *(Marino and Graf 2016)*.

Nonetheless, in renovation projects, the different technical systems can cause complications due to their inefficiency in ensuring user comfort or due to not meeting the current requirements set by norms and certifications. The level of difficulty in replacing these systems varies between projects.

There are projects where their replacement with a similar system or its refurbishment is possible, thus preserving one of the building’s aspects while guaranteeing user comfort in the indoor environment. However, in some cases, due to the complexity of the original system or due to economic or accessibility reasons, the original system becomes obsolete, and a new

system is integrated in the building. This change of systems occurred in the renovation of Rinascente Department Store, where the centralized dual-duct air conditioning system has been replaced by several induction sub-systems *(Marino and Graf 2016)*. That system replacement might not have affected the appearance of the building however it altered its essence and the reason for its architectural unique character was replaced.

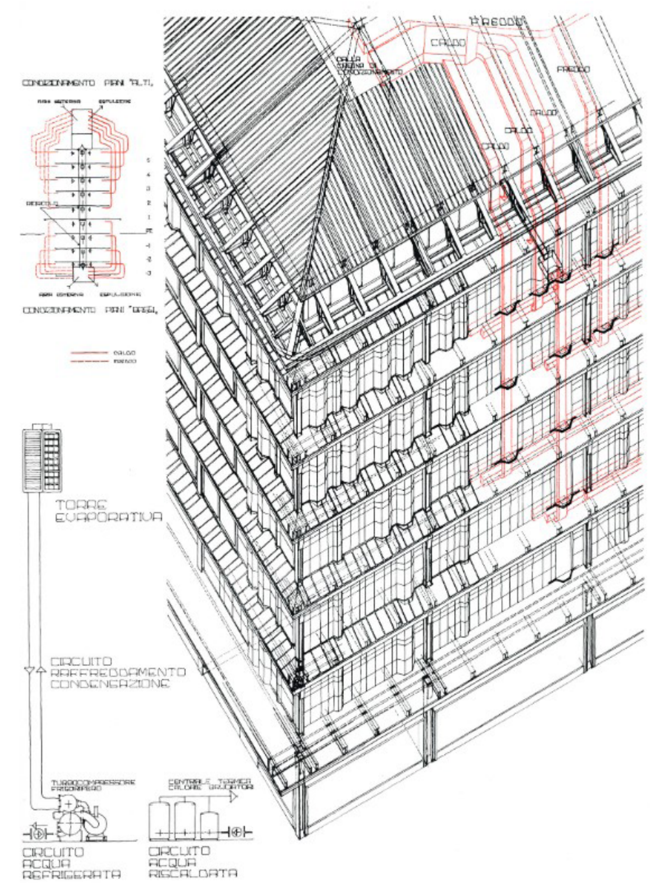


Fig 20: Diagram of the double distribution of the air conditioning networks

The integration of these technical systems that partakes in the users’ comfort are one of the roles of an architect. Their adequate integration in the design of the building, sometimes even to the point of them influencing and improving its architectural character, exhibits the architects’ skill and talent.

4.1.2 Architects' social role

Architects have an immense influence on the "world and the people in it" *(Frausto et al. 2016)* as they have multiple interventions from houses to cities and infrastructure. That's why the contact between architects and the "people" and their needs is essential in every project. The user is and should always be at the center of every project. Some certifications like WELL try to put this concept forward by giving some criteria to achieve users' comfort.

However, these general values and norms can't achieve user comfort since it is a sensation that varies between different users. Architects usually are in contact with the client or owner which in most cases are not the users. For example, in office or commercial buildings, architects are in contact with the management. However, their preferences and goals don't necessarily benefit users' comfort. There is usually an inconsistency between the view of management and that of the employees on the benefits of green certification *(Armitage, Murugan, and Kato 2011)*. The architect doesn't always have access to the users' opinions and preferences. Therefore, the importance of the direct connection between the user and the architect should be encouraged and fortified.

Putting the user in the center of building design as a part of the built environment is essential considering that users are active components of it *(Vischer 2008)*. They don't just experience the indoor environment; they also interact with it and alter it. Therefore, while designing the indoor space, architects must allow users to have personal control on their environment whether it be by having control on measurable elements like temperature, air renewal and the amount of daylight entry in the space, or by having a flexible space that can change easily depending on the users and their activities.

Currently, with the high energetic performance standards and norms, the aspect of user control is less and less adopted especially in Switzerland *(Pastore and Andersen 2019)*. In order to ensure an airtight building with no energy loss, buildings are designed with central systems without the possibility of individual control, from automated shading systems to inoperable windows. This increase of user control should naturally be accompanied with users' education on the use of the building *(Potrč Obrecht et al. 2019)*.

The users' education on the use of the building should include an understanding of the functioning of the building to better interact with it. Depending on the building and its systems there are better moments for natural ventilation to limit energy loss, for example night cooling should be encouraged with high thermal mass buildings. This better understanding can also help users to adapt their environment to ensure better comfort while saving energy for example by shutting down artificial light when daylight is sufficient...etc.

This is when the architects' knowledge and connection to the user is essential as they should be able to spread this knowledge to users. This connection can sometimes be established when the owner and/or management of the project are well informed of its importance. However, to make it more prominent and effective, a more influential force is needed which can be through certifications.

This social connection between the architect and the user doesn't only affect the technical decision in a project to ensure comfort, it also has a great influence on the design process.

4.1.3 Architects as designers of space

Architecture surpasses the technical design of a building as it also focuses on the space by creating its boundaries and how users interact with this space *(Frausto et al. 2016)*. They don't just design the space and how it's used comfortably by its occupants, but they also ought to take into consideration the possibility of change of use in this space and how it can be adapted to the new functions.

That aspect of space design has different opinions and theories. The Corbusier created the Modulor, which is a scale of harmonious proportions based on the measurements of a human body, and used it to create functional, well-proportioned, and comfortable spaces *(Ostwald 2001)*. It was used in the Unité d'habitation to create the perfect space for a defined number of people, to set the adequate height for each floor and even in smaller details like paint patterns or the shading system.

