POLITECNICO DI TORINO

Master Degree Course in Architecture for Sustainability Design

Master Degree Thesis

Energy Performance of a Real Office Building
A Case Study at Politecnico di Torino

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Academic Year 2023/2024

ABSTRACT

This thesis investigates the critical influence of office room environments on the physical and psychological well-being of workers, emphasizing the significance of creating conducive spaces for increased productivity and satisfaction. The research delves into the integration of sustainable practices within office settings, focusing on essential factors such as HVAC systems, artificial lighting, and daylight strategies. The study employs a comprehensive approach by conducting an in-depth analysis of the Energy Department at Politecnico di Torino, specifically examining two floors.

The energy analysis encompasses a thorough evaluation of the Heating, Ventilation, and Air Conditioning (HVAC) systems, scrutinizing their efficiency and impact on indoor air quality. Additionally, the research investigates the role of artificial and daylight, exploring their potential to enhance both energy efficiency and occupant well-being.

Keywords: Sustainable Architecture, Offices, Energy Performance, Lighting

ACKNOWLEDGMENTS

I would like to express my heartfelt gratitude to my esteemed thesis supervisor, Prof. Valerio Roberto Maria Lo Verso for their unwavering guidance, mentorship, and support throughout my master's journey. His expertise and encouragement have been invaluable in shaping the trajectory of my academic pursuits.

My deepest appreciation to my father and to my mother whose unwavering support and encouragement have been my pillars of strength with their constant belief in me has been my driving force. I am profoundly thankful for their sacrifices, understanding, and endless encouragement. This accomplishment is as much theirs as it is mine, and I am truly grateful for their enduring love and support.

SEMA TAS
February 2024

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ABBREVIATIONS

ASE: Annual Sunlight Exposure

BOCA: Building Officials and Code Administrators

CIE: Commission Internationale de l’Eclairage

DF: Daylight Factor

DIN: Daylight in interiors

HVAC: Heating, Ventilation and Air Conditioning

IES: Illuminating Engineering Societies

K: Kelvin

LED: Light Emitting Diode

lm: Lumen

LPD: Lighting Power Density

lx: Lux

m: Meter

m^2: Square meter

PVC: Polivinil Klorür

sDA: Spatial Daylight Autonomy

UDI: Useful Daylight Illuminance

UV: Ultraviolet

U-value: Thermal Transmittance

W: Watt

WFR: Window to Floor Ratio

WWR: Window to Wall Ratio

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1. INTRODUCTION

1.1.Subject and Purpose of the Study

This study highlights the importance of establishing a consistent relationship between environmental conditions and occupant well-being, especially in office spaces. In an environment where traditional energy sources are in danger of rapid depletion, there is a critical need to prioritize the provision of natural light to meet basic lighting requirements, optimize indoor air temperatures and implement energy efficient practices.

The inclusion of natural light and natural ventilation as central design elements in office architecture works to raise awareness among both designers and users about the development of sustainable buildings. Therefore, an analytical review of the existing office environments on the top two floors which are 3rd and 4th floors of the Energy Department of the Politecnico di Torino University.

1.2.Scope of the Study

The present study undertakes an examination of the environmental parameters within office settings, with a particular emphasis on the uppermost levels which is 3rd and 4th floors of the Energy Department premises at Politecnico di Torino University. Encompassing an investigation into the amalgamation of both natural and artificial lighting systems, approached through the lens of sustainable architectural principles, it further accentuates the delineation of temperature comfort thresholds within these spatial confines, delineating the extant conditions against the backdrop of recommended benchmarks. The introductory segment of the study elucidates the objectives, scope, and methodological framework underpinning the research endeavor.

1.3.Methodology of the Study

This thesis delves into the realm of sustainable architecture, focusing on the interplay between natural and artificial illumination, the intricacies of office lighting, and the multifaceted physical and psychological impacts on individuals laboring within such environments. A comprehensive review of pertinent literature elucidates a methodological framework for investigating sustainable architectural practices, encompassing aspects of light, lighting, architectural design, and energy dynamics. Subsequently, the examination was directed towards the office spaces situated on the uppermost levels which are 3rd and 4th floors of the Energy Department building at Politecnico di Torino University in Turin, Italy. The study scrutinized the prevailing state of the building which is non-insulated, including the condition of its insulation materials, and assessed the optimal indoor temperature dynamics during both winter and summer periods under the influence of the heating and cooling system. Additionally, an evaluation of the daylighting efficacy originating from the windows during both summer and winter seasons, in conjunction with artificial lighting, was conducted, considering the interplay of shading and non-shading systems. To underpin this investigation, a laser meter was used for taking measurements of the building, a diverse array of scholarly resources, including books, articles, theses, and scientific publications, were consulted. Furthermore, in the context of this specific case study, the utilization of DesignBuilder software facilitated the quantitative assessment and scrutiny of the environmental parameters governing these office spaces.

2. Sustainability

2.1.Definition of Sustainability

The world’s ecosystem is in danger from environmental contamination and disturbed natural harmony. The availability of many resources in the future is a controversial topic that is debated from various viewpoints and so the ideas of “sustainability” and “sustainable architecture” become more important. Sustainability means a harmony that meets human demands without harming the natural systems’ well-being and efficiency. “Sustainable design is a design philosophy that seeks to maximize the quality of the built environment by minimizing or eliminating negative impacts on the natural environment” (Mclennan, 2004).

Sustainability is the ability to maintain or support a process continuously over time. It aims to prevent the depletion of natural or physical resources so that they will remain available for the long term. Sustainability is often divided into three core concepts: economic, environmental and social. Many businesses and governments have committed to sustainable goals, such as reducing their environmental footprints and conserving resources (Sustainability | Description, Theories, & Practices | Britannica)

Sustainability is not a field with institutional boundaries like architecture; It is a field of discourse and practice that spans across multiple professions and disciplines such as architecture, engineering, urban planning, ecology and climate. The absence of institutional boundaries increases the competition to determine legitimacy and symbolic capital in the field (Owen and Dovey, 2008).

Sustainability is a term that has been used since renewable resource management theory in the early 20th century, especially in sustainable agriculture and forestry and in theories of productivity which is a thery of “sustained” yield (Cordero, 2001).

The first known use of the word sustainability (German: Nachaltigkeit) in Europe was in 1713 in the book Sylvicultura Oeconomica by German forester and scientist Hans Carl von Carlowitz. Later, French and English foresters adopted the practice of planting trees as a path to “sustained-yield forestry” (Heinberg, 2010). The most lasting description of sustainability is based on the 1987 “Brundland Report” which introduced the concept of sustainable development and described how it could be achieved. The report promoted a notion of development set within environmental “limits”. Governments and permutations of the concept of sustainability that is based on accepting both objective science and continued development (Owen and Dovey, 2008).

Dr. Karl-Henrik Robert, a Swedish oncologist, gathered prominent scientist in the 1980s to reach an agreement on the prerequisites for a sustainable society. Over 80 municipalities and several regions (25 percent of all Swedish municipalities) have adopted the TNS sustainability principles based on the system conditions (Heinberg, 2010). The four conditions are:

1. Concentrations of substances taken out of the ground,
2. Concentrations of substances created by people,
3. Physical damage,
4. And in the society,
5. People are not exposed to circumstances that consistently reduce their capacity to satisfy their requirements (Heinberg, 2010).

The concept of sustainability has undergone two significant changes: one is its interpretation in terms of three dimensions that must be balanced: social, economic and environmental (Kuhlman and Farrington, 2010).

2.2.Sustainable Development: Definition and Principles

The aim of sustainable development (SD) is to ensure the long-term stability of the economy and environment which can be achieved by considering economic, environmental, and social concerns throughout the decision-making process (Emas, 2015).

Government organizations are typically organized into sectorial ministries and departments which works well until the system encounters something comprehensive and highly integrated in nature such as sustainable development. Sustainable development requires the integration of economic, environmental, and social objectives across sectors, territories, and generations. Therefore, sustainable development requires the elimination of fragmentation by integrating environmental, social, and economic concerns throughout decision-making processes to achieve truly sustainable development (Emas, 2015).

2.3.People, Planet, Profit

The Brundtland report discusses two issues that must be resolved: development and the environment. They can also be viewed as needs versus resources or short-term versus long-term. Nowadays, sustainability is typically viewed in terms of three dimensions: social, economic and environmental**.** The description of sustainability by the United Nations in its Agenda for Development: “Development is a multidimensional undertaking to achieve a higher quality of life for all people. Economic development, social development and environmental protection are interdependent and mutually reinforcing components of sustainable development” (Kuhlman and Farrington, 2010).

The idea of sustainability having three dimensions stems from the Triple Bottom Line concept which was told by John Elkington in 1994. The concept originates from the world of management science and Elkington intended it as a way to operationalize corporate social responsibility. The concept suggests that conventional bottom line (profit) should be for caring the environment (the planet) being good to people, such as providing services for the disabled and hiring minorities (the social dimension) (Kuhlman and Farrington, 2010).

The profit pillar is the economic dimension and it can be the money made by the entire country, such as gross domestic product (GDP) which is connected social dimension (people) with human aspirations: fairness (earnings issue), containment (often organized by job) and health (access to medical services) (Kuhlman and Farrington, 2010).

2.4.Resources and the Future

Sustainability is the ability to continue over a long period of time and according to Kuhlman and Farrington thought as “Sustainability may then be defined as minting well-being over a long, perhaps even an indefinite period.” For instance, water pollution and many forms of air has a dangerous impact as environmental degradation. The things we leave for future generation include cultural heritage such as art and cultural landscapes as well as infrastructure, technology and institutions (Kuhlman and Farrington, 2010).

The heritage we leave for future generations includes resources needed for production and survival, as well as resources appreciated for their aesthetic, scientific or intrinsic value. Some of these are not easily lost or are well protected; others are more difficult to preserve. It makes more sense to distinguish between natural and man-made resources, and between renewable and non-renewable ones. Renewable man-made resources are equivalent to what economists call capital (Kuhlman and Farrington, 2010).

The importance of the discount rate for intergenerational equity, which is equated with sustainability cannot be considered as zero because value of today's natural resources will be in the future by depending on the state of technology (for instance, the need for oil). Sustainability can now loosely be defined as a state of affairs where the natural and man-made resources remains at least constant for the foreseeable future, in order that the well-being of future generations does not decline. The ideal thing, when people assess the potential impact of a proposed policy, programmed or project, it should both lead to higher well-being and a positive or at least neutral effect on the overall state of resources for the future-in which case can be spoken of sustainable development (Kuhlman and Farrington, 2010).

3. ARCHITECTURAL DESIGN AND SUSTAINABLE ARCHITECTURE

3.1.Architectural Design

Design is a way for people to interact with the environment. The approach in this style is conscious, constructive and product-oriented which is sets it apart from other work for the environment and it involves a lot of knowledge, skill and experience with analyzing existing things and coming up with new solutions through trial and mistakes to have new needs (Hasol, 1998).

Design is the ability from the realities of today to the possibilities of tomorrow to the possibilities of tomorrow by combining knowledge from various fields such as science, art, mathematics, technology, philosophy, theory and history at the same level therefore, design requires a special talent (Jones, 1980).

Architectural design is a process that involves the role and responsibilities of the architect in society, as well as technical systems and requirements. It reflects the cultural, mental, social, economic and environmental situation of architecture (UIA, 2002).

Architectural design is a complex process that involves many uncertainties and complexities that can be expressed as a “visual and verbal game” but the rules of this game are not clear exactly and this process, cannot be considered as a synthesis based solely on logic of the components obtained through theoretical analysis (Schön, 1985).

Architecture is the process of designing and constructing buildings or other structures. It reflects society and is a manifestation of the intersection of different opposing forces brought to life through artistic design. It is a creating spaces that are essential for people to live, work, rest and play while ensuring that functional requirements are compatible with economic and technical capabilities through aesthetic creativity (Hasol, 1998).

Architecture is an art and science which that designs not only structures and objects but also systems. What distinguishes architecture from other applied sciences and engineering is the attempt to capture aesthetics through volume, light, surface games while considering function and technological suitability and to concretize ideas (Conway, 1994).

Architects are responsible for promoting sustainable and accurate development in the international standards of the International Union of Architects (UIA) and ensuring that the environment in which social life takes place is happy and culturally expressive in spatial, formal, and historical context. Architects are expected to communicate well with the user and the practitioner while designing. In this context, it is expected that architectural offices, where architects provide services and carry out design-construction actions, reflect the sustainable developments they advocate (UIA, 2002).

3.2.Sustainable Architecture

Sustainable architecture is an architectural design approach that aims to reduce decency and minimize resource consumption to reduce the use of natural resources. It focuses on the design, construction, operation and environmental areas of buildings and aims to regulate the relationship between buildings and their surroundings and users (Shaviv, 1998). Shaviv (1998) thinks that the aim of sustainable architecture is to design buildings that are environmentally delicate, consume less energy, have minimal negative impact on the environment, provide healthy indoor environments for their users, and provide optimum comfort conditions. Sustainable construction are minimizing the use of non-renewable energy, ensuring the effective use of renewable energy sources, and reducing resource consumption, harmful waste and environmental damage (Celebi, 2003).

Sustainable architecture develops solutions under three main principles for this concept. These three principles are the "conservation of energy and natural resources" which improves solution methods for energy, material and water conservation issues; "building life cycle design" which develops solution methods for environmental issues encountered in pre-construction, construction and post-construction stages, and "biological structure design" which improves solutions methods for human health and comfort problems (Celebi, 2003).

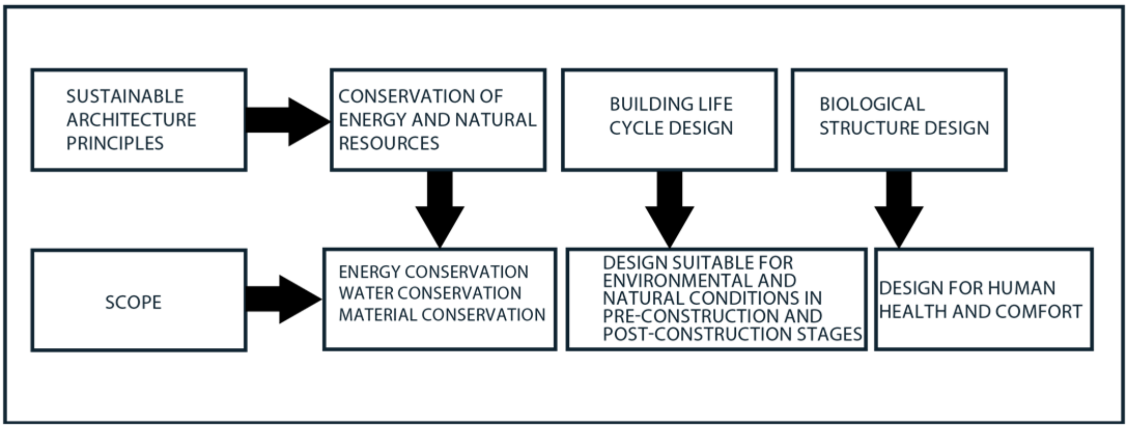


Figure 3.1. Sustainable Architecture Principles and Scope (Celebi, 2003)

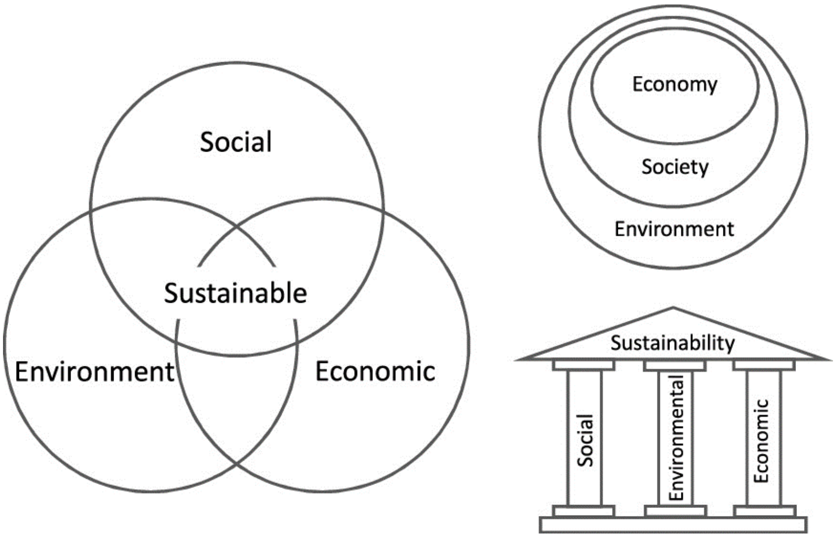


Figure 3.2. Left, typical representation of sustainability as three intersecting circles. Right, alternative depictions: literal "pillars" and a concentric circles approach (Purvis et al., 2019)

Sustainable architecture can be defined as an "Application that evaluates the production process of the building in a comprehensive integrity, which has high economic, social and environmental efficiency in terms of itself and its immediate environment, and has the least negative impact on the natural environment" (Sakinc, 2006).