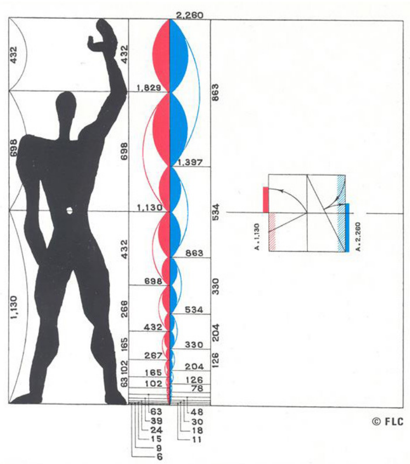


Fig 21: Le Corbusier's Modulor
© FLC/ADAGP

However, this rigorous system of design following specific measurements is somewhat different to his earlier theories of the five points of new Architecture that included the free plan *(Oechslin and Wang 1987)*. The free plan is the concept of a floor plan free of all load-bearing walls that enables a more flexible interior space design. That concept was employed by other notable architects like Ludwig Mies Van der Rohe in the Barcelona Pavilion.

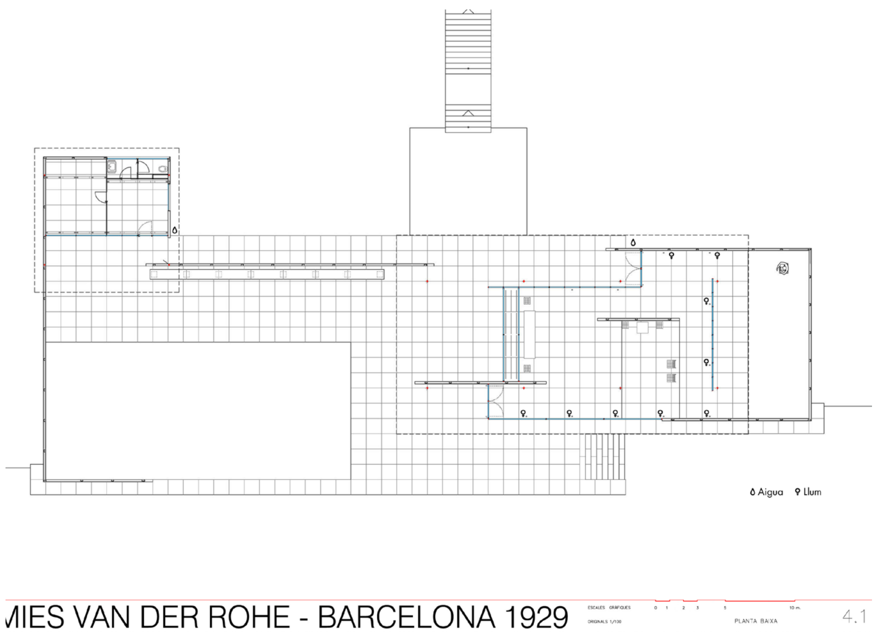


Fig 22: Barcelona Pavilion plan by Mies Van der Rohe

That free plan might even be the predecessor of the growing office open plans of today. The flexibility and the possibility of modification in an interior space is becoming more and more appreciated and required. However, to ensure users comfort in such an open space, there are also other non-technical aspects that must be considered by the architect during the design of the space.

ERGONOMIC DIMENSION

4.2 Ergonomic dimension

Candidly, ensuring full users' comfort might be unattainable due to the variability of each person's level of comfort. Nonetheless, there are multiple decisions taken during design that can improve the users' comfort. These decisions go beyond choosing a building's technical systems or designing the façade. It is the design of space, from the general layout, materials and colors to furnishings and decor. All these aspects can be grouped under what will be addressed here as the Ergonomic dimension.

4.2.1 General definition

Ergonomics is usually considered as the study of the design of furniture, equipment, or products and how they affect people's ability to work effectively through psychological and physiological principles. However, Ergonomics will be redefined in this part to have a more global meaning as it will not be specific to product design but to space design.

Ergonomics is the study of human behavior and interaction with their surroundings in order to design spaces and products more adapted to the user. This is in fact what an architect does unknowingly, or without giving it a specific denomination, especially that this dimension can't be measured and can't be represented in certifications *(Potrč Obrecht et al. 2019)*. This dimension can't be measured because there isn't a best solution in the absolute. It is usually a different solution for each special case with similarities and differences from one case to the other.

4.2.2 Comfort through ergonomics

Since this dimension isn't a physical and measurable one, there aren't specific factors that influence comfort in spaces. However, there are aspects and domains that architects consider and examine during space design that affect users' comfort.

Layout

Spatial layout is usually described as the position of furnishings and equipment in a space, with their exact shape and size, the spatial relation between them and how people interact with them. However, in architecture spatial layout embodies a wider significance including the partitions as space dividers and limits and defining the functionality of the space and how it will be used. It's been revealed that building layout and design had a significant impact on users' comfort and satisfaction *(Pastore and Andersen 2018)*.

For instance, in office buildings, depending on the type of work, an open- space layout with few private offices enhances the work experience in some cases or can be unfavorable in others *(Altomonte and Schiavon 2013)*. However, each plan choice has its own consequences on comfort due to different complications that might be produced. For example, open-space offices tend to have more acoustic problems and indoor noise due to the bigger volume with few separations or partitions *(Licina and Yildirim 2021)*, while private offices require a more detailed ventilation system to ensure ventilation in each cubicle or office.

Colors and materials

The highlight of colors and textures' importance in architecture was significant in the 20th century, during the Modern architecture era. Most of the architects in this period studied the influence of color and textures on human behavior and had a specific reason for every material and color used in the designed space.