According to Bourdeau (1999), the basic characteristics of a sustainable architectural product should follows as: Sustainable structure,

- Maximizing human health and comfort
- Improving human quality of life
- Using energy and resources efficiently
- Preserving biological diversity
- Producing waste at a minimum level and controlling it
- Having the highest quality of construction and being long-lasting
- Using reusable and recyclable materials

There are strategies, components and technologies that have been developed to reduce environmental effects and increase spatial comfort and quality in sustainable architecture. These include, but are not limited to, building with timber, going carbon-neutral, rewinding and passive design strategies:

- Daylight use
- Indoor air quality
- Passive solar energy use
- Natural ventilation
- Effective use of energy
- Effective energy use at every stage of the design process
- Minimizing construction waste
- Water conservation
- Operational effectiveness (evaluation of whether the building complies with the targets and criteria in terms of energy design strategies and energy performance during the design and construction phases)
- Solid waste management
- Renewable energy use
- Use of natural landscape
- Land preservation (Mclennan, 2004).

4. LIGHT

4.1.Definition of Light

Light is a form of physical energy that enables objects to be seen and colors to be distinguished (Hasol, 1998). According to Sirel’s (1997) definition, “Since the human eye is sensitive to radiation with wavelengths between 380 and 780 nanometers, radiations between these wavelengths are called light.”

The CIE defines light as the data of all sensations and perceptions connected to the sense of sight or relied through vision, and the radiation that simulates of the vision (Sirel, 1973).

Light can be described as “visible radiation and energy or electromagnetic wave perceived by the photoreceptor in the eye. But the reaction of the eye comes later. Electromagnetic waves; Light is detected when it interacts with surfaces, objects and materials. This reflected and/or transmitted light creates our visual scene.” by Steffy (2002).

Light is a form of energy that affects the eye and creates vision. It is explained by various theories such as propagation and wave theories. According to the wave theory, light propagates in the form of electromagnetic radiation and has a certain propagation speed, wavelength, and frequency. According to quantum theory, light is emitted from sources in very small particles in all direction (Serefhanoglu, 1972).

Bell, identified the following basic judgments for light to work with:

- We require light to perceive our surroundings
- Light can be either natural or artificial
- The amount, quality, and direction of light are all important
- Light can be direct or indirect
- Color is determined by light
- The quality of the light indicates the harshness of light and the cleanliness of the atmosphere
- Artificial light allows for complete control over desired lighting effects (Bell, 1993).

According to Meiss, light has physical effects due to its apart from making it visible. Light also gives heat and sunlight gives life to the earth. However, apart from these physical features, our experience of light also includes other intellectual dimensions. The light from matter is no brighter than the light from the sun and the sky, which is the main source of light. The both of them covers the earth and hides them with darkness and distinguishes those (Meiss, 1991).

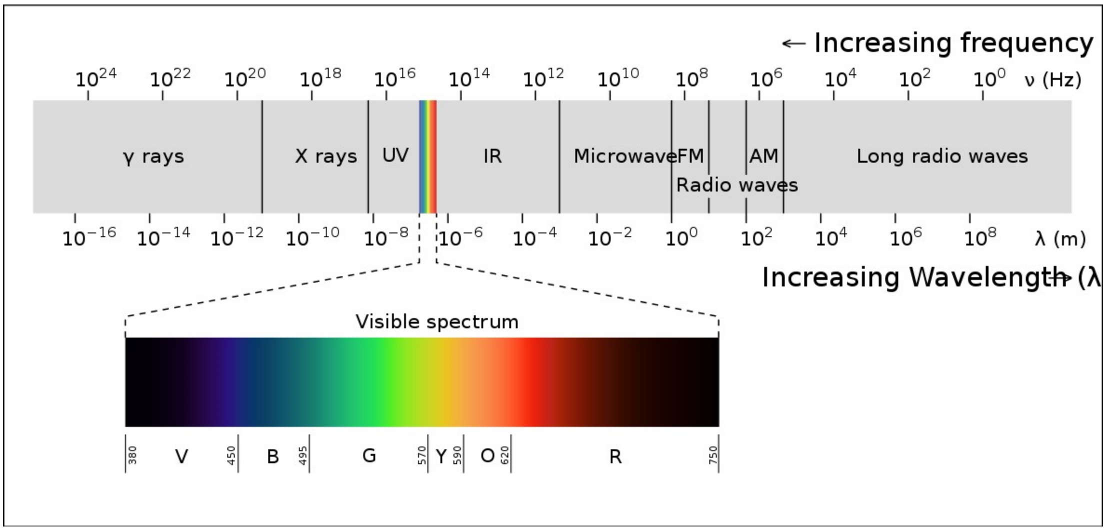


Figure 4.1. Electromagnetic energy spectrum classified by wavelength (File:EM spectrum.svg - Wikipedia)

According to James Cler Maxwell's 'Electromagnetic Wave theory ', light is composed of electromagnetic waves that can penetrate all objects and fill space. The human eye perceives light with a wavelength between infrared an ultraviolet radio, which is a very narrow band of the electromagnetic spectrum. The 'light spectrum' is the range of wavelength from 760 nanometers (red) to 380 nanometers (violet). Every wave length has a different colors from red to violet, including red, orange, yellow, green, blue, indigo, and violet but the eye is not equally sensitive to all wavelengths of the light spectrum. The most effective wavelength is yellowish green light with 555.5 nanometers (Imert, 2008).

The light which is in a space, whether it is natural or artificial, can give different meanings to the space and the objects in it depending on how it is directed and used. Therefore, it is significant to illuminate objects and surfaces in a way that is most conductive to visual perception rather than spreading the light as uniformly as possible (Atabay, 2010).

The amount and quality of light in a space is a significant factor in people's feelings, communication and behaviors (Altan, 1983). According to Hayward (1980), light is an essential condition for life and must be considered during the design process. The quantity and quality of light shapes our experience in any given situation and has a powerful influence on human emotions, communications and behavior.

Watson (1993) mentions that light has the same physiological effects as other types of light, but it differs from a psychological perspective and lists these groups as follows:

- Light is perceptual because it provides visibility of surrounding objects and gains lexical qualifications in proportion to the observer's experience.
- Light is physical because it is essential concept that can be defined and measured.
- It is considered blessed because it is a known but unreachable reality that has some thoughts and ignored things to explain.
- Light is previewed with the help of design elements such as color, texture, shape, and shadow.

4.2.Effect of Lighting on Human Soul and Body

Light is a vital prerequisite for life and should be integrated into the design process. The amount and quality of light shape our experiences in various situations and significantly influence human emotions, communication, and behavior. Simultaneously, the proficient utilization of light serves as a key determinant of aesthetic experiences in architecture (Hayward, 1980).

Psychological Response	Light Feature
Stress	Harsh, blinding and flickering light
Comfort	soft light
Fear	Pale and flickering or, conversely, blinding and bright flashy light
Joy	Always bright and improvised light to contrast with darkness and time
Thoughtfulness	Soft diffused light
Dynamic Motion	Flashing lights encourage movement
Emotional Love	Soft light from rosey to golden yellow
Majestic-Sacred Reverence	Light scattered and shining with the help of a light chimney

Table 4.1. The psychological responses elicited by light within a space and the characteristics of light that give rise to these reactions (Simonds, 1961). Landscape Architecture

The distinct attributes of light travel through space, triggering psychological responses in individuals. Light and other physical stimuli, categorizing them into specific emotional states: Tension, Comfort, Fear, Joy, Reflective, Dynamic Movement, Emotional Love, and Majestic-Holy Love (Simonds, 1961).

4.3.Light Sources

Light is present in nature and sunlight, moonlight, and starlight are the most important sources of light for life. However, humans have learned to create light as well because of their need for additional light (Karlen and Benya).

People can adjust the amount and timing of artificial light sources, which can be made from different thing like burning wood, oil or gas, using electricity, causing chemical changes, or setting off explosions. Electric lamps have become the primary source so lighting in the built environment due to their availability, safety, cleanliness, and remote energy generation. However, since man-made sources consume natural resources, natural light sources should be used as much as possible especially for sustainable design (Karlen and Benya).

4.3.1. Natural Light

Natural light is a combination of sunlight and skylight in diversifying ratios. When sunlight enters the atmosphere, some of its spreads inversely proportional to its wavelength and creates purplish blue sky light. Direct sunlight takes a pinkish yellow color and descends to the earth. Atmospheric pollution changes this situation with the presence of particles larger than water vapor and air molecules in the atmosphere. The variability of natural light depends on many elements such as atmosphere conditions, time of day, seasons, nebulousness, and region (Sirel, 1997).

Natural light can be named as the combination of skylight and sunlight existing in nature in different amounts at many different time of the days and Serefhanoglu (1992) mentions light types components as following:

Daylight; It is the light formed by the combination of sunlight and sky light in different proportions and is defined as natural light. The different proportions in the union of these two lights complement each other in terms of color and multiplicity. Daylight, which consist of sun and sky light, constantly changes according to the hours of the day, seasons, climates and different meteorological conditions, in accordance with the changing natural conditions of the ratio and sum of these two separate lights in terms of color and abundance. The constant change of daylight in terms of quality and quantity is the most distinctive feature that distinguishes it from artificial light.

Sunlight; It is a directional light that changes direction continuously and creates hard, precise, limited shadows in this direction, depending on its proximity to the horizon.

It is light that changes color between orange and white. As a natural light source, the color temperature of the sun is around 1800K at sunrise and sunset, and around 5000-5800K at noon. As the angle of incidence of the sun’s rays on the earth decreases, the thickness of the atmosphere through which the rays pass will increase, so the luminance on the earth decreases.

Sky light; Skylight is formed by the scattering of sunlight in the atmosphere. Solar radiation entering the atmosphere determines the quality and quantity of sky light by reflecting, absorbing and scattering according to the effects of different substances and gases in the atmosphere. Since skylight is a non-direct, diffused light coming from every point of the sky, it does not cost cast a shadow like sunlight".

Even on a cloudy day, sunlight can provide fifty times more light than what is required for visual perception with the quality of light changes. The sun enter an area directly or indirectly by a reflecting form from the cloudy sky or from the flooring and surrounding structures (Lecher, 1991).

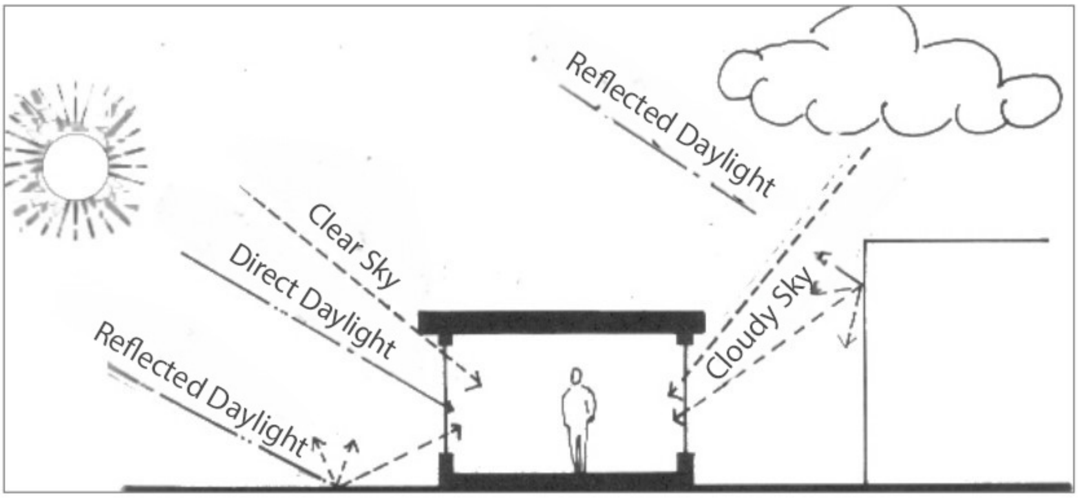


Figure 4.2. Daylight in a cloudy and clear sky (Lecher, 1991)

Light reflects differently on different surfaces. When light reflects smoothly on surface such as mirrors, it enables the surfaces it reflects to be seen at different perspectives. On the other hand, dull surfaces such as opaque glass reflect light diffusely and are perceived as their own space from every perspective (Serefhanoglu, 1974).

CIE in their respective publications:

- CIE Standard Overcast Sky
- CIE Standard Clear Sky
- Intermediate Sky
- Average Sky
- Mean Sky

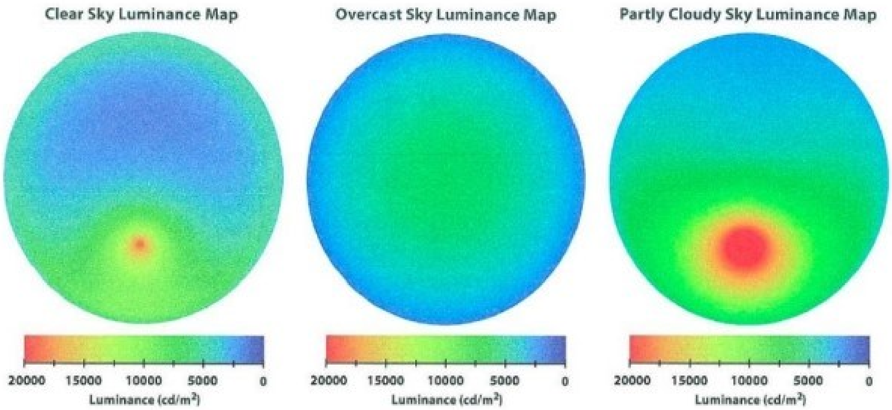


Figure 4.3. Luminance sky models (DiLaura et al., 2011)

4.3.1.1.Natural Light and Psychological and Biological Effects on People

Natural light is essential for human health and well-being. It is important to use natural light effectively, provide proper lighting, and control glare by protecting from direct sunlight. Establishing a visual relationship with the external environmental and being compatible with other physical environmental issues such as climate control are also important for psychological and psychological comfort. In addition to visual comfort and perception, feeling the differences of the external light level during the day (biorhythm) is very important for the correct functioning of the human body and maintaining its health (Atabay, 2010).

Having a view of the outdoors through windows in rooms is essential for the well-being and mental state of people. The advantages of windows have been verified by a study done by the energy division of the Building Performance Center (Washington). This research shows that workers who have a view of the outdoors from their rooms are 20-25% less likely to report sickness than those who lack natural light and interaction with the outside world (Boubekri, 2008).

The sun’s movement during the day simulates our brain and ensures that the hormones in our body work in a certain order. These stimuli arranged in the brain enable our body to realize what it needs to do biologically during the day. This is known as the biological clock and it is arranged according to the movements of the sun (Atabay, 2010).

4.3.2. Artificial Light

People found out about artificial light when they learned how to make fire. As time passed, they invented ways to light up spaces that allowed them to manage the fire and move it around if necessary. They learned how to constitute light so they created artificial lighting (Karlen and Benya, 2004). Torches were the first artificial light sources that people could move around, and later they invented lamps that were convenient to use and made from different materials depending on the climate and location. Therefore, effective lighting plays a crucial role in enhancing visual performance, creating a pleasant ambience, promoting well-being, and contributing to overall prosperity (Shams et al., 2021).

When there is no natural light, artificial light keeps the spaces livable. Artificial light is a vital design component for lighting the space, as it ensures good visibility mainly when natural light is lacking, inadequate or unsuitable (Beazley, 1999).

According to Beazley (1999), La Courbusier, a pioneer of light and a leading architect of the 20th century, describes the house as a device that captures light and sun, a machine made for living so that he understood that the effect of light could change modern architecture from a boring condition to a feeling of emotion.

4.2.3. Effects of Light in Architecture

"Architecture is the masterly, correct and magnificent play of masses brought together in light. Our eyes are made to see forms in light; light and shade reveal these forms" (Le Corbusier, 1999).