For example, le Corbusier, the French-Swiss architect, had a whole color theory that he used in his works and projects. He created a color palette that he upgraded and continually implemented new hues. In this palette he relied on three principles: using natural colors to create certain atmospheres, using contrast and hues to enrich the space, and deploying transparent pigments to alter surfaces and how the eye perceives space *(Budds 2016)*. He employed color theory as well as the finishings of concrete (smooth or rough with the imprint of the formwork/casing)

Other modern architects used specific materials and colors depending on the use of the space. Jean Tschumi, the Swiss architect, used in the "Mutuelle Vaudoise Accidents" headquarters in Lausanne specific colors in different levels to improve performance. He used green for its calming effects in levels that were intended for heavy and noisy machinery, while using brighter colors like yellow and red in the office intended levels to boost alertness and thus improve work efficiency and concentration. He also employed specific colors in art works accompanied with the material of offices. Some levels had wooden desks that complemented the warm colors of a painting while the other had metal desks and chairs to compliment the colder colors of art works.

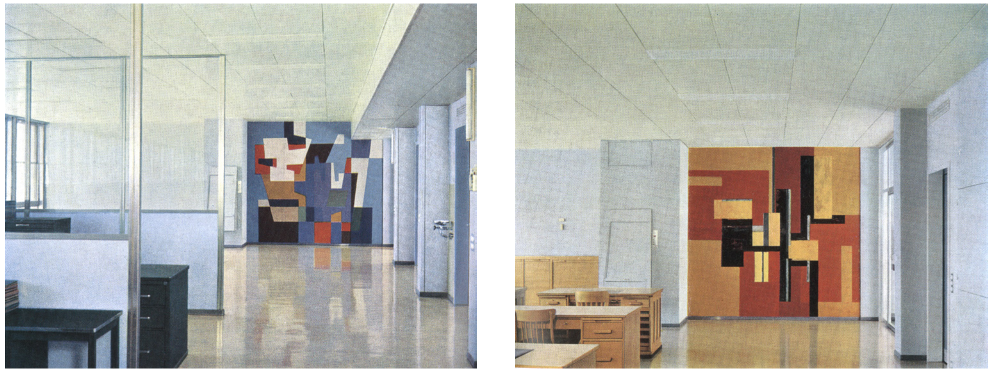


Fig 23: Paintings, colors and atmosphere intended for different office levels of the Mutuelle Vaudoise building

There was a lot of thought and consideration for the influence of colors and textures in the 20th century that is slowly diminishing in our contemporary architecture. While some articles and research are interested in polychromy and its effects on human behavior *(Grzegorzewska and Kirschke 2021)* this field is not well addressed and explored both by architects and certifications in most cases.

Plants and natural materials

As mentioned above, materials and textures influence buildings' users and their comfort and psyche. There are multiple articles and research papers that prove the positive influence of natural material like the use of wood in buildings' interior on users *(Khusaini, Pradana, and Kusmayandi 2022)*. Plants and vegetation also have a very positive effect on users in the built environment.

Plants have a double role in building design, it has a positive psychological effect as part of the décor, but also has an active role in air purification as mentioned before and can also be used as separation or partition. The ingenuity of the architect is how they can integrate it in the design, making it a fundamental element rather than an expendable piece of decor or object.

Fig 24: Integration of plants in indoor space design
© Alexandre Oliveira – Jafo Fotografia

This dimension with its multiple aspects also influences the other technical or measurable dimensions discussed above. For example, colors can influence visual and acoustic comfort as it was revealed that green walls can enhance acoustic comfort *(Grzegorzewska and Kirschke 2021)*. Materials also impact visual and acoustic comfort due to their sound insulation and their reflection properties. Plants as discussed above have a great impact on air purification which improves air quality. These mutual aspects influence multiple dimensions of comfort, and these influences have to be considered while designing the space. The below figure is an illustration to summarize the links between the different dimensions with the Ergonomics dimension and comfort.

This dimension of ergonomics is very vast and contains more aspects and criteria that are unmeasurable and uncontrollable. The focus in this part was on some of the aspects that can be managed by the architect in their design and that can contribute to the improvement of users' comfort. As these aspects and factors can't be regulated in certifications, it's the architect's role to be aware of their influence on user satisfaction and to adopt them in favor of improving the user experience in the indoor environment.