Architectural spaces are analyzed in various numerical and descriptive ways based on their light levels, and are planned to show the impact that the designer chooses and intends to produce (Tezel, 2007).

Light is crucial for the user to sense and recall the physical features of the space. The person's mental attitude and actions also vary depending on the lighting as they perceive the space. The space gains more clarity and significance with uses that will accentuate and stress the common traits of the space and generate the spatial impact (Tezel, 2007).

4.2.3.1. Light and Space

Light makes space and perceives spatial concepts as whole, and the environment in which it takes place is considered an atmospheric space (Schulz, 1972). According to Schulz (1972) the relationship between people and architectural space may be two-way process and that architectural space makes the specific physical appearance of this interrelationship.

Light helps to have a new qualities in the space and creates existential significance for the place and “Spaces can be changed, even created or removed by light, objects can be highlited, textures can be changed, a new atmosphere and a new meaning can be given to the space.” (Altan, 1983).

According to Millet (1996), each unique location has its own light and “Light has two different meanings for places: their physical properties and their character. With these features it adds to the ground, it allows places to be separated from each other. Different patterns form on the ground as the light continues and with daily and seasonal changes. There are places that are remembered because of the quality of their light, and there are architects that bring to mind with their lights on the ground.”

4.2.3.2.Light and Color

The optical perception of color is a result of light. Color is the collective term for all of the sensations that are seen by the eye as a result of light rays reflected off an object also, the retina and brain detect color and light (Caglarca, 1993). A surface can be seen colorful because none of the colored lights that make up its composition, nor the white light that illuminates it, reflect off of it at the same rate. On the other hand, the surface seems colored because the kind of light that is reflected from it and reaches the eye differs from that of white light (Unver, 1985).

Isaac Newton, the physicist, carried out the initial systematic categorization of colors in the year 1666. Newton formed the inaugural color wheel by uniting the extremes of color types within the spectrum. As per Newton's classification, the fundamental colors consist of the hues found in the rainbow: red, orange, yellow, green, blue, indigo, and violet (Itten, 1970).

In the connection between color and human psychology, factors such as an individual's cultural background, economic status, and health, past experiences, memories, current psychological condition, age, and location play a significant role. Warm colors have the tendency to elevate blood pressure, whereas cool colors tend to reduce it. The immediate visual perception triggers a subsequent psychological response. For instance, the warm hue of red has a stimulating effect due to its resemblance to blood, and the impression it imparts can be associated with feelings of pain or sadness. Second example is: Pale yellow creates a tangy and acidic impression as it brings to mind the image of a lemon (Kandinsky, 1993).

Alterations in elements like color concentration arise due to the interaction of colors among surfaces in use, impacting the perception of spatial size and the color attributes of the illuminating light, including color temperatures or the application of colored light, contribute to diverse perceptions of spaces (Serefhanoglu, 1992).

The spatial impact of color and light is directly influenced by the surfaces and materials constituting the space. Therefore, the reflective qualities and luminosity of surfaces play a crucial role in determining the light levels within the space. The reflectance of any surface is contingent on both the color of the material and the roughness of the surface. Various surfaces within the space, such as walls, tabletops, interior surfaces, or counters, typically serve as the backdrop for visual tasks to take place (Faulkner, 1972).

4.2.3.3. Light and Darkness

Light is symbolized by the color white, while darkness is commonly associated with the color black. A space characterized as dark is perceived as black, and this association is rooted in traditional settlements and historical concepts. The terms "megaron" and "atrium," originating from Greek and Latin words for "house," carry connotations of darkness and blackness (Arendt, 1958).

The defining aspects of architectural space are delineated by natural light and artificial illumination. Beyond light as a defining factor, the presence of darkness within the architectural space is also perceived as a constraining element (Jeodicke, 1985).

The illumination penetrating a dark space devoid of discernible objects serves as the most effective means to direct one's focus toward a specific point, accentuating the inherent meanings of light but the prevailing darkness in the environment will also impact our perception of meaning. A setting where the contrast is prominently highlighted will amplify the significance of light, attracting individuals toward the purity and sanctity it embodies (Yildiz, 1995).

4.2.3.4.Light and Shadow

The obscured representation of light originating from a light source, cast on the side opposite to the illuminated surface of an object, is termed as a shadow (Serefhanoglu, 1992).

Light engages with the architectural elements it encounters in diverse manners, primarily through the opposing shadows it casts. It forges connections and contributes to the visual coherence formed, shaping the elements within the space. In assuming a semantic identity, light influences the characteristics of materials and the form of spatial elements. Functioning as a complementary factor in the design process, light is pivotal in sculpting space, and its judicious use, along with shadows, enhances the aesthetic perception in architecture (Altan, 1983).

As per Meiss (1991), the significance of light lies in the perception of the characteristics and textures of spatial boundaries, producing plastic effects in conjunction with shadows.

The characteristics and amount of light that permeate an architectural space play a crucial role in shaping human activities within the space, influencing interactions with the surroundings and behavior, and attributing significance to the environment. Proper and apt utilization of light and shadow in design enhances the impact of aesthetic perception in architectural endeavors. This interplay of light and shadow, juxtaposed opposites that reinforce each other's effects, especially when employed judiciously, evoke varied emotions in the observer (Altan, 1983).

The attributes of a shadow are contingent on factors such as the nature of the light source, the distance of objects, and the reflective properties of surfaces. Additionally, the presence of other illuminating sources can alter shadow characteristics. Shadows may become translucent when exposed to primary or secondary light sources. The absence of shadows or their inconspicuousness can result in luminance contrasts on surfaces. For instance, deep shadows within a space can induce fatigue in the observer so shadow qualities significantly impact the perception of space, it is imperative to delineate these qualities to achieve the desired effect (Serefhanoglu, 1992).

A sharp shadow is characterized by distinct and abrupt edges as it transitions from the shaded region to the unshaded area. Lighting that produces such hard shadows can result in deceptive and unnatural depictions, particularly for objects with non-planar, curved surfaces commonly found in nature and our surroundings. For instance, it may lead to the misperception of a cone as a pyramid, introduce additional lines on a human face, and accentuate and solidify soft images (Sirel, 1992).

A diffuse shadow lacks distinct boundaries, gradually fading as it transitions from the shaded region to the unshaded area. This form of shadow is achieved using expansive light sources, and its softness increases with the size of the light source. Highlights accompanied by soft shadows typically yield precise and natural representations for various surfaces, effectively capturing three-dimensional characteristics (Sirel, 1992).

4.2.3.5.Light and Material

Material and light are intricately linked and exert mutual influence on each other. These two elements play a crucial role in their reaction to light. Surfaces with a glossy finish, acting as reflective surfaces, mirror light and may project the light source onto the surface. Therefore, understanding the relationship between light and materials is crucial as the quality and quantity of light in a building are directly impacted by the choice of materials used (Millet, 1996).

Altering the material can influence both the luminosity and the ambiance of the space. Areas painted in dark hues tend to appear dim consistently, day and night, whereas spaces adorned with light colors consistently project a bright perception. Conversely, the ambient light in the surroundings plays a role in determining the overall brightness of the space (Atabay, 2010).

5. LIGHTING

Light stands as a paramount physical element in architecture, and the visual impact of a space is solely comprehensible through it and illumination involves a light source enhancing visibility by emitting light onto another object or a specific environment (Sirel, 1997). Lighting, with its influential roles in defining, constraining, and leaving an impression, is an essential factor in accentuating architectural creativity and urban values. It is crucial to implement lighting techniques in architectural spaces within a framework of architectural principles and urban design, adhering to specific aesthetic guidelines (Sozen, 2004).

Light as a fundamental role, serves as the paramount factor that renders a space visible and elevates it to a habitable standard. It imparts significance to illuminated spaces across various dimensions. However, the key consideration lies in not uniformly illuminating the space at a constant level. Achieving distinct feelings and fostering selectivity in perception is particularly crucial in the strategic use of lighting (Hoffman, 1992).

The visual representation achieved through lighting should align not only with technical requirements but also with artistic and architectural considerations, meeting specific purposes and requests (Sirel, 1992).

The objective of architectural lighting is to establish a visual environment tailored to the specific function, aiming to optimize visual performance within the space. The intended purpose of light within the space and its directional source play crucial roles in the design process, influencing the configuration of the illuminated environment (Hoffman, 1992).

The space acquires distinct meanings through the presence of natural or artificial lighting. Lighting styles can be categorized into three groups:

- General lighting pertains to the lighting arrangement necessary for comprehensive spatial perception and ensuring visual comfort
- Accent lighting serves as a lighting style designed to illuminate a specific object or surface within a space, accentuating it and distinguishing it from other elements in the environment
- Specialized lighting constitutes a lighting style specifically crafted to accentuate an object or surface within a space, facilitating a focused and effective perception limited to that designated area (Hoffman, 1992).

The distribution of light exhibits various characteristics within a given space. Adequately distributed light imparts a static and uniform quality, proving essential in scenarios where every segment of the space serves a comparable purpose. Instances of such environments include expansive offices filled with desks and sizable workshops housing machinery for similar tasks. When every area of a space is not uniformly utilized simultaneously, with identical intensity and manner, it becomes more suitable to establish a brightness level that is dynamically varied. This not only aligns with the usage, function, and architectural nature of the space but also facilitates a more efficient utilization of energy (Sirel, 1992).

Localized lighting serves various objectives, such as highlighting a specific zone within a space, guiding individuals toward that area, or meeting heightened brightness requirements in a particular region. For regional luminance to exhibit this characteristic, its intensity should be at least three times greater than the general luminance level and even when a space necessitates only localized lighting for a specific duration, it is essential to supplement it with a designated level of general illumination to mitigate eye fatigue (Hoffman, 1992).

5.1.Adequate Lighting Schemes and Space

The luminance level is defined as the luminous flux received by a minuscule particle encompassing a point on a surface, divided by the area of this surface particle, and it is measured in lux (lx) (BOCA, 1990). Additionally, this should yield an average luminance level of 65 lux on a horizontal plane at a height approximately 76 cm above the floor. Achieving this level of illumination is feasible not only with natural light but also through artificial lighting means (BOCA, 1990). The average light level for offices is a minimum of 300 lux, while it is a minimum of 500 lux for lecture halls, laboratories, and auditoriums, 200 lux for entrance halls, and 100 lux for circulation areas (Erlalelitepe et al., 2011).

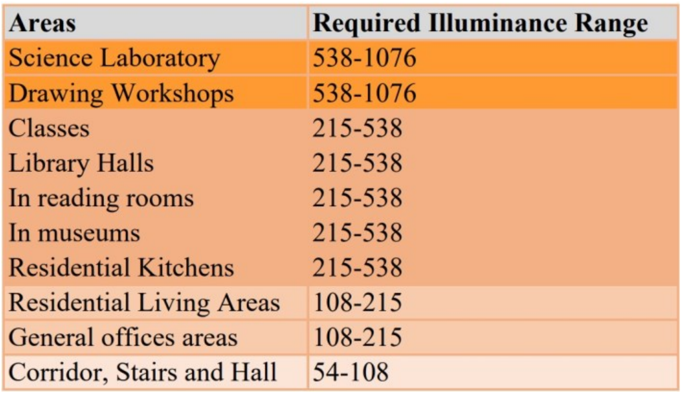
Natural light penetrates the interior space through building apertures such as windows. To maintain the desired illumination level within the volume consistently, it is evident that window sizes need to be larger during periods of lower sky position and smaller during periods of higher sky position (Serefhanoglu, 1992).

The dimensions of windows also influence the distribution of light within the volume, resulting in variations between the light levels near the window and those in the inner parts of the space. This variance in luminance distribution may lead to visual discomfort. According to the standard in England (The Building Research Establishment, BS8206 Part 2: Code of Practice for Daylighting), for rooms less than 8 meters deep, the window area should constitute 20% of the external wall area where the window is located. In office spaces, the window area should be 35% of the external wall surface, while in public buildings, it is advised to have a window area equivalent to 25% of the total external wall area (Boubekri, 2004).

5.2.Visual Comfort in Lighting

One crucial aspect of assessing lighting design involves generating data related to visual comfort and user satisfaction. As outlined by CIE (2012), visual comfort aims to ensure precise and comfortable visual perception during the utilization of a space. This involves considering both the quality and quantity of illumination, the appropriate use of ceiling, wall, and floor surfaces, and the management of undesired reflections and shadows. The goal is to enhance user productivity (CIE, 2012).

Architectural lighting serves the goal of crafting a visual environment tailored to the specific needs of its function and ensuring optimal visual performance within the space. Other essential aspect in evaluating lighting design involves establishing visual comfort and satisfaction, a prerequisite applicable to all environments irrespective of their functions. Adequate brightness is necessary to facilitate effortless visibility, and the distribution of illumination should be such that it avoids causing glare to the eyes and so the brightness level must be adequate to facilitate uncomplicated visual perception (Igdir, 1998).



Areas	Required Illuminance Range
Science Laboratory	538-1076
Drawing Workshops	538-1076
Classes	215-538
Library Halls	215-538
In reading rooms	215-538
In museums	215-538
Residential Kitchens	215-538
Residential Living Areas	108-215
General offices areas	108-215
Corridor, Stairs and Hall	54-108

Table 5.1. Suggested indoor lighting intensities (Brown and DeKay, 2001)

The significance of lighting design in offices and similar workplaces lies in its ability to fulfill visual comfort standards, influence employee performance, mirror the identity of the organization, and play a crucial role in determining a substantial portion of energy consumption. A lighting system capable of ensuring users' visual comfort positively impacts both the physiological and psychological well-being as well as the performance of individuals. Achieving such a system involves a conscious selection of numerous parameters, and decisions regarding each component, including natural and artificial light sources, devices, and lighting control, play a pivotal role in shaping these characteristics (Igdir, 1998).

5.3.LIGHTING SOURCES

5.3.1.1.Natural Lighting

The integration of natural light plays a crucial role in diminishing the energy consumption associated with artificial lighting. While 25% of global energy usage is allocated to lighting, adept design strategies can leverage the sun to fulfill up to 70% of lighting requirements. By incorporating natural light judiciously in building interiors, aligned with visual comfort requirements, the reliance on artificial lighting diminishes, contributing to reduced energy consumption throughout the building's operational phase. Natural illumination can be achieved through architectural openings and light tubes designed to channel sunlight from outdoors to indoors (Yelmen and Cakir, 2011).

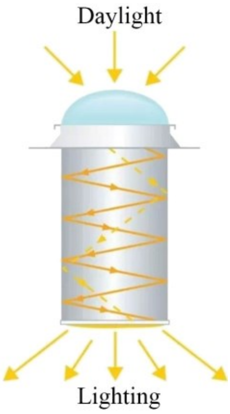
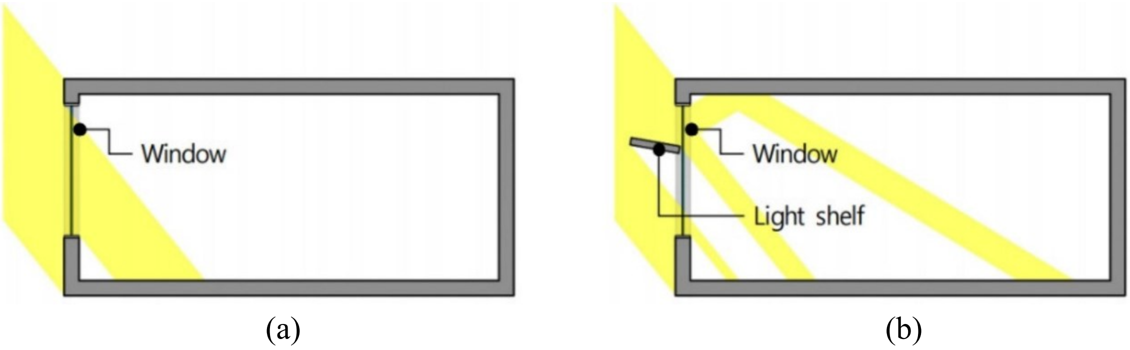


Figure 5.3. Functionality of a light tube (Sunvia Günışığı Doğal Aydınlatma Uygulamaları - Erdinç Klima (erdincklima.com.tr)

A light shelf is an architectural system intended to disperse natural light throughout a space. Typically employed in office or official buildings, where the interior depth is considerable, necessitating artificial lighting during daylight hours, light shelves prove to be an efficient method for augmenting the incoming light from windows within the space (Gorgulu and ark, 2010).