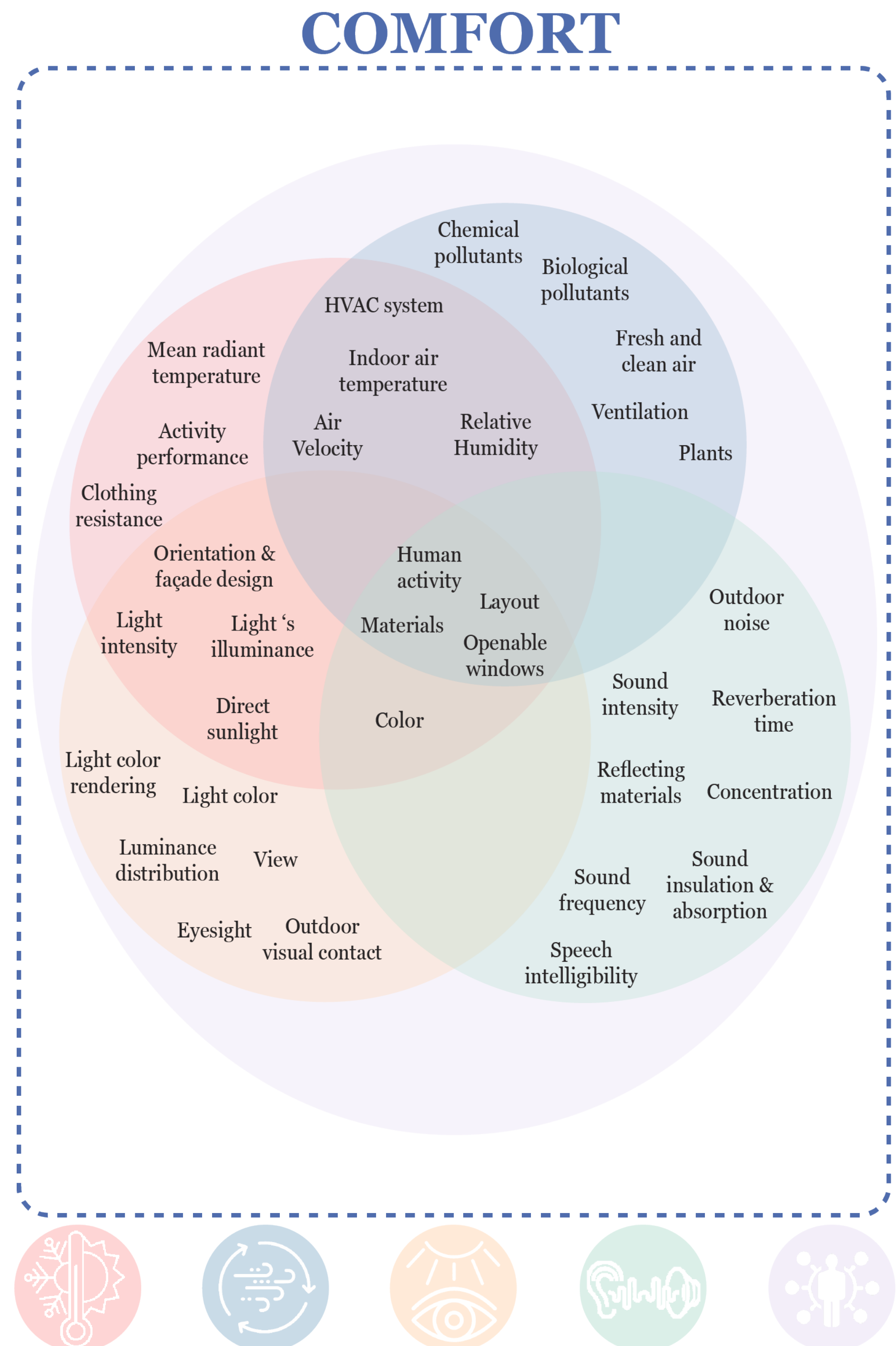


Fig 25: Complex relationship between dimensions of comfort

4.3 Impact on renovations

Buildings in Europe are major energy consumers, they account for around 40% of total energy consumption, and they are also responsible for 36% of greenhouse gas emission *(Jiménez-Pulido, Jiménez-Rivero, and García-Navarro 2022)*. To achieve the European Union's goal of carbon neutrality by 2050, a major campaign of existing buildings' renovation is essential. These renovations target energy efficiency and carbon neutrality, without neglecting user's comfort. In this section, the influence of the architect and certifications on user comfort in renovation projects will be discussed.

4.3.1 Architects' role in renovations

The question of color and textures is more essential in heritage renovation projects. Prior to any renovation project whether it concerns heritage buildings or not, there is a study and examination of the actual status of the building to detect shortcomings but also special characteristics to maintain while renovating. Those special features include technical systems and structure as well as colors and materials used for heritage buildings.

This global analysis is done by the architect with the help of other specialists, from structural experts to technical engineers. The architect examines the history of the building, its initial design, its translation to reality after construction, the possible changes in the building.... etc. After this thorough analysis, the architect, after deliberation with the different experts, decides the components to maintain, those to be modified or repaired, and components to change completely *(Puteri and Puspitasari 2021)*.

After defining the level of intervention in the different components, architects begin to design the new space according to its new function while ensuring its occupant's comfort. They need to consider the possibility of new and varying functions that can survive in the future *(Puteri and Puspitasari 2021)*. This can sometimes conflict with the preservation and conservation aspects in heritage renovation projects.

This conflict can be due to technical systems that are outdated which have to be replaced to ensure users comfort today but can damage the architectural integrity of the building like in the case of La Rinascente Department Store in Rome *(Marino and Graf 2016)*. This is where the architect as the decision maker has to decide and find balance between preservation and the new function and design.

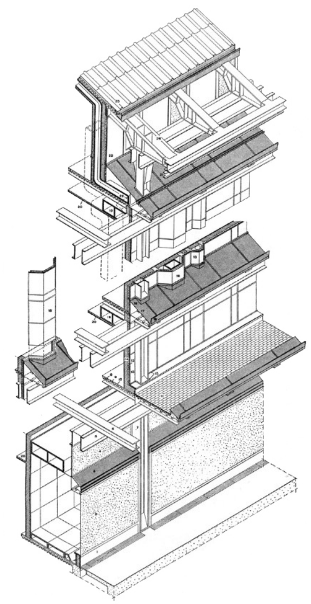


Fig 26: Constructive axonometry of the envelopes of La Rinascente

Fig 27: Model of the corner solution, exhibited at the XII Triennale in Milan in 1960

As the designer and the only expert who is present in all the deliberations and analyses, the architect usually has the task of monitoring and supervising the construction all while providing solutions to problems arising on the construction site. The architect is usually the one with a clear knowledge of the wider framework of the project. This general knowledge allows them to make informed decisions by referring to experts if needed without compromising another aspect of the project.

4.3.2 Influence of certification on heritage renovation

Although most of the certifications can be obtained for renovation projects, with the difference of reducing some of the values recommended and adapting them to renovation, they are most of the time not well designed for heritage renovation. Some of the criteria for energy renovation and performance occasionally conflict with the historical characteristics of some buildings and the heritage preservation goal.

Some of these conflicts are related to energy performance, especially with the thermal insulation of the facades. To have a tight-air building for energy preservation, the facades must be thermally insulated from the outside or the inside. However, adding this insulated layer changes the appearance and essence of the building which makes it problematic in some heritage renovation projects. There is also the thermal efficiency factor of windows influencing the airtightness of the buildings. Changing window's frames and type to be more thermally efficient has an impact on both the character of the building and the entering daylight's perception.

Another type of conflict is related to the design of the interior space, and how to offer a flexible space for the new users with the minimal modification of the existing layout. This is more challenging in heritage buildings as the limit of the buildings' preservation is vague. Should the act of preservation surpass the new function of the space in importance? Or should its use and function regulate the extent of the preservation? Both aspects: heritage preservation and the new function and use of the space should be equally as important. For to preserve a heritage building or interior that can't be comfortably used is a misuse of space and materials.

There should be a new type of certifications that is most adapted to heritage renovations that can combine these three goals: improvement of the building's energy performance, preservation of historical architecture and the enhancement of indoor environmental quality for users. This certification should adapt the energy and indoor quality targets to the historical preservation goal and vice-versa.

By designing a certification that considers these three goals equally, renovation of heritage buildings can be both successful in preserving the architectural heritage while achieving the general aim of other certifications: creating a sustainable building that have a low impact on the environment while providing a comfortable indoor environment for its users.

Actual building certifications have various flaws and limits that can't always be resolved. However, it is the architect's role to understand the qualities of these certifications, to use them while designing, and to understand their flaws and compensate them with their own knowledge and experience.

CONCLUSION

During this theoretical thesis, the question was the effectiveness of these certifications in ensuring users 'comfort and satisfaction and how architects can improve this comfort through design. However, the definition of comfort as seen is a complex one as it doesn't solely consist of the measurable environmental dimensions usually evaluated in the different studied certifications.

The environmental dimensions: Thermal, visual, acoustic and air quality, rely on physical aspects such as air and material properties. Those different physical aspects have specific measurements and values that allegedly ensure users' comfort in the built environment. They can be tuned and controlled via different technical systems like ventilation and artificial lighting as well as some passive solutions like facade and space design to ensure daylight entry and operable windows for higher user control. However, these different aspects tend to influence more than one dimension at a time which creates a complex relationship between the different dimensions of comfort.

The different values and standards of these physical aspects are applied in green building certifications. However, in the different case studies analyzed, the users' comfort was not achieved. Some aspects were more problematic like acoustic and thermal comfort in most cases. Nonetheless the positive influence of these green certifications on users' satisfaction must be acknowledged. The higher user satisfaction in certified buildings, in comparison to non-certified ones, was particularly due to non-environmental aspects and dimensions like the cleanliness or maintenance of the building that was improved in certified buildings. This discrepancy between the fact that these certifications don't ensure users' full comfort, yet they improve their general satisfaction with the building expresses their necessity but also their deficiencies in some respects.

The architect is supposed to be aware of these limits and to be able to, through his experience and knowledge, deal with these deficiencies in ensuring users' comfort. They can accomplish that comfort through their complex and multiple roles and through different technical systems and how they can integrate them in their design. Putting the user in the center of their design is essential to ensure their comfort and can be done through their connection to the users.

As a designer of the interior space, architects make decisions on non-environmental aspects such as the interior layout, the materials, and colors of the space. These aspects can create a new dimension of comfort under the name of the ergonomic dimension. This dimension has a considerable influence on users' comfort and satisfaction, however it can't be controlled or regulated through certifications. This dimension is solely controlled by the architect through their design which reinforces their role in ensuring users' comfort and balance the deficiencies of green building certifications.

All these complex and multiple roles of the architect can be challenging in renovation projects due to the frequent discrepancies that can occur between obtaining green certifications and having a minimal intervention while renovating. These discrepancies are more prominent in heritage buildings' renovations where the conservation of the heritage character often conflicts with the norms and values of certifications, especially the environmental aspects like thermal insulation or the energetic efficiency of different technical systems.

The architect is usually the decision maker in these situations due to their knowledge of both the technical systems and the architectural value of the building. This general knowledge of the architect on multiple subjects allows them to have this complex role. It also gives them the responsibility of recognizing the advantages and limits of certifications and how to exploit them to ensure the most comfortable environment for the users.