(a) (b)

Figure 5.4. Light penetration based on the installation of a light shelf: (a) without a light shelf and (b) with a light shelf (Lee et al., 2021).

Apart from channeling natural light into the expansive interior sections of structures, light shelves also play a role in minimizing glare originating from windows. Light shelves positioned externally exhibit greater effectiveness compared to their indoor counterparts, benefiting from exposure to natural light from multiple angles. The light reflected from the ceiling serves to diminish or eliminate shadows, consequently reducing the dependence on artificial lighting, particularly within interior spaces (Gorgulu and ark, 2010).

5.3.1.2.Artificial Lighting

Artificial lighting involves the use of various lighting components to provide illumination when natural light is unavailable, inadequate, or when suitable conditions are lacking (Sirel, 1997).

Electric light sources supply artificial lighting, and based on the types of sources employed, this illumination can be categorized into subtypes such as incandescent lamps, fluorescent lighting, or LED lighting. The intended use of lighting within a space, the desired direction of light, and the resulting light-shadow effects contribute to the spatial configuration (Sirel, 1997).

According to Isik (2006), lighting category involves specifying how the light emitted by lighting devices is directed towards the surface to be illuminated and so lighting is categorized in three ways:

a. Direct Lighting: This lighting method directs 90-100% of the light emitted by lighting devices straight to the surface intended for illumination. As a result, this approach produces well-defined boundaries and distinct shadows. Spotlights serve as an illustration of direct lighting, and it is particularly suitable for illuminating substantial works of art. For instance, when applied to sculpture exhibitions, this lighting type accentuates the volume and shadows in the artworks.
b. Semi-direct Lighting: This lighting style directs 60-90% of the light towards the intended illuminated surface, with ceiling lighting serving as an exemplar. As a portion of the rays is absorbed by the ceiling and walls, shadows tend to soften, and distinct boundaries of sharp shadows are not formed.
c. Mixed Lighting: This lighting variant permits the direct dispersion of 40-60% of the light onto the designated illuminated surface and it can be as a mixed lighting include ceiling and wall reflectors (Isik, 2006).

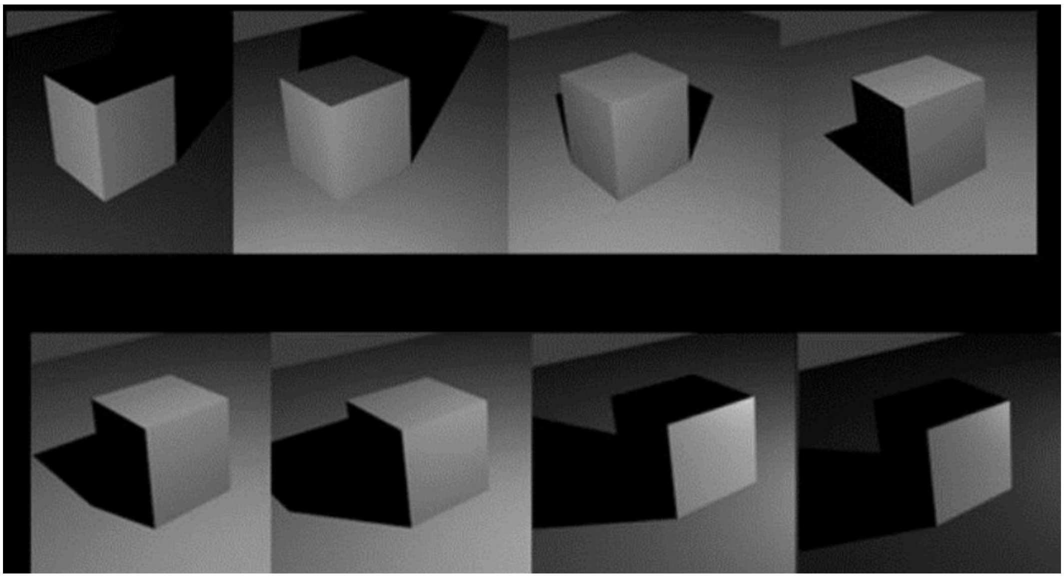


Figure 5.5. Example illustration demonstrating the impact of light on object perception (Erturk and Ormecioglu, 2018)

The way light is directed can influence how we perceive edges, either making them appear smooth or sharp and it impacts our visual ability to perceive the entire form or specific parts of it (Erturk and Omercioglu, 2018).

The overall ambiance within a space can undergo transformation due to variables like light direction, the materials employed in construction, and the color temperature of the light (Zielinska, 2006). According to Zielinska (2006), the seemingly straightforward and intuitively perceived aspect of how light reflects, though often overlooked in our daily experiences, holds a crucial role in shaping architecture therefore, the light's direction has diverse effects on architectural aesthetics as:

- Front lighting is employed to diminish the prominence of visible shadows and details on a surface, creating a perception of reduced space size. This type of lighting is well-suited for spaces characterized by vibrant colors and where depth is not a crucial requirement.
- Employing diffuse lighting from the rear can reveal light-transmitting objects and generate images with pronounced contrast in specific areas therefore, objects acquire a dramatic and abstract effect through back lighting.
- Utilizing side lighting increases the perceived spatial size and depth, accentuating the details of the illuminated surface and enhancing the perception of environmental and formal features and so this approach is employed when there is a desire to create intense contrasts on three-dimensional objects.

- Illuminating objects from the ceiling plane downwards can accentuate them as desired and this lighting method is familiar to people, contributing to a sense of comfort in spaces illuminated in this manner.
- Upward lighting is employed to produce a dramatic effect within the space and this technique emphasizes specific architectural elements or details, such as walls, columns, statues, and trees.

Various lighting techniques can fulfill distinct objectives, including facilitating easy and rapid detail visibility, highlighting decorative and aesthetic elements, directing objects for emphasis with heightened brightness, thereby directly influencing the perception and fostering diverse experiences and interactions within the space (Zielinska, 2006).

5.4.LIGHTING ELEMENTS

The light required for accurate visual perception can be supplied by artificial light sources when natural light is unavailable or inadequate. Lighting schemes devised using artificial light sources make it feasible to achieve the desired illumination in both quantity and quality (Sirel, 1992).

The luminosity produced by lamps and their characteristics, which may vary based on production methods, need to be predetermined (Sirel, 1992). Lighting elements should be initially assessed considering three factors:

- Luminous efficiency
- Color rendering
- Color appearance

Luminous efficacy is expressed as Lumens per Watt (Lumen/Watt). The lamp's efficiency is associated with the efficiency factor, indicating the lumens emitted by the lamp relative to the power (watts) needed by both the lamp and the ballast. Lamps with a high efficiency factor consume less electrical energy to illuminate a space (Sirel, 1992).

Color rendering refers to how the spectral distribution of light from different lamp types influences the colors of objects illuminated by them. Certain lamps alter the inherent colors of illuminated objects by emitting light at specific wavelengths (Hasdemir, 1987).

Color appearance entails information regarding the color of light emitted by the light source. This is assessed from two perspectives. The first involves a general categorization into warm, medium, and cold-colored light. The second perspective is the color temperature, measured in degrees Kelvin (K) (Hasdemir, 1987). CIE (International Commission on Illumination) divides the color temperature of light sources into three categories as follows:

- Color temperature < 3300 K= warm-colored light
- Color temperature between 3300 K - 5000 K= medium-colored light
- Color temperature >5000 K signifies cool-colored light

Higher color temperatures are commonly favored in situations with elevated brightness levels, while lower color temperatures are preferred in environments with subdued brightness levels (Hasdemir, 1987).

There are four techniques employed to transform electrical energy into light: the heating method, the low-pressure and high-pressure metal vapor discharge methods, and the luminescence method involving excitation (Sirel, 1992). These are can be listed as:

1. Heating Method: This method involves passing an electric current through a filament structure, causing the filament to heat up and emit visible light. Incandescent lamps and halogen lamps are examples of this process.
2. Gas Discharge: In gas discharge, visible light is produced by an arc formed through passing current in a tube containing evacuated air and metal vapor. This is achieved by applying voltage through two electrodes and the example of this method include mercury vapor lamps, metal halide lamps, and sodium vapor lamps.
3. Luminescence Method with Excitation: This technique involves stimulating a phosphor layer with invisible UV light generated in low-pressure mercury vapor lamps, transforming it into visible light. Fluorescent lamps and compact fluorescent lamps operate based on this principle.
4. Direct Conversion with Electroluminescence: As a method directly converting electrical energy into light, visible light is produced by exciting electrons within a solid structure. LED lamps are a notable example of this approach (Sirel, 1992).

5.4.1.1.Incandescent Lamps

Incandescent lamps generate light through filament heating by an electric current. The light's color whitens with increasing filament temperature. However, a challenge emerges as the filament becomes hotter, leading to more rapid metal evaporation. While a dim lamp emitting yellow-orange light (2200K) may endure for an extended period, a lamp emitting pure white light (5000K) is likely to last only a brief duration (Karlen and Benya, 2004).

Figure 5.6. Incandescent Lamps (Karlen and Benya, 2004)

5.4.1.2.Halogen Lamps

A halogen lamp is a thermal light source created by adding halogen to the gas mixture around an incandescent lamp. The presence of halogen molecules aids in regenerating the tungsten wire, potentially elevating its temperature. This process results in a slight enhancement in both light efficiency and color temperature compared to an equivalent-power incandescent lamp.

Tungsten-halogen lamps emit a whiter light and have a longer lifespan compared to regular incandescent lamps. The color temperature of halogen lamps is approximately 3000K, imparting a slightly whiter and cooler appearance to their light compared to incandescent lamps (Karlen and Benya, 2004).

Figure 5.7. Halogen Lamps (Karlen and Benya, 2004)

Halogen lamps, adhering to the incandescence principle, emit a warm reddish-yellow glow, creating a cozy ambiance. Their bright and attention-grabbing light enhances the brightness and three-dimensional look of objects, making them a favored lighting choice (Sahin, 2006).

5.4.1.3.Gas-discharge Lamps

The light and color produced in discharge lamps depend on factors like the gas type, pressure, and the presence of phosphor coating on the inner glass tube. Common gases used are sodium and mercury vapor, with high-pressure gas lamps demonstrating high efficiency. The phosphor coating on the inner glass converts ultraviolet rays released during gas discharge into visible light, enhancing their efficiency and high-pressure gas discharge lamps exhibit color temperatures ranging from 1800 to 6000 K. (Neufert, 1983). These lamps are classified into four types:

- Fluorescent Lamps
- Mercury-Vapor Lamps
- Metal Halogen (Halide) Lamps
- Sodium Vapor Lamps

5.4.1.3.1. Fluorescent Lamps

The fluorescent lamp, commonly employed in commercial and institutional buildings, operates through fluorescence. Electric energy stimulates the gas, generating ultraviolet light, which further excites the phosphors. These phosphors, made up of a mineral mixture, are coated on the bulb's interior (Karlen and Benya, 2004).

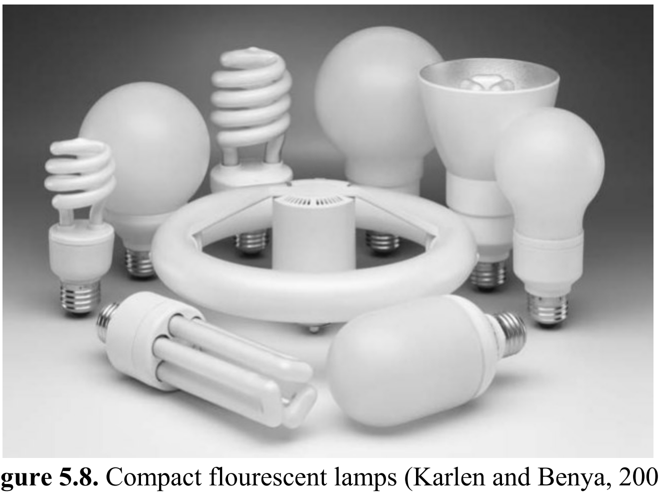


Figure 5.8. Compact flourescent lamps (Karlen and Benya, 2004)

Figure 5.9. Flourescent lamps (Karlen and Benya, 2004)

Fluorescent lamps require a ballast for proper operation, serving to initiate and control the electric power supplied to the lamp. There are two types: magnetic and electronic and electronic ballasts, known for being more energy-efficient, quieter, and effective in minimizing lamp flicker, are generally preferred. The usual dimming range is approximately 10 to 100 percent or better, and advanced ballasts can extend this range to 0.5 to 100 percent (Karlen and Benya, 2004).

5.4.1.3.2. Mercury Vapor Lamps

Mercury vapor lamps consist of mercury, argon, krypton, and neon gases in a quartz glass arc tube. When an electric arc interacts with vaporized mercury, light is produced. Ranging from 40 W to 1000 W, these lamps offer double the light output of incandescent lamps and nearly match the light efficiency of fluorescent lamps. Equipped with three electrodes for initiation and sustaining the arc, they are suitable for large-space lighting, reaching up to 1000 W (Ching, 2004). Mercury vapor lamps, used for streetlights and security lights, exhibit comparatively inferior color quality and lower energy efficiency (Karlen and Benya, 2004).

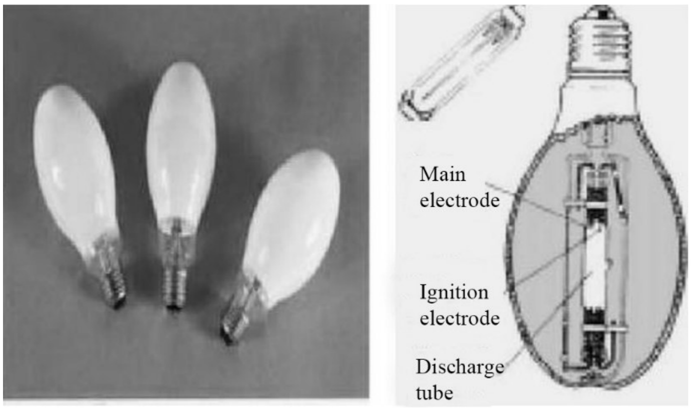


Figure 5.10. High pressure mercury vapor lamps (Atlas Akvaryum: Akvaryum Aydınlatması Hakkında)

Mercury vapor lamps consist of mercury, argon, krypton, and neon gases in a quartz glass arc tube. When an electric arc interacts with vaporized mercury, light is produced. Ranging from 40 W to 1000 W, these lamps offer double the light output of incandescent lamps and nearly match the light efficiency of fluorescent lamps. Equipped with three electrodes for initiation and sustaining the arc, they are suitable for large-space lighting, reaching up to 1000 W (Ching, 2004).

5.4.1.3.3. Metal Halogen Lamps

Metal halide lamps produce high-quality white light and are available in various sizes, suitable for a range of applications, from compact track lighting to large fixtures for illuminating stadiums. Standard metal halide lamps typically have a color temperature between 3700 and 4100K, giving off a cool and slightly greenish appearance. They are commonly used in areas where color accuracy is not critical, such as sports arenas, parking lots, landscape lighting, and building floodlighting (Karlen and Benya, 2004).

The latest innovation in metal halide lamps is the ceramic metal halide lamps, which offer enhanced color rendering (80 to 85) and provide the option of warm (3000K) or cool (4100K) lighting and these lamps are versatile, serving both interior applications like down lighting, display lighting, and exterior lighting (Karlen and Benya, 2004). Due to their advanced technology, these lamps possess advantages compared to other bulb types and they incorporate high-pressure mercury and metal halide and come in both double-ended and single-ended configurations (Neufert, 1983).

Figure 5.11. Metal halide lamps (Karlen and Benya, 2004)

5.4.1.3.4. Sodium Vapor Lamps

Sodium vapor lamps produce light in a U-shaped arc tube by incorporating sodium metal and other auxiliary gases at low pressure and to reduce heat losses, the lamp is enclosed in a second tube with evacuated air (Neufert, 1983). Sodium lamps come in two types: high-pressure sodium (HPS) and low-pressure sodium (LPS). These lamps usually have a yellowish color (Karlen and Benya, 2004).

Figure 5.12. High Pressure Sodium Lamps (Karlen and Benya, 2004)

Despite HPS lamps offering high lumens per watt, their color limitations restrict their use to areas like roads, parking lots, industrial spaces, warehouses where light color is not a critical factor (Karlen and Benya, 2004).