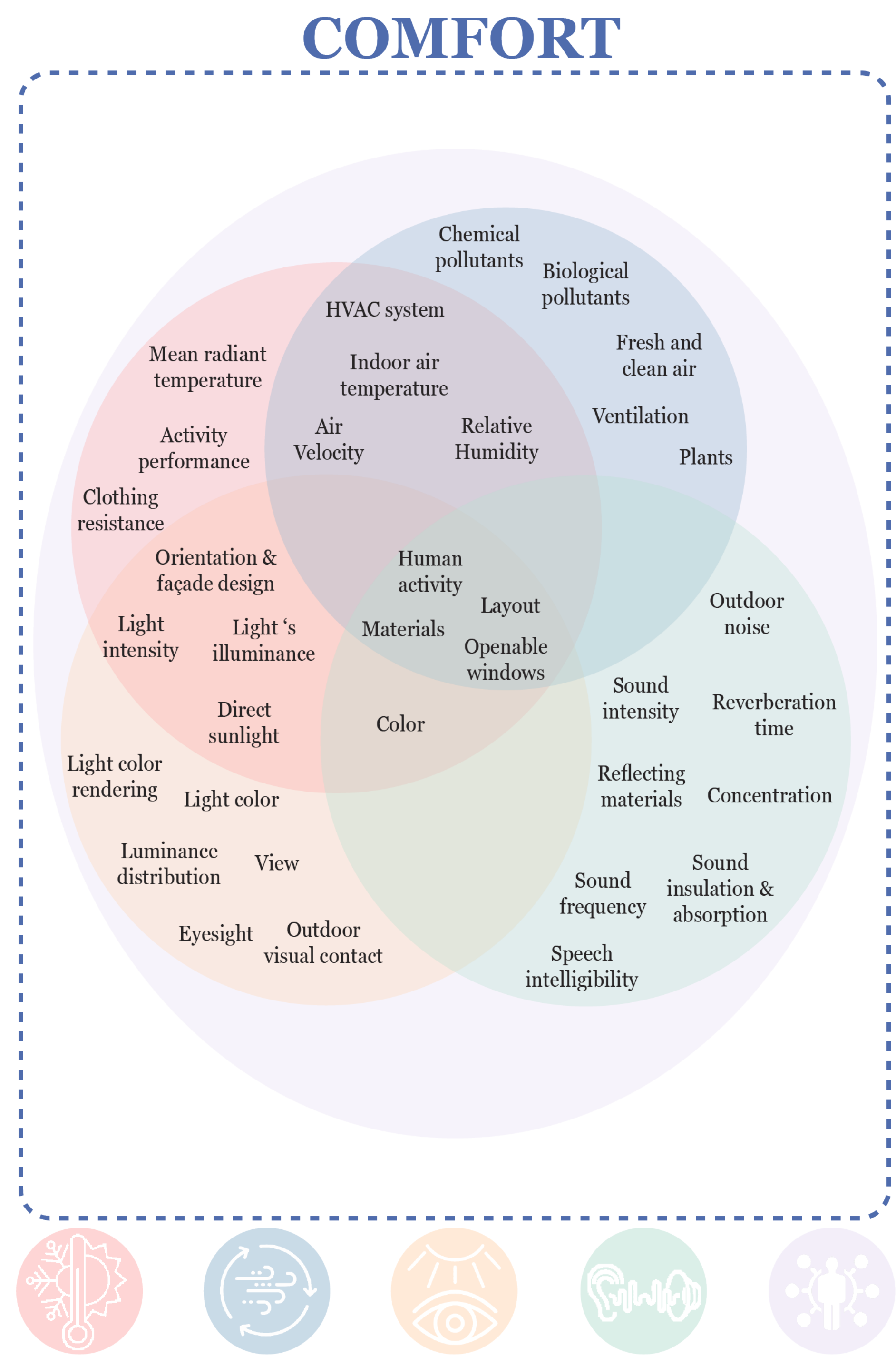


Fig 28: Complex relationship between dimensions of comfort

BIBLIOGRAPHY

BIBLIOGRAPHY

'Alliance HQE-GBC'. n.d. Alliance HQE-GBC. Accessed 26 October 2022. https://www.hqeg-bc.org/.

Afroz, Zakia, H. Burak Gunay, and William O'Brien. 2020. 'A Review of Data Collection and Analysis Requirements for Certified Green Buildings'. Energy and Buildings 226 (November): 110367. https://doi.org/10.1016/j.enbuild.2020.110367.

Altomonte, Sergio, and Stefano Schiavon. 2013. 'Occupant Satisfaction in LEED and Non-LEED Certified Buildings'. Building and Environment 68 (October): 66–76. https://doi.org/10.1016/j.buildenv.2013.06.008.

Araújo Alves, Juliana, Filipa Neto Paiva, Lígia Torres Silva, and Paula Remoaldo. 2020. 'Low-Frequency Noise and Its Main Effects on Human Health—A Review of the Literature between 2016 and 2019'. Applied Sciences 10 (15): 5205. https://doi.org/10.3390/app10155205.

Armitage, Lynne, Ann Murugan, and Hikari Kato. 2011. 'Green Offices in Australia: A User Perception Survey'. Journal of Corporate Real Estate 13 (3): 169–80. https://doi.org/10.1108/14630011111170454.

Bluyssen, Philomena. 2009. The Indoor Environment Handbook: How to Make Buildings Healthy and Comfortable. London: Routledge. https://doi.org/10.4324/9781849774611.

Bluyssen, Philomena M. 2010. 'Towards New Methods and Ways to Create Healthy and Comfortable Buildings'. Building and Environment 45 (4): 808–18. https://doi.org/10.1016/j.buildenv.2009.08.020.

Budds, Diana. 2016. 'Le Corbusier's Color Theories, Explained'. Fast Company. 29 November 2016. https://www.fastcompany.com/3066011/le-cobusiers-color-theories-explained.

'BREEAM | BRE Group'. 2022. 23 February 2022. Accessed 23 October 2022. https://bregroup.com/products/breeam/.

'DGNB – German Sustainable Building Council'. n.d. Accessed 10 October 2022. https://www.dgnb.de/en/index.php.

Frausto, Salomon, Tom Avermaete, Hans Teerds, and Jean-Louis Cohen. 2016. 'Forty-Two Keywords Cross-Referenced into Ten Critical Positions in an Attempt to Articulate a Theory of Practice in Relation to the Changing Role Ofthe Architect.'

Frontczak, Monika, and Pawel Wargocki. 2011. 'Literature Survey on How Different Factors Influence Human Comfort in Indoor Environments'. Building and Environment 46 (4): 922–37. https://doi.org/10.1016/j.buildenv.2010.10.021.

Grzegorzewska, Magdalena, and Paweł Kirschke. 2021. 'The Impact of Certification Systems for Architectural Solutions in Green Office Buildings in the Perspective of Occupant Well-Being'. Buildings 11 (12): 659. https://doi.org/10.3390/buildings11120659.

Guldager Jensen, Kasper, Kåre Stokholm Poulsgaard, Lasse Lind, Casper Østergaard Christensen, Ole Skjelmose, Susan Jayne Carruth, Kristian Knorr Jensen, et al. 2018. Guide to Sustainable Building Certifications. Statens Byggeforskningsinstitut, SBi.

Ildiri, Nasim, Heather Bazille, Yingli Lou, Kathryn Hinkelman, Whitney A. Gray, and Wangda Zuo. 2022. 'Impact of WELL Certification on Occupant Satisfaction and Perceived Health, Well-Being, and Productivity: A Multi-Office Pre- versus Post-Occupancy Evaluation'. Building and Environment 224 (October): 109539. https://doi.org/10.1016/j.buildenv.2022.109539.

Karmann, Caroline, Stefano Schiavon, and Fred Bauman. 2017. 'Thermal Comfort in Buildings Using Radiant vs. All-Air Systems: A Critical Literature Review'. Building and Environment 111 (January): 123–31. https://doi.org/10.1016/j.buildenv.2016.10.020.

Keeble, Brian R. 1988. 'The Brundtland Report: "Our Common Future"'. Medicine and War 4 (1): 17–25. https://doi.org/10.1080/07488008808408783.

Khusaini, Alif, Mohammad Arziz Raka Pradana, and Dandi Kusmayandi. 2022. 'The Importance of Building Design and Its Contribution to Human Health'. International Journal of Research and Applied Technology (INJURATECH) 2 (1): 210–17. https://doi.org/10.34010/injuratech.v2i1.6929.

Jiménez-Pulido, Cristina, Ana Jiménez-Rivero, and Justo García-Navarro. 2022. 'Improved Sustainability Certification Systems to Respond to Building Renovation Challenges Based on a Literature Review'. Journal of Building Engineering 45 (January): 103575. https://doi.org/10.1016/j.jobe.2021.103575.