5.4.1.4.LEDs (Semiconductor)

Light-emitting diodes (LEDs) face constraints related to color and efficiency, making them relatively expensive for general lighting display lighting, and widely used in exit signs and their usage in automotive lighting (Karlen and Benya, 2004).

Figure 5.13. Light Emitting Diodes (LEDs) (Karlen and Benya, 2004)

5.4.1.4.1. Advantages of LED’s

LED lamps offer significant advantages, including up to 85% energy savings compared to traditional bulbs, exceptional performance, reliability, and a lifespan at least 35 times longer. The absence of a burning filament contributes to this extended lifespan, allowing them to be used for an additional approximate 15 years (Chrobak-Kando, 2012).

The prominence of LED technology is underscored by the fact that 25% of the world's energy is consumed in lighting. The advantages of LED lamps over incandescent and fluorescent lamps include:

- LED lamps generally have a lifespan five times longer than compact fluorescent lamps, instant illumination, and are free from hazardous substances like mercury
- LED lamps exhibit resilience to impact and vibration
- LEDs deliver exceptional light quality, allowing for high brightness and intensity
- The ability to generate both dazzling white light and a warm, inviting ambiance Adjustable and easily controllable light levels
- LEDs present opportunities for innovative, low-profile, compact lighting designs due to their small size and directional light emissions (Chrobak-Kando, 2012).

5.4.1.4.2. Life of LED’s

The primary challenge in designing LED lighting systems seems to be managing high temperatures. Despite being recognized as efficient light sources, LEDs tend to convert a substantial portion of the electrical energy they consume into heat (Ozuturk, 2002).

Light	**Incandescent Flemish (%)**	**LED (%)**
Visible Light	8	20
Infrared	73	0
Temperature	19	80
Total	100	100

Table 5.2. Energy conversion for white light sources (Ozuturk, 2002)

Given that the latest generation of LEDs operates with elevated currents, a thermal design is essential to ensure the junction temperature remains below 110 °C. The junction temperature, located where light is generated within the LED, must not surpass the maximum permissible temperature and also the current flowing through the LED at the junction should be carefully selected to avoid generating excessive thermal power, thereby preventing temperature escalation (Ozuturk, 2002).

5.4.1.5.Quantity and Quality in Lighting

The foundation of effective lighting encompasses two crucial aspects: quantity and quality. Quantity refers to the measurement and specification of the required luminance level as a numerical value. This determination takes into account various factors, including the nature of the task, working duration and pace, environmental conditions, and the specific characteristics of the individuals involved in the work (Sozen, 2006).

The luminance quantity pertains to the necessary brightness for perceiving the environment and this brightness level can differ based on individual visual sensitivity, with some perceiving the space as dimmer and others perceiving it as brighter (Sirel, 1992).

Advancements in lighting techniques have introduced the importance of both quantity and quality of illumination, aiming not only for vision but optimal visual conditions (Sozen, 2006). In addition to the quality aspect of illumination for good visual conditions:

- Visual perception can be effortlessly achieved and sustained over extended periods,
- Accurate recognition and distinction of colors are facilitated,
- Precise perception of surface characteristics such as shape, texture, and size is ensured,
- Features related to movement, such as direction and speed, can be easily discerned,
- Opportunities, such as distinguishing the object from the environment and ensuring the visibility of necessary details, have been realized (Sozen, 2006).

The vision process, constituting up to 95% of an individual's perceptual engagement with the environment, is essential for a comprehensive and flawless understanding of the nearby and distant surroundings. Vision relies on light, with objects becoming visible as light reaches the eyes through reflection and transmission. Therefore, the quality of light and, by extension, the quality of illumination, plays a decisive role in ensuring optimal vision (Sirel, 1992).

Raising the brightness level hinders effective vision in qualitatively inappropriate conditions because the eye can adjust to various brightness levels but lacks the capability to perceive accurately in qualitatively inappropriate environments. “Contrary to the brightness level, the visual organ does not correct the visual conditions by adapting to the wrong quality. This kind of adaptation of the eye is absolutely out of the question because the eye cannot change the image outside itself.” (Sirel, 1992).

The advantages offered by favorable visual conditions, as identified through research and measurement outcomes and documented in reputable literature, can be outlined as follows:

- Enhanced productivity and efficiency in work environments,
- Lowering the incidence of defective production in manufacturing processes,
- Minimized rates of traffic and workplace accidents,
- Decreased errors in visually dependent diagnoses,
- Improved success rates in educational institutions,
- Elevated work commitment,
- Reduced overall fatigue and irritability,
- Lowered lighting expenses (Sirel, 1992).

Scientific studies have consistently demonstrated that properly illuminated workspaces and educational institutions contribute to increased success and efficiency, reduced eye fatigue, and lower energy consumption, both qualitatively and quantitatively (Sirel, 1992).

6. OFFICE STRUCTURES AND USER RELATION

6.1.OFFICE STRUCTURES

In contemporary times, the careful planning and management of the physical environment within office buildings, which serve as a second home for individuals given the considerable time spent in these spaces, have become crucial and this focus is driven by the recognition that the physical conditions experienced by employees directly impact their productivity, as well as their physiological and psychological states (Boyce, 2003).

Working environments, crucial for daily work activities, are housed within office buildings. The demand for office spaces grew in the 19th century, leading to the creation of large, complex offices to accommodate numerous users. Advances in technology, evolving systems, and shifts in the business landscape have driven existing office setups to redefine themselves to meet new demands (Sallworth, 1996).

6.1.1. Historical Development of Offices

The design of office spaces has a history dating back to the 15th century, with substantial transformations occurring in the latter part of the 19th century to align with the needs of the modern information and communication era. Innovations, expanded trade, and increased international engagement during the post-Renaissance period led to a more intricate organizational structure within offices. This development manifested in the creation of distinct departments, such as personnel, accounting, and sales, marking the increased complexity of office environments in the 19th century (Cete, 2004).

In the latter part of the 20th century, while the core purpose of office work remained unchanged, there was a substantial shift in its execution due to technological advancements. The modernization of technology, accompanied by increased commercial activities, has mandated the widespread use of computers in offices. The higher lighting levels initially designed for improved visibility in paper-based tasks have inadvertently hindered the visibility of information on vertical screens used for computer-based activities so that a thoughtful consideration of physical environmental conditions, especially in terms of lighting design, is crucial to accommodate these transformations (Boyce, 2003).

The rapid advancement of industry and technology, the coexistence of multiple business branches in shared spaces, an expanding workforce, and rising rental costs have led to challenges, including difficulties in optimizing space utilization in horizontally expanding office buildings and limited access to natural lighting due to depth-related constraints (Bal, 2005).

6.1.2. The Importance of Offices in Today's Life

The notion of work encompasses various definitions and perspectives. Etymologically, it originated from ancient Greek and Roman terms denoting "pain," "tiredness," and "toil." (Lordoglu ve Ozkaplan, 1999).

In modern societies, people work to establish social status, realize their potential, and achieve economic independence. Work influences various aspects of their lives, serving as a means to gain status and autonomy. Offices, recognized as spaces dedicated to work, constitute the primary venues where individuals spend most of their day involved in professional activities (Cotok, 2011).

6.1.3. User and Visual Comfort Conditions in Offices

User actions encompass the behaviors needed to achieve goals, while user needs involve the environmental conditions that enhance productivity and ensure users' well-being in their tasks. These requirements collectively define the comfort conditions in a person's work environment (Bayazit, 1994).

The physical conditions in workspaces significantly influence the execution of user actions and the interplay between user comfort and productivity. If office conditions hinder work, it may cause employee dissatisfaction, leading to negative moods and decreased work efficiency. Acknowledging the importance of these connections underscores the necessity to customize physical environmental conditions to fulfill user needs in office design (Kavuran 2006).

As per a 1984 study conducted by the National Institute of Occupational Safety and Health in the United States, it was found that employees working in an office system designed considering physical environmental conditions demonstrate higher efficiency compared to their counterparts performing similar tasks outside such facilities (Mahnke, 1993).

A study carried out by the United States Department of Health and Human Services in America, focusing on individuals working in enclosed offices assessed as either favorable or unfavorable based on physical environmental conditions, indicated that conducive conditions could enhance employees' work efficiency by 25% (Mahnke, 1993).

7. LIGHTING CONDITIONS AND USERS IN OFFICE SPACES

Lighting is a scientific discipline governing the generation and dispersion of light tailored to meet users' physiological vision requirements, with the objective of enhancing user efficiency through visual comfort so that lighting design not only contributes to the aesthetics and light quality of a space but also exerts psychological effects intertwined with human physiology, influencing good vision and visual comfort (Demirdes, 1993).

7.1.EFFECTS OF LIGHTING CONDITIONS ON THE USERS IN OFFICES

Providing suitable lighting conditions aligned with the function and setting in workspaces has a positive impact on users' satisfaction with lighting, visual comfort, and mood therefore, it facilitates the execution of work in a healthy, effortless, and efficient manner for employees (Boyce et al., 2003).

An unsuitable lighting system for the purpose and environment results in an unpleasant work setting, leading to strain and debilitation of the optic nerves, potentially causing temporary or permanent vision impairment. Poor lighting-induced fatigue contributes to attention distraction, morale decline, and irritable behavior, reflecting a negative mood (Giray, 2009)

7.1.1. Effects in Terms of Visual Comfort in Offices

Individuals have distinct physiological and psychological needs crucial for their productivity in a workplace, commonly known as comfort conditions in their working environment (Cete, 2004). Maintaining specific levels of these values is essential to enhance visual comfort for users, ensure sustained visual well-being, protect eye health, and ultimately boost overall performance and work efficiency (Alkan, 2010).

Visual perception plays a crucial role in individuals' interaction with their surroundings, encompassing both immediate and distant environments. In offices, the 'visual comfort effect' is established through adequate illumination, reflections enhancing illumination, surface contrast in illumination, and considerations of shadows and color characteristics, collectively shaping the optical conditions within the workspace. (Sirel, 1997).

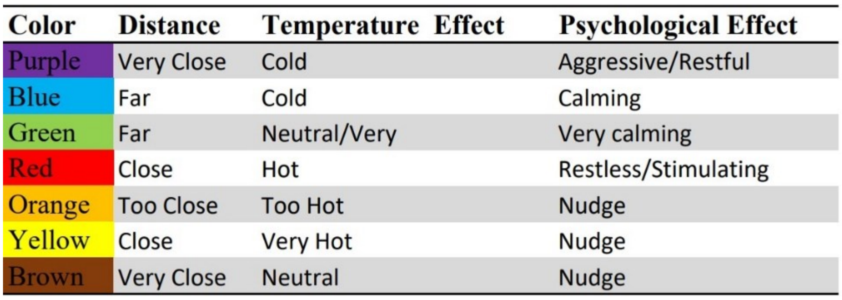
The concept of brightness level varies based on the activities and purpose of the space. In design offices, it is advised to maintain a horizontal illumination level of 500 lm/m2 at a height of 0.80 cm from the floor on the working plane. In open offices, the recommended horizontal illumination level for working spaces falls within the range of 500 to 750 lm/m2 (Sirel, 1997). The quality of brightness is crucial for optimal visual conditions and natural lighting in office buildings influences the human biological clock, increasing overall brightness and connecting visually with the external environment. Enhanced lighting quality has positive effects on employees' physical and psychological well-being. (Sirel, 1997).

Figure 7.1. Office Room (Modern Office Design: Features and Trends in 2023 | Foyr)

In private offices, which are typically small and have limited occupancy, there is a significant opportunity to utilize natural light. Extensive general lighting is often unnecessary, and focused illumination of the immediate work area is generally sufficient so that a combination of general and localized lighting is viable. General lighting can be provided through ceiling-mounted fixtures (Kucukdogu, 1982).

Direct illumination, causing locally high light levels, casts dark shadows behind objects in the light's direction, potentially causing discomfort and dazzle to the eyes. Indirect lighting produces diffuse light without creating shadows and reduces the risk of glare, it may induce glare through reflections on glossy surfaces such as walls, ceilings, and screens in office settings (Hoffman, 1992).

The selection of colors in spaces serves diverse purposes such as improving visual comfort, fostering a sense of security, impacting brightness levels, and enhancing aesthetics and this underscores the importance of color in elevating working conditions and promoting productivity (Dokmeci et al., 1993).



Color	Distance	Temperature Effect	Psychological Effect
Purple	Very Close	Cold	Aggressive/Restful
Blue	Far	Cold	Calming
Green	Far	Neutral/Very	Very calming
Red	Close	Hot	Restless/Stimulating
Orange	Too Close	Too Hot	Nudge
Yellow	Close	Very Hot	Nudge
Brown	Very Close	Neutral	Nudge

Table 7.1. Overall Psychological Impact of Colors (Dokmeci et al., 1993)

In work environments, it is crucial to choose colors that align with the space's function for optimal visual comfort. The color of ceilings, floors, and walls has distinct effects on users. White, with high reflectivity, is recommended for ceilings, while light colors on work surfaces to prevent reflection are discouraged. If opting for a colorless surface, white is the preferred choice and a preference for white and its shades in offices to balance the positive and negative psychological effects of colors on individuals (Dokmeci et al., 1993).

7.1.2. Effects of Lighting on People in Terms of Mood in Offices

Inadequate lighting for office functions can result in headaches, emotional disturbances, and eye fatigue among users. Understanding the correlation between light and health is crucial. Incorporating health-focused recommendations in office lighting designs is essential for positive effects on users' moods and productivity and considerations such as light color, angle, and the quality of lighting design play significant roles in achieving this goal (Oldham and Fried, 1987).

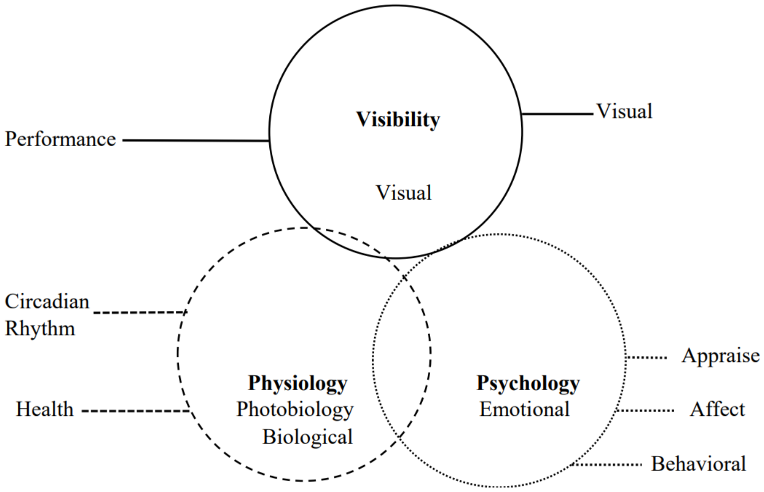


Table 7.2. The multiple effects of the lighting experiences. Diagram adapted from Veitch and Newsham (1996)

Physically		Psychologically	
Improve	Decrease	Improve	Decrease
Vitamin D	Cancer Possibility	Mood	Depression
Visual System	Abnormal Bone Formation	Mental Performance	Stress
Circadian Rhythms	-	Alertness	Sadness
Sleep Quality	-	Brain Activity	Violent Behavior

Table 7.3. The effects of lighting as physically and psychologically (Salares and Russell, 1996)

7.2.THE CONCEPT OF LIGHTING IN OFFICES

Inadequate lighting for office functions can result in headaches, emotional disturbances, and eye fatigue among users. Understanding the correlation between light and health is crucial. Incorporating health-focused recommendations in office lighting designs is essential for positive effects on users' moods and productivity (Boyce-Raynham, 2009).

7.2.1. Use of Natural Lighting in Offices

The key factor in creating suitable and accurate lighting designs within a space is the illumination source, which is light to assess the quality of light in a given space, factors such as visual performance, social communication, and satisfaction hold significant importance. Light is acquired through two means: the first being natural light, resulting in natural lighting, and the second being artificial lighting, which generates light through electricity consumption when natural daylight is insufficient (Boyce et al., 2003).

In workspaces, careful and controlled incorporation of indoor daylight is essential for optimal use. In such offices, strategic planning involves designating areas with openings as shared spaces for universal access and configuring partition panels in open office sections to facilitate the unrestricted spread of daylight (Charles and Pero, 2006).