Licina, Dusan, and Sarka Langer. 2021. 'Indoor Air Quality Investigation before and after Relocation to WELL-Certified Office Buildings'. Building and Environment 204 (October): 108182. https://doi.org/10.1016/j.buildenv.2021.108182.

Licina, Dusan, and Serra Yildirim. 2021. 'Occupant Satisfaction with Indoor Environmental Quality, Sick Building Syndrome (SBS) Symptoms and Self-Reported Productivity before and after Relocation into WELL-Certified Office Buildings'. Building and Environment 204 (October): 108183. https://doi.org/10.1016/j.buildenv.2021.108183.

'Label de Construction Suisse'. n.d. Minergie. Accessed 5 January 2023. https://www.minergie.ch/fr/.

'Living Building Challenge - International Living Future Institute'. n.d. Accessed 20 October 2022. https://living-future.org/lbc/.

'LEED Rating System | U.S. Green Building Council'. n.d. Accessed 15 October 2022. https://www.usgbc.org/leed.

'LEED Scorecard | U.S. Green Building Council'. n.d. Accessed 27 December 2022. https://www.usgbc.org/leed-tools/scorecard.

Majerska-Palubicka, Beata. 2019. 'Architectural Design in the Context of Sustainable Development'. In Advances in Human Factors, Sustainable Urban Planning and Infrastructure, edited by Jerzy Charytonowicz and Christianne Falcão, 118–27. Advances in Intelligent Systems and Computing. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-94199-8_12.

Marino, Giulia, and Franz Graf. 2016. '« L'accidentalità tecnica » comme source de composition architecturale. L'immeuble commercial La Rinascente à Rome Franco Albini, Franca Helg, 1957-1962'. In Les dispositifs du confort dans l'architecture du XXe siècle: connaissance et stratégies de sauvegarde = Building environment and interior comfort in 20th-century architecture: understanding issues and developing conservation strategies. Lausanne: Presses polytechniques et universitaires romandes.

Oechslin, Werner, and Wilfried Wang. 1987. 'Les Cinq Points d'une Architecture Nouvelle'. Assemblage, no. 4: 83–93. https://doi.org/10.2307/3171037.

Ostwald, Michael J. 2001. 'Le Corbusier (Charles Edouard Jeanneret), The Modulor and Modulor 2 – 2 Volumes. Basel: Birkhäuser, 2000.: Reviewed by Michael J. Ostwald'. Nexus Network Journal 3 (1): 145–48. https://doi.org/10.1007/s00004-000-0015-0.

Pastore, Luisa, and Marilyne Andersen. 2018. 'Comfort, Climatic Background and Adaptation Time: First Insights from a Post-Occupancy Evaluation in Multicultural Workplaces'. In Proceedings of the 10th Windsor Conference: Rethinking Comfort, 814–23. NCEUB 2018.

Pastore, Luisa, and Marilyne Andersen. 2019. 'Building Energy Certification versus User Satisfaction with the Indoor Environment: Findings from a Multi-Site Post-Occupancy Evaluation (POE) in Switzerland'. Building and Environment 150 (March): 60–74. https://doi.org/10.1016/j.buildenv.2019.01.001.

Potrč Obrecht, Tajda, Roman Kunič, Sabina Jordan, and Mateja Dovjak. 2019. 'Comparison of Health and Well-Being Aspects in Building Certification Schemes'. Sustainability 11 (9): 2616. https://doi.org/10.3390/su11092616.

Puteri, S., and P. Puspitasari. 2021. 'Exploratory Study: Conservation Practices and the Role of Architect'. IOP Conference Series: Earth and Environmental Science 780 (1): 012061. https://doi.org/10.1088/1755-1315/780/1/012061.

Rupp, Ricardo Forgiarini, Jungsoo Kim, Enedir Ghisi, and Richard de Dear. 2019. 'Thermal Sensitivity of Occupants in Different Building Typologies: The Griffiths Constant Is a Variable'. Energy and Buildings 200 (October): 11–20. https://doi.org/10.1016/j.enbuild.2019.07.048.

Sarbu, Ioan, and Calin Sebarchievici. 2013. 'Aspects of Indoor Environmental Quality Assessment in Buildings'. Energy and Buildings 60 (May): 410–19. https://doi.org/10.1016/j.enbuild.2013.02.005.

Schellen, Lisje, Marcel G.L.C. Loomans, Martin H. de Wit, Bjarne W. Olesen, and Wouter D. van Marken Lichtenbelt. 2013. 'Effects of Different Cooling Principles on Thermal Sensation and Physiological Responses'. Energy and Buildings 62 (July): 116–25. https://doi.org/10.1016/j.enbuild.2013.01.007.

Shamsul, B.M.T, C.C. Sia, Y.G Ng, and K. Karmegan. 2013. 'Effects of Light's Colour Temperatures on Visual Comfort Level, Task Performances, and Alertness among Students'. American Journal of Public Health Research 1 (7): 159–65. https://doi.org/10.12691/ajphr-1-7-3.

Simon, Mark, and Cathy Jackson. 2020. 'Yale Experts Explain Green Building Certifications | Yale Sustainability'. Yale Sustainability. 10 October 2020. https://sustainability.yale.edu/explainers/yale-experts-explain-green-building-certifications.

Taleghani, Mohammad, Martin Tenpierik, Stanley Kurvers, and Andy van den Dobbelsteen. 2013. 'A Review into Thermal Comfort in Buildings'. Renewable and Sustainable Energy Reviews 26 (October): 201–15. https://doi.org/10.1016/j.rser.2013.05.050.

Teitelbaum, Eric, and Forrest Meggers. 2017. 'Expanded Psychrometric Landscapes for Radiant Cooling and Natural Ventilation System Design and Optimization'. Energy Procedia, CISBAT 2017 International ConferenceFuture Buildings & Districts – Energy Efficiency from Nano to Urban Scale, 122 (September): 1129–34. https://doi.org/10.1016/j.egypro.2017.07.436.

Thuillier, Laura. 2017. 'What Is Visual Comfort and How Do You Achieve It?' Saint-Gobin: Multi Comfort. 21 Au-gust 2017. https://multicomfort.saint-gobain.co.uk/recommended-level-of-light-into-a-building/.