The Daylight Factor, defined by CIE, represents the ratio of luminance level on a specific plane due to direct or indirect light from a known or assumed sky to the luminance level on the horizontal plane from unobstructed hemispherical sky light (Arpacioglu, 2012). The Illuminating Engineering Society (IES) provides recommended daylight factor values for offices. Studies indicate that a value below 1 percent is insufficient, while a range of 2 to 5 percent signifies satisfactory illumination but a ratio exceeding 10 percent can result in increased visual discomfort and glare problems (Kucukdogu, 1976).

Function	Daylight Factor (%)
General offices	2
Computer	4
General	2

Table 7.4. Daylight factor values recommended by IES (Kucukdogu, 1976)

Sunlight entering workspaces, considered an inefficient light source, often causes substantial brightness variations and disrupts visual comfort in offices. Various controlled methods, crucial for incorporating daylight into interior spaces, can be grouped into three categories: vertical introduction, horizontal introduction, and advanced daylight systems (Gordon, 2003).

7.2.2. Use of Artificial Lighting in Offices

Artificial lighting, derived from electric light sources when natural daylight is insufficient, has evolved into a necessity driven by the demand for visibility and productivity in various environments regardless of the time of day. In workplaces characterized by a high pace of activity during daylight hours and in office buildings situated away from windows, artificial lighting is increasingly perceived as the primary solution (Ozkum, 2011).

The qualities of artificial light are crucial for vision, visual perception, and user mood, and their spatial distribution is equally important. In workspaces with diverse functions and users with varied visual needs, achieving uniform brightness may not be effective. Different areas catering to distinct purposes and employees with varying characteristics require different light levels. Lighting strategies for consistent illumination across the entire volume and dynamic illumination in specific areas include general illumination, zoned illumination, and zoned illumination (Boyce et al., 2007). General Lighting involves one or more light sources positioned on the ceiling or walls of the office, strategically arranged to uniformly illuminate the entire space. In office environments with this lighting design, every area maintains a consistent and evenly distributed brightness level and alterations to the space's furnishings do not impact the established lighting arrangement (Boyce-Raynham, 2009).

In areas where general lighting, high brightness levels, and visual comfort are essential, obstacles hinder the effectiveness and adequacy of regional lighting elements. A study that variations in user characteristics and tasks performed contribute to dissatisfaction with the overall brightness level, underscoring the importance of regional lighting that allows for individual lighting control in office settings (Veitch, 2005).

Figure 7.2. Regional lighting (Waldmann Lighting's Singapore Regional Headquarters | Office Snapshots)

Ensuring that general lighting fixtures in office spaces are positioned in direct correlation to the size of the office and light intake is a crucial necessity so this approach helps prevent glare and facilitates the even distribution of light rays throughout the room (Bal, 2005).

7.2.3. Energy Efficient Lighting in Offices

In office buildings, it is common for almost 50% of energy costs to be dedicated to lighting. Implementing a lighting system that ensures visual comfort conditions and applying fundamental principles for effective energy utilization in lighting can lead to savings in energy consumption for illumination (Lechner, 1991).

The following steps can be outlined to decrease energy consumption related to lighting in office spaces:

- The design of the office building's façade should prioritize maximizing the use of natural light, and if needed, integrating natural lighting systems into the building structure
- The recommended lighting level for office workspaces is within the range of 700 - 1000 lux
- Utilize individually adjustable zoning lighting elements to allow employees to customize the lighting according to their needs
- Select surface materials in the workspace (walls, ceiling, decoration) with features that prevent light absorption, and opt for light colors whenever feasible
- Maintain the optimal lighting intensity in workspaces, aiming for values between 9.4-14 W/m2
- Implement energy-efficient, color-accurate, durable, and economically viable LED lamps for office lighting
- Employ automatic lighting control systems and daylight systems to reduce lighting energy consumption, utilizing these controlled systems to the fullest extent (Lechner, 1991).

8. CASE STUDY of ENERTGY DEPARMENT of POLITECNICO DI TORINO

8.1.History of Politecnico di Torino

Figure 8.1. The view of Politecnico di Torino (About us | Politecnico di Torino (polito.it))

The Politecnico di Torino, the inaugural Engineering School in Italy, originated during the mid-19th century as a result of the surge in technical and scientific advancements that gave rise to the most distinguished polytechnic schools in Europe (About us | Politecnico di Torino (polito.it).

The Regio Politecnico di Torino, also known as the Royal Turin Polytechnic, traces its roots back to the establishment of the Technical School for engineers in 1859 and the Italian Industry Museum in 1862. These institutions, operating under the Italian Ministry of Agriculture, Trade, and Industry, laid the groundwork for the later formation of the Politecnico. While the former emphasized research and higher education in technical disciplines within a university framework, the latter focused on the industrial context of a nation poised for significant industrialization. The introduction of pioneering subjects such as Electrotechnics and Building Science by distinguished scholars and researchers further enriched the educational landscape of the institution. Ultimately, in 1906, the Regio Politecnico di Torino was formally established, consolidating these earlier initiatives into a single, renowned polytechnic institution (History | Polytechnic University of Turin (polito.it)).

The Technical School for Engineers, now Politecnico di Torino, acquired Valentino Castle in 1859, which it still owns today. Drawing inspiration from esteemed European Polytechnic Schools, the institution, later known as Regio Politecnico di Torino, charted diverse trajectories as the 20th century approached. It fostered connections with the European scientific community and local and national industries. Within its new laboratories spanning disciplines from Chemistry to Architecture, aspiring professionals from across Italy converged in Turin, shaping their careers amidst a vibrant and innovative milieu, coinciding with the burgeoning field of aeronautics and over the years, the Politecnico di Torino marked its 160^{th} academic year from its creation, and has transformed into an international school that links traditions and future, past and modernity (History | Polytechnic University of Turin (polito.it)).

8.1.1. History of Energy Department (DENERG) of Politecnico di Torino

The structure is situated within the central region of Turin, Italy, on the primary campus of Politecnico di Torino (latitude: 45.1°N, coordinates 45.06, 7.66) (Lo Verso et al., 2014). The large complex on Corso Duca degli Abruzzi which includes Department of Energy (DENERG), the study case, opened in November 1958 and grew with the expansion of the Ciitadella Politecnica, a campus that integrated classrooms, labs, education, research and town services (History | Polytechnic University of Turin (polito.it)). The building houses the Department of Energy (DENERG) and includes 67 offices, a library, and two laboratories. Each internal space encounters external frontal obstacles. Specifically, the library and 31 offices face north, 28 offices face south, and 8 offices face west. Additionally, the two laboratories are situated to face both south and east directions. The offices are primarily equipped with internally adjustable vertical blinds for managing daylight exposure, although exceptions include internal roller blinds for north-east-facing rooms and external venetian blinds for south-east-facing rooms. Manual operation is employed for these shading systems. Ceiling luminaires with fluorescent lamps are installed in most spaces, with some recessed luminaires in corridors. Lighting systems are manually controlled using on/off switches. Cooling is provided by a high-efficiency heat pump and the heating network. Each office has a thermostat and double-pipe fan coil units (FCU, COP=4). There is no ventilation system in the offices, but laboratories are cooled by air conditioners. The heating/cooling and fresh air handling units (AHUs) are located on the roof (Lo Verso et al., 2014).

8.2.Case Study of Energy Department (DENERG) of Politecnico di Torino

8.2.1. Method

This thesis undertakes a focused analysis of the office spaces situated atop the Energy Department premises at Politecnico di Torino University, nestled within the urban landscape of Turin, Italy. Specifically, the investigation encompasses a meticulous scrutiny of 28 distinct areas distributed across the 3rd and 4th floors of the campus, comprising 24 office spaces, 2 meeting rooms, and 2 corridors. In particular, 4 offices, 1 meeting room and 1 semi-office area were examined by DesignBuilder software. Leveraging DesignBuilder software, comprehensive calculations were conducted, juxtaposing various parameters including thermal transmittance (U-value) according to current non-insulated and suggested insulated building, shading configurations, indoor air temperature, and lighting conditions—both natural daylight and artificial illumination—across the spectrum of existing conditions and hypothetical scenarios incorporating insulated materials. Through this rigorous examination, the study endeavors to furnish valuable insights into the working environments experienced by individuals within the Department of Energy at the Politecnico di Torino campus.

Figure 8.2. Perspective view of two floor of the Energy Department

8.3.Energy Department Building

8.3.1. Site Plan

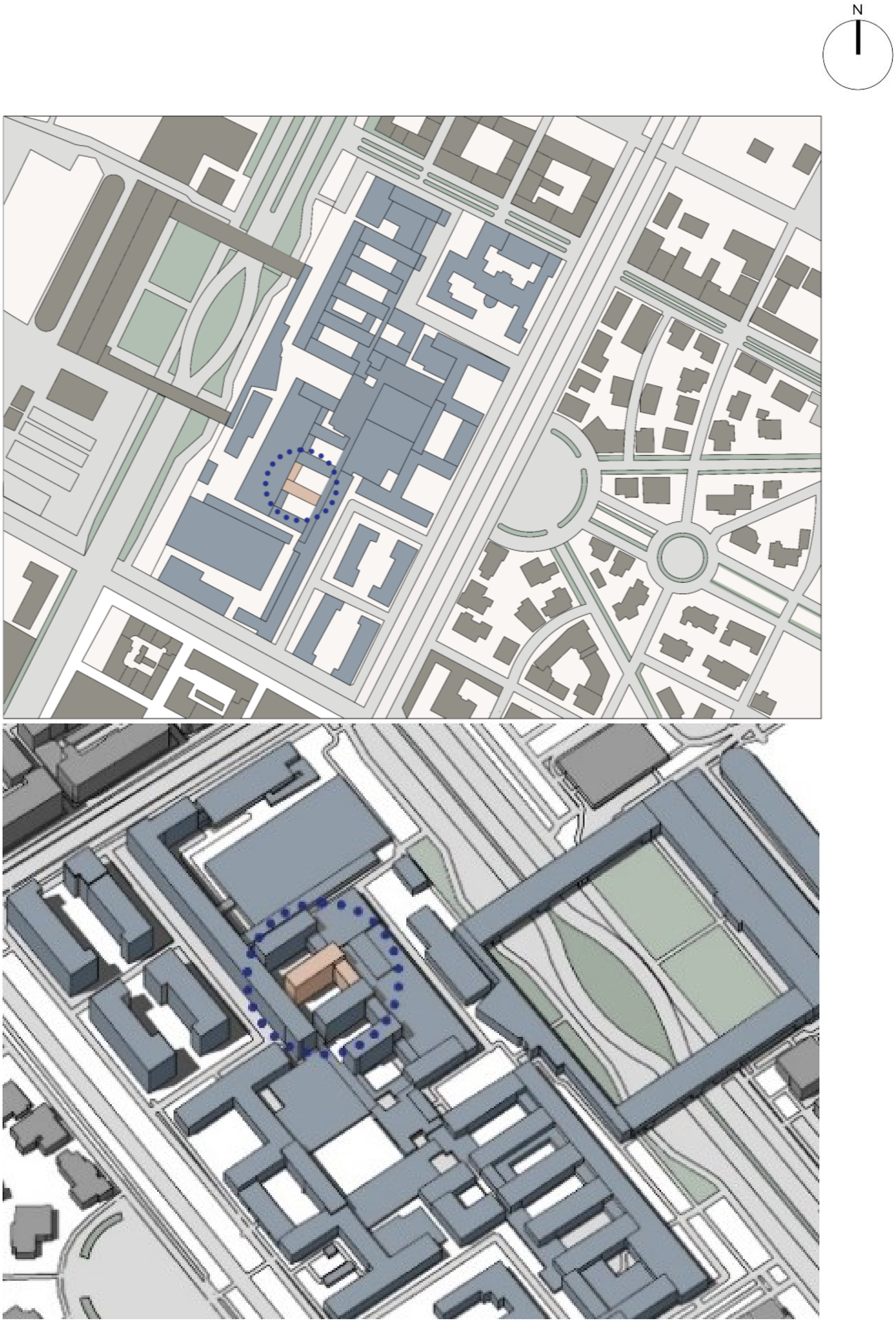
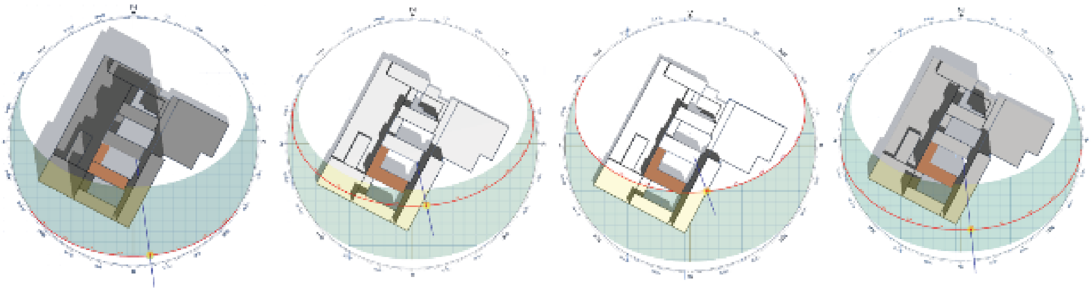


Figure 8.3. Site plans and 3D model of the Politecnico di Torino main campus and around of the campus

The main campus of Politecnico di Torino is situated on Corso Duca degli Abruzzi street in Turin, Italy ((latitude: 45.1°N, coordinates 45.06, 7.66), as depicted in the site plan on figure 8.3. The specific building under examination is represented by a blue circle on the plan and comprises four floors constructed with uninsulated materials. The focus of the study is on the third and fourth floors of this building with a "L" shape and its adjacency to other structures, the building forms a courtyard, potentially leading to shadow castings from neighboring buildings due to its enclosed configuration. These shadow angles, varying month by month, are visually presented in the accompanying figure 8.4. The seasonal variation in sun path angles manifests distinct patterns across various months of the year. Notably, certain groupings of months exhibit comparable sun path angles, exemplified by the sequential alignment of December, January, and February; March, April, and May; June, July, and August; and finally, September, October, and November. This phenomenon facilitates the categorization of these months into four distinct groups, as visually depicted in Figure 8.4.



a) b) c) d)

Figure 8.4. Sun path of the main campus with other buildings of Politecnico di Torino a)December=January=February; b)March=April=May c) June=July=August d)September=October=November

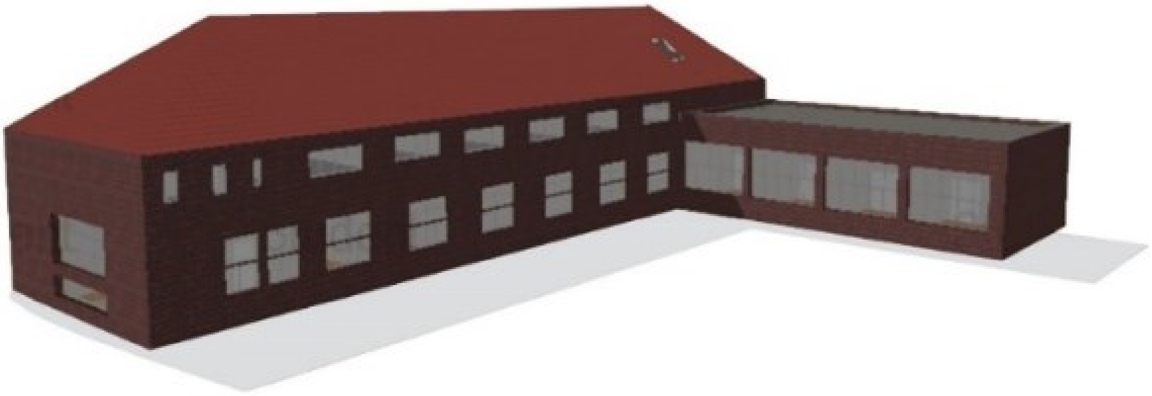


Figure 8.5. 3D model of Energy Department at Politecnico di Torino main campus from DesignBuilder

8.3.2. Office Rooms Analysis of Energy Department Building

3rd Floor Plan

4th Floor Plan

Figure 8.6. Third and fourth floor plans and perspective of the Energy Department building

Two architectural schematics pertinent to the examined case study is illustrated from figure 8.6. The primary plan delineates the structural layout of the building, characterized by an L-shaped configuration, thereby engendering the creation of a central courtyard encompassed by four distinct facades showcasing apertures of diverse geometries. Within this architectural framework, the third floor, demarcated in red on the left-hand side of Figure 8.6, serves as a pivotal locus accommodating 11 office chambers, 2 connecting corridors, and a singular meeting space. Notably, room D-09 is spatially demarcated from its adjacent counterpart, room D-08, through the implementation of glass partitions.