Vischer, Jacqueline C. 2008. 'Towards a User-Centred Theory of the Built Environment'. Building Research & Information 36 (3): 231–40. https://doi.org/10.1080/09613210801936472.

Vosoughkhosravi, Sorena, Lesheena Dixon-Grasso, and Amirhosein Jafari. 2022. 'The Impact of LEED Certification on Energy Performance and Occupant Satisfaction: A Case Study of Residential College Buildings'. Journal of Building Engineering 59 (November): 105097. https://doi.org/10.1016/j.jobe.2022.105097.

Wargocki, Pawel, and David P. Wyon. 2017. 'Ten Questions Concerning Thermal and Indoor Air Quality Effects on the Performance of Office Work and Schoolwork'. Building and Environment 112 (February): 359–66. https://doi.org/10.1016/j.buildenv.2016.11.020.

'WELL v2 Certification | IWBI'. n.d. Accessed 16 November 2022. https://www.wellcertified.com/certification/v2/.

Xue, P., C.M. Mak, and Z.T. Ai. 2016. 'A Structured Approach to Overall Environmental Satisfaction in High-Rise Residential Buildings'. Energy and Buildings 116 (March): 181–89. https://doi.org/10.1016/j.enbuild.2016.01.006.

Yang, Shen, Joëlle Goyette Pernot, Corinne Hager Jörin, Hélène Niculita-Hirzel, Vincent Perret, and Dusan Licina. 2020. 'Energy, Indoor Air Quality, Occupant Behavior, Self-Reported Symptoms and Satisfaction in Energy-Efficient Dwellings in Switzerland'. Building and Environment 171 (March): 106618. https://doi.org/10.1016/j.buildenv.2019.106618.

Images & figures refrences

Fig 2: BREEAM certification logo
Source: 'BREEAM | BRE Group' (2022) [Accessed 23 October 2022] https://bregroup.com/products/breeam/.

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Fig 8: WELL certification logo
Source: 'WELL v2 Certification | IWBI'. [Accessed 16 November 2022] https://www.wellcertified.com/certification/v2/.

Fig 10: Measurable factors influencing user thermal comfort
Source: Created based on the photo from Kumar, Praveen. 'Role of CFD in Evaluating Occupant Thermal Comfort | SimulationHub Blog'. SimulationHub. [Accessed 7 January 2023]. https://www.simulationhub.com/blog/role-of-cfd-in-evaluating-occupant-thermal-comfort.

Fig 11: Types of air pollutants
Source: Created based on the photo from 'Your Home, Your Health'. [Accessed 8 January 2023] https://www.ecvt.net/blog/your-home-your-health.

Fig 12: Types of ventilation systems
Source: Created with the photo from 'Figure 4.2 The Three Main Types of Ventilation Systems'. n.d. ResearchGate. [Accessed 8 January 2023]. https://www.researchgate.net/figure/The-three-main-types-of-ventilation-systems_fig3_27341908.

Fig 13: Use of plants combined with ventilation system
Source: Spaceways. n.d. '4 Ways Office Space Management Leads To Success'. Spaceways. Accessed 6 January 2023. https://www.spaceways.co.uk/blog/office-space-management/.

Fig 15: Influence of sunlight on thermal comfort
Source: Created with the photo from Munari Probst, Maria Cristina, 2022. 'Confort thermique :Stratégies solaires passives' presented at cours Architecture et Energie solaire, EPFL, Lausanne, March 2022

Fig 18: Criteria of Minergie & Minergie-ECO
Source: Created based on the photo from 'ECO'. n.d. Minergie. [Accessed 27 December 202w] https://www.minergie.ch/fr/certification/eco/.

Fig 19: Distribution of LEED credits
Source: Created based on the data from 'LEED Rating System | U.S. Green Building Council'. n.d. [Accessed 5 January 2023]. https://www.usgbc.org/leed.

Fig 20: Diagram of the double distribution of the air conditioning networks
Source: Marino, Giulia, and Franz Graf. 2016. '« L'accidentalità tecnica » comme source de composition architecturale. L'immeuble commercial La Rinascente à Rome Franco Albini, Franca Helg, 1957-1962'. In Les dispositifs du confort dans l'architecture du XXe siècle: connaissance et stratégies de sauvegarde = Building environment and interior comfort in 20th-century architecture: understanding issues and developing conservation strategies. Lausanne: Presses polytechniques et universitaires romandes.

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Fig 22: Barcelona Pavilion plan by Mies Van der Rohe
Source: 'The Pavilion - Fundació Mies van Der Rohe'. n.d. [Accessed 10 January 2023] https://miesbcn.com/the-pavilion/.

Fig 23: Paintings, colors and atmosphere intended for different office levels of the Mutuelle Vaudoise building
Source: Minnaert, Jean-Baptiste, Stéphanie Quantin, and Cité de l'architecture et du patrimoine (Paris, France), eds. 2021. Jean Tschumi, Architecte. Paris: Cité de l'architecture & du patrimoine : Bernard Chauveau édition.

Fig 24: Integration of plants in indoor space design © Alexandre Oliveira – Jafo Fotografia
Source: 'Gallery of IT'S Biofilia Office / IT'S Informov - 18'. n.d. ArchDaily. [Accessed 11 January 2023] https://www.archdaily.com/920540/its-biofilia-office-its-informov/5d210521284dd1f51f00008f-its-biofilia-office-its-informov-plan.

Fig 26: Constructive axonometry of the envelopes of La Rinascente
Source: Marino, Giulia, and Franz Graf. 2016. '« L'accidentalità tecnica » comme source de composition architecturale. L'immeuble commercial La Rinascente à Rome Franco Albini, Franca Helg, 1957-1962'. In Les dispositifs du confort dans l'architecture du XXe siècle: connaissance et stratégies de sauvegarde = Building environment and interior comfort in 20th-century architecture: understanding issues and developing conservation strategies. Lausanne: Presses polytechniques et universitaires romandes.

Fig 27: Model of the corner solution, exhibited at the XII Triennale in Milan in 1960
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