The fourth floor, situated at the highest level of the Energy Department building and highlighted in gray on the right side of the figure 8.6, comprises 1 corridor, 12 office rooms, and 1 meeting room. The exterior walls of the fourth floor are inclined due to the pitched roof design, resulting in shorter walls for the office rooms compared to the overall height of the third floor's walls.

Figure 8.7. Corridor D-07 and room D-10

Figure 8.8. Corridor D-14, Corridor E-13 and meeting room E-14

The third-floor spaces boast a luminous white color scheme, creating a vibrant ambiance, particularly evident in the D-07 corridor flooded with ample daylight from the south-facing facade. Room D-10 benefits from larger windows, while corridor D-14's unshaded west-facing windows are uniquely positioned. On the fourth floor, corridors E-13 and E-14 exhibit distinctive features; E-13 has a reduced height, while E-14, a meeting room, occupies an attic space with a sloped roofline.

Figure 8.9. Room E-14 on the 4th floor

The meeting room which is named as E-14 depicted in the figure 8.9, situated on the fourth floor of the Energy Department building, is characterized by comparatively smaller windows on the south façade and skylight windows integrated into the ceiling. The room's interior is adorned with a white color scheme, resembling paintings, and features sloping ceiling and this room’s windows on the wall are smaller than third floor rooms’ windows.

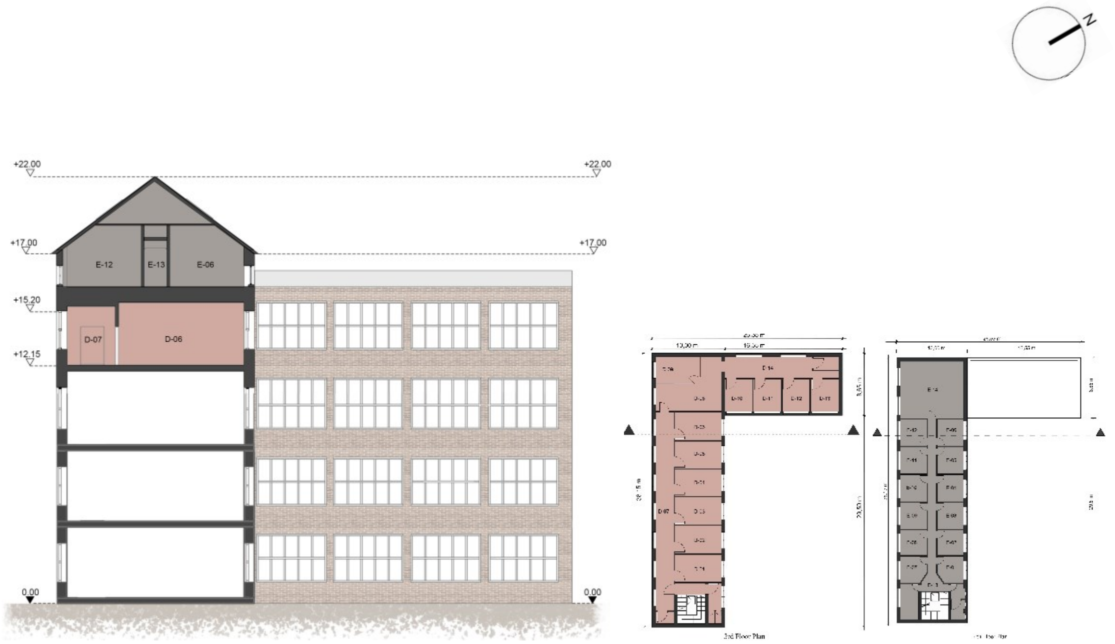


Figure 8.10. Section A-A

The third-floor's southern facade, including areas D-07 and D-08, features a brick facade with generously sized windows spanning approximately 16.55 meters. Fourth floor, an analysis of section A-A highlights distinctive features, such as sloping ceilings in office chambers E-12 and E-06 due to the pitched roof design and the exterior walls of the fourth floor have reduced heights compared to those on the third floor, as depicted in Figure 8.10.

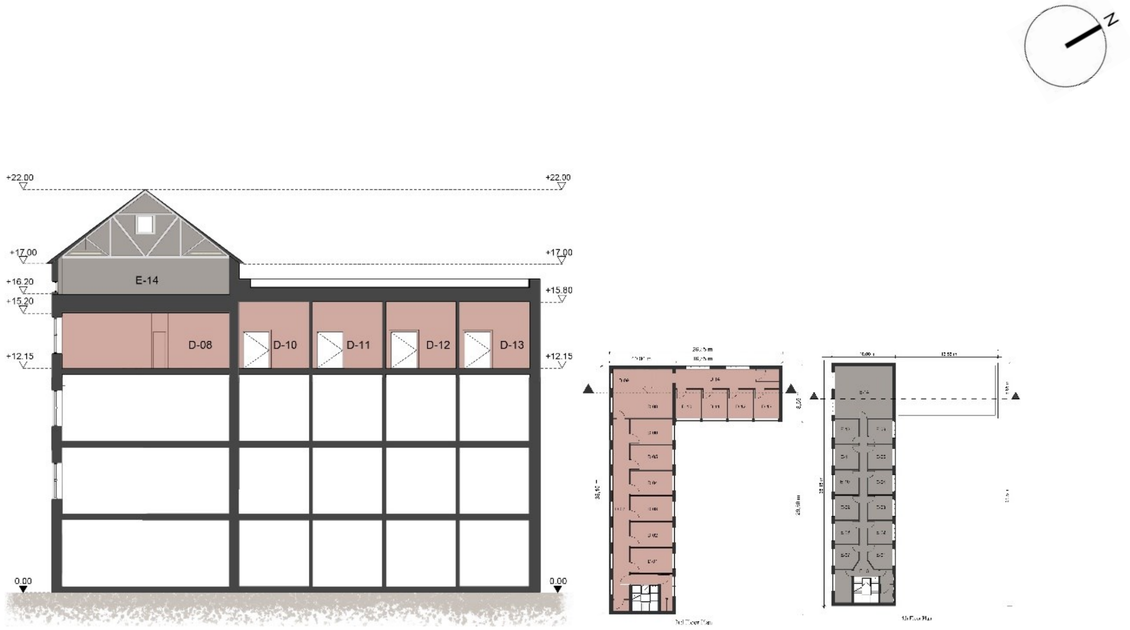


Figure 8.11. Section B-B

Section B-B traverses through several office rooms on the third floor, including D-08, D-10, D-11, D-12, and D-13, each equipped with installed artificial lighting systems. The meeting room E-14 is characterized by windows of diminished height relative to those observed on the third floor and the artificial lighting fixtures within room E-14 consist of suspended lighting fixtures, while a discernible skylight feature is evident in section B-B, as depicted in Figure 8.11.

Each room within the architectural ensemble displays distinctive height dimensions, a fact evident upon examination of Figure 8.11. Specifically, room D-08, situated on the third floor, possesses a height of 3.05 meters, while the adjoining rooms, spanning from D-10 to D-13, boast greater vertical clearances, measuring at 3.65 meters. Notably, the meeting room E-14 on the fourth floor exhibits significant variability in height, with its maximum clearance reaching 5.80 meters and its minimum height registering at 1.20 meters. This nuanced variation in vertical dimensions underscores the deliberate architectural considerations employed to accommodate diverse spatial requirements within the structural framework.

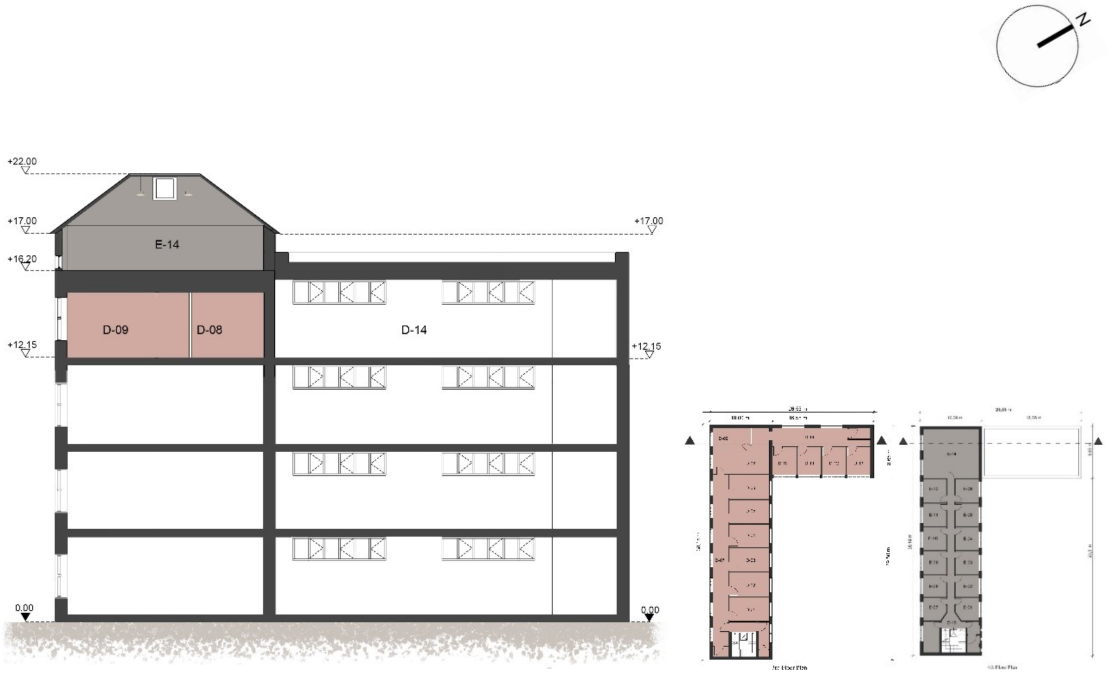


Figure 8.12. Section C-C

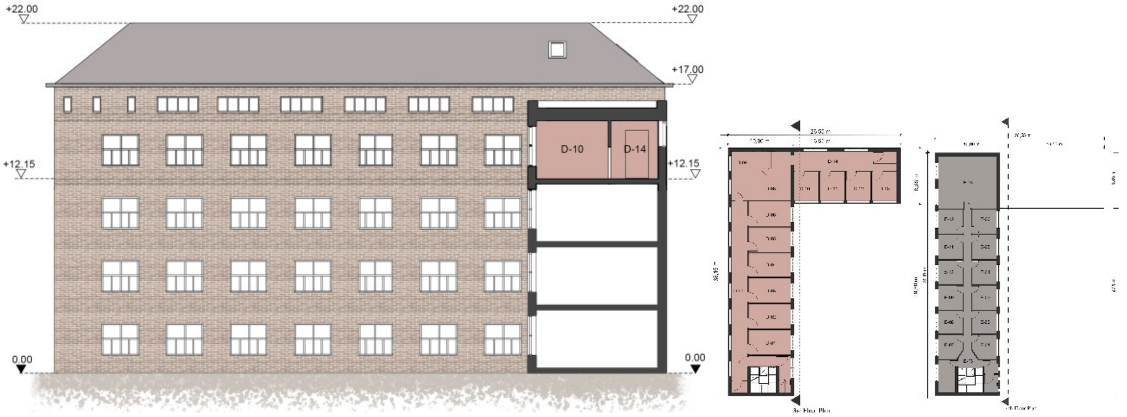


Figure 8.13. Section D-D

Room D-08, serving as a dual-purpose semi-office space alongside room D-09, is located on the third floor, while meeting room E-14 is positioned on the fourth floor, reflecting an elevated spatial hierarchy as illustrated in Figure 8.12. Corridor D-14 stands out due to its two elevated windows, exceeding the height of neighboring apertures. The intersecting D-D section reveals notably larger windows in office room D-10 and corridor D-14 compared to adjacent sections, as visually depicted in Figure 8.13.

The analysis focused on six specific rooms, denoted as D-01, D-08, D-10, E-01, E-08, and E-14, with a more detailed examination evident in their corresponding.

Figure 8.14. Photo of room D-01

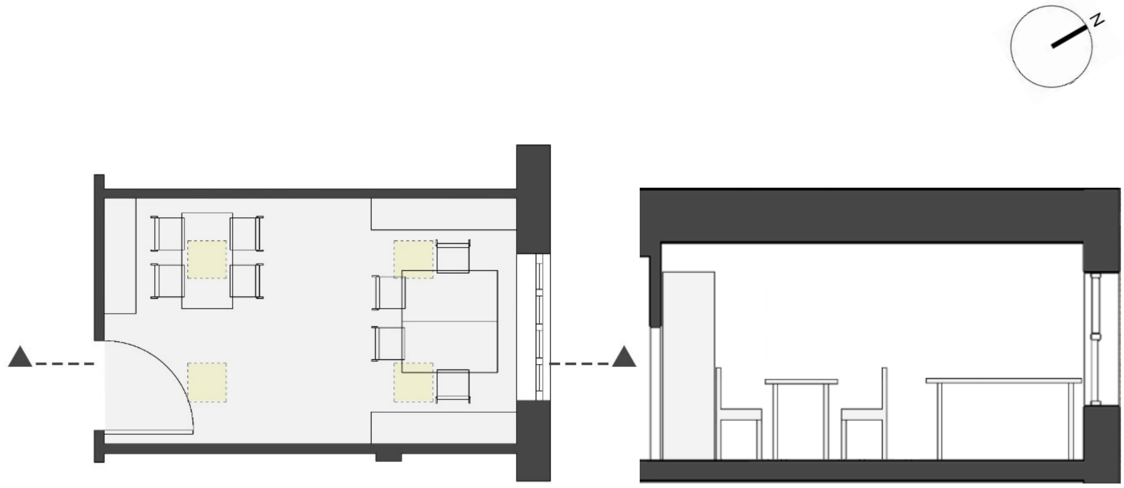
Room D-08

Figure 8.15. Photos of room D-08 and room D-10

Room D-01 serves as an office space situated on the north façade of the building. Room D-08 functions as a semi-office area utilized by students for study and work, as well as serving as a circulation space to the east and west façades of the building. Room D-10, positioned on the east façade, boasts the largest window among the six rooms analyzed, measuring 3.60 meters by 2.50 meters which can be seen from figure 8.15.

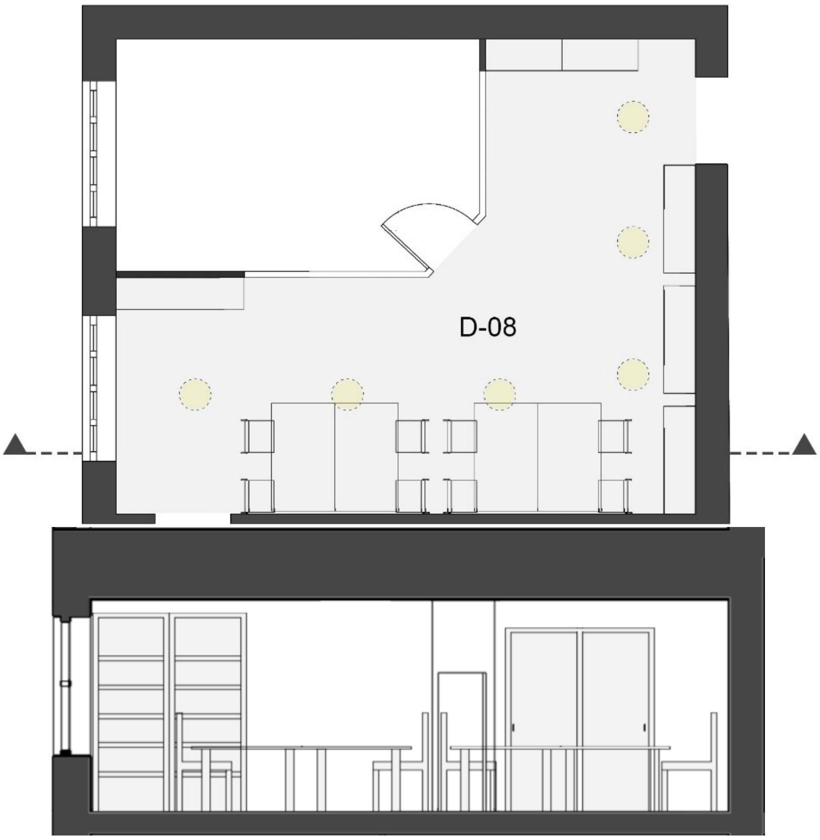
Figure 8.16. Photos of rooms E-01, E-08, and E-14

Rooms E-01 and E-08, located on the fourth floor, are designated as office spaces and feature comparatively smaller windows. Room E-14, also situated on the fourth floor, functions as a meeting room positioned within the attic space, characterized by a sloped ceiling resulting from the pitched roof, akin to Rooms E-01 and E-08 which can be seen from figure 8.16 and due to the proximity of the windows to the ground and the table height being 0.76 meters, daylight penetration to desks surface is limited.



Plan of room D-01 Scale: 1/100

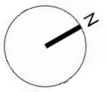
Section of room D-01 Scale: 1/100

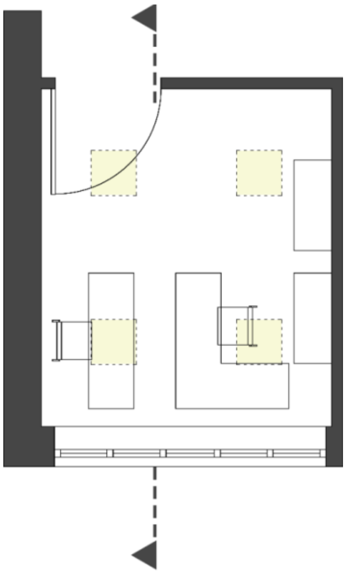


Plan of room D-08 and Section Scale: 1/100

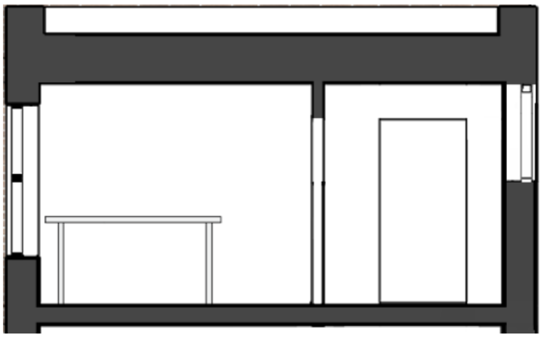
Figure 8.17. Plans and sections of rooms D-01, and D-08 with artificial lightings and furniture

In office room D-01, four desks are arranged, with two located near the window and one positioned farther from the window near the door. Examination of the section of D-01 indicates that the desks have a height of 0.76 meters, with those closer to the window receiving more daylight. Additionally, the room is illuminated by four recessed fluorescent artificial lighting fixtures on the ceiling. Room D-08, as illustrated in Figure 8.17, features four desks and a window situated away from the desks.

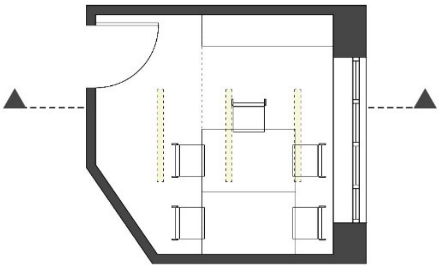




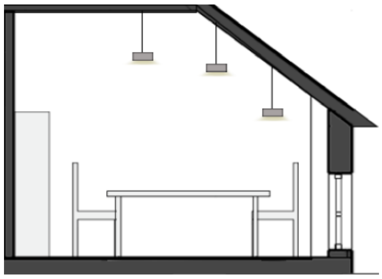
Plan of room D-10 Scale: 1/100



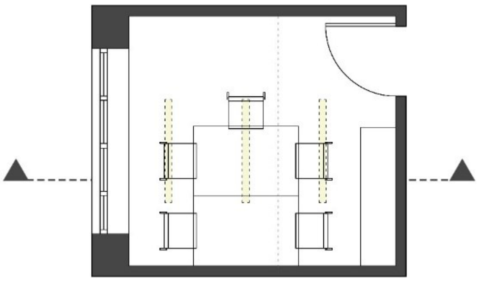
Section of room D-10 Scale: 1/100



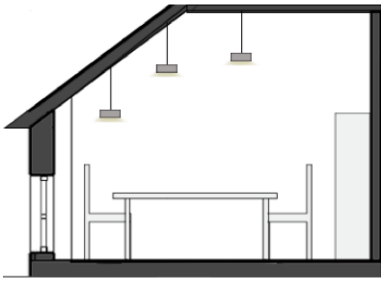
Plan of room E-01 Scale: 1/100



Section of room E-01 Scale: 1/100

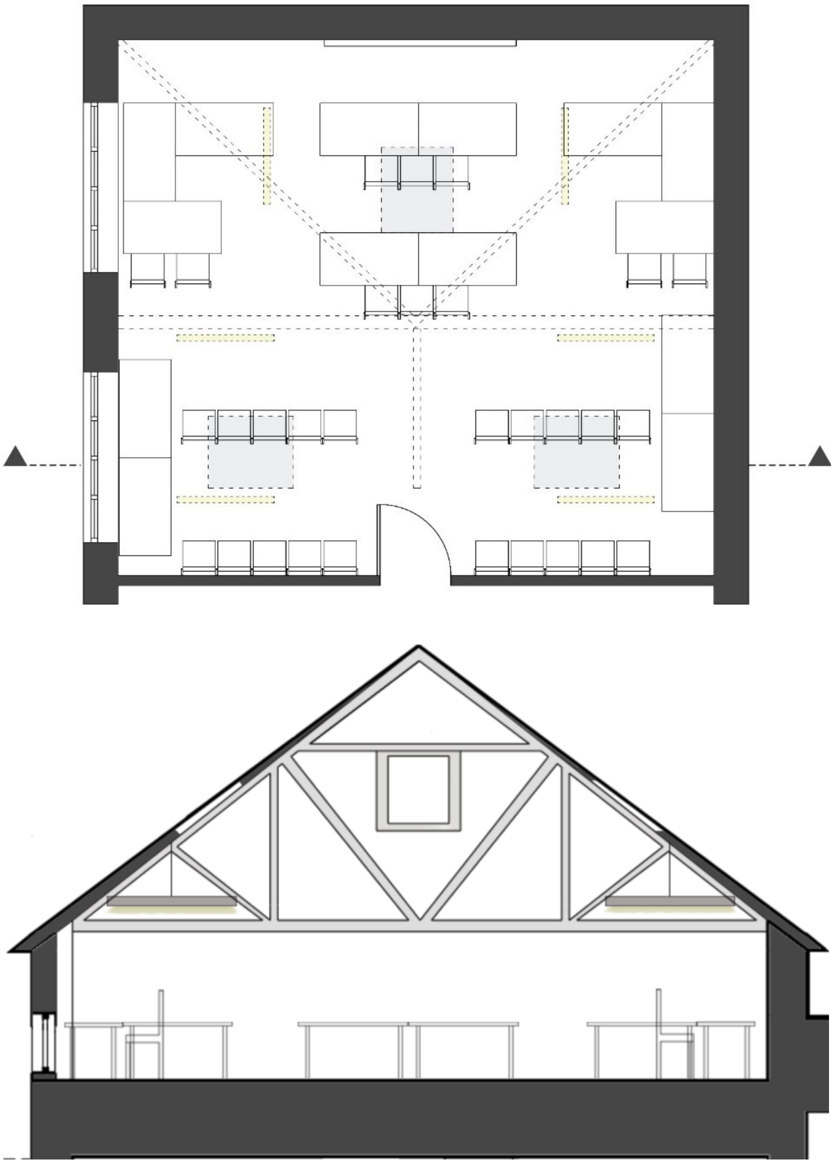


Plan of room E-08 Scale: 1/100



Section of room E-08 Scale: 1/100

Figure 8.18. Plans and sections of rooms D-10, E-01 and E-08 with artificial lightings and furniture



Plan of room E-14 Scale: 1/100 Section of room E-14 Scale: 1/100

Figure 8.19. Plans and sections of rooms E-01, E-08 and E-14 with artificial lightings and furniture

In Room D-10, four recessed fluorescent lamps illuminate the space, while two desks are situated near the window at a height of 0.76 meters, as shown in Figure 8.18. Similarly, Rooms E-01 and E-08 on the fourth floor feature three suspended and adjustable lamps each, as depicted in their respective plans and sections in Figure 8.18. In contrast, Room E-14, serving as a meeting room, has desks positioned near the windows, walls, and center, as illustrated in Figure 8.19. The windows in Rooms E-01, E-08, and E-14 are smaller due to their location on exterior walls, potentially limiting daylight exposure for desks with a height of 0.76 meters. However, Room E-14 benefits from three skylights, enhancing its daylighting compared to Rooms E-01 and E-08 as shown figure 8.19.

8.3.2.1.HVAC Analysis of Energy Department Building

Thermal transmittance, often denoted as the U-value, measures the rate of heat transfer through a structure relative to the temperature difference across it, typically expressed in W/m²K. Lower U-values indicate better insulation. The U-value reflects both material properties and installation quality, with gaps and cold bridges leading to higher-than-desired values. It encompasses heat loss mechanisms like conduction, convection, and radiation, making it a crucial parameter in assessing insulation effectiveness (What is a U-value? Heat loss, thermal mass and online calculators explained | NBS (thenbs.com)).

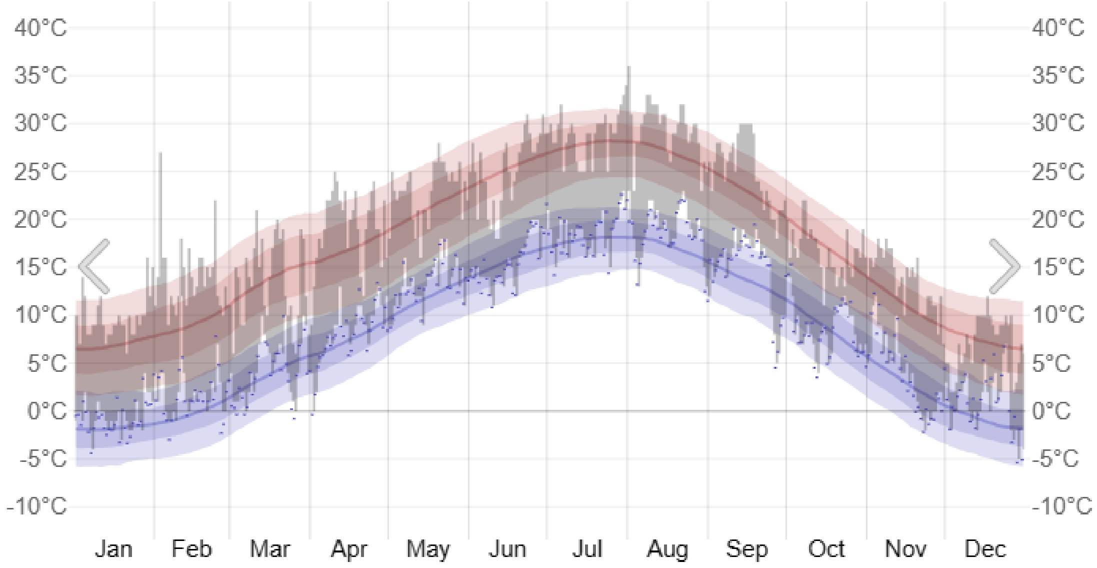


Table 8.1. Monthly weather graph of Turin in year 2020 (Turin 2020 Past Weather (Italy) - Weather Spark)

HVAC	**Information**
Template	Fan Coil Unit District Heating and Cooling
Heating: On (Winter Times)	Electricity
Heating System Seasonal CoP	1
Operation of Heating	Scheduled: Weekdays, Time 08:00-18:00
Cooling: On (Summer Times)	Electricity
Cooling System Seasonal CoP	4
Operation of Cooling Schedule	Scheduled: Weekdays, Time 08:00-18:00
Natural Ventilation: On/Off	Scheduled: Weekdays, Time 08:00-18:00
Outside Air Definition Method ac/h	5
Schedule	Scheduled: Weekdays, Time 08:00-18:00

Table 8.2. HVAC table of building Energy Department Building

Current Material	Layers	Thickness (m)	U-Value (W/m²-K)
Template	Uninsulated Brick Wall/Medium Weight		
External Wall	Brick-Air Gap-Brick-Cement Plaster-Plaster	0.55 m	1,174
Pitched Roof	Clay Tile-Air Gap-Roofing Felt-Rubber-Cast Concrete-Mortar-Plaster	0.40 m	0,906
Internal Wall	Plaster (Lightweight)-Cement Plaster-Brick-Cement Plaster-Plaster	0.21 m	1,368
Internal Floor	Gypsum Plasterboard-Air Gap-Concrete-Cement Plaster-Mortar-Ceramic Tile	0.30 m	1,269
Flat Roof	Asphalt-Rubber-Fibre Board-Cast Concrete-Mortar- Plaster	0.30 m	0,809

Table 8.3. Thermal transmittance of current materials of Energy Department Building

The determination of U-values has been conducted using Design Builder software to assess the internal air temperature comfort conditions for occupants within the office rooms. Table 8.3 presents the materials utilized in the current configuration of the Energy Department building, along with their corresponding U-values, delineating the properties of each material. Current building's exterior and interior walls' material is brick which is non-insulated.

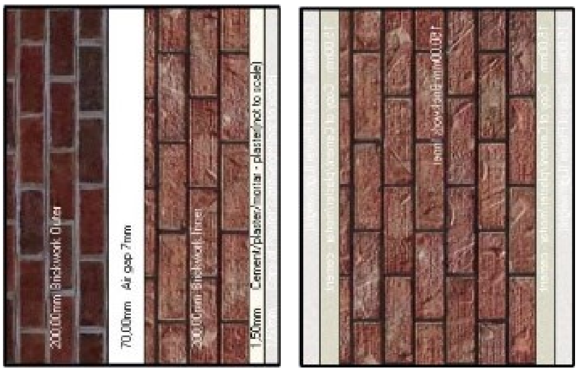


Figure 8.20. Exterior wall and interior wall layers of non-insulated building

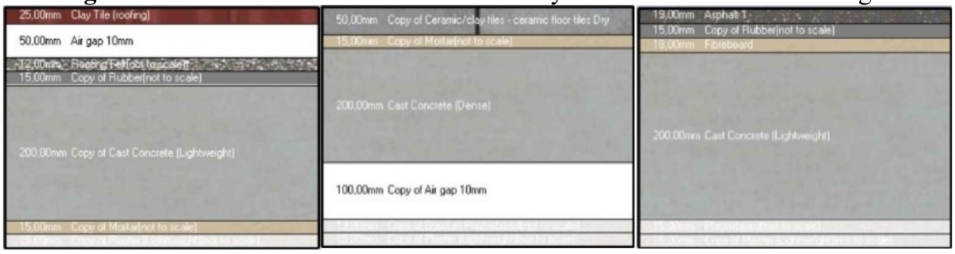


Figure 8.21. Roof, ceiling and floor material layers of non-insulated building

The determination of the U-values for the building involves the incorporation of insulated materials positioned on the interior and exterior side of the external walls. This specific choice stems from an architectural aesthetic consideration unique to the main campus, focusing exclusively on the DENERG building as the subject of the study. This approach ensures a cohesive and visually harmonious integration, recognizing the need for consistency in material usage within the confined scope of the DENERG building.

Materials with Insulations	**Layers**	**Thickness (m)**	**U-Value (W/m²-K)**
Template	Insulated Brick Wall/Medium Weight		
External Wall	Brick-Air Gap-Brick-Cement Plaster-Plaster-Mineral Fibre Wool-Gypsum Plaster Board-Gypsum Plastering	0.78 m	0,211
Pitched Roof	Clay Tile-Air Gap-Roofing Felt-Rubber-Cast Concrete-Mortar-Mineral Fibre Wool-Gypsum Plaster Board-Gypsum Plastering	0.55 m	0,193
Internal Wall	Plaster -Cement Plaster-Brick-Cement Plaster-Plaster	0.36 m	0,293
Internal Floor	Gypsum Plasterboard-Air Gap-Mineral Fibre Wool-Concrete-Cement Plaster-Mortar-Ceramic Tile/Linolemun	0.40 m	0,292
Flat Roof	Asphalt-Rubber-Fibre Board-Cast Concrete-Mortar- Mineral Fibre Wool-Gypsum Plaster Board-Gypsum Plastering	0.45 m	0,254

Table 8.4. Thermal transmittance of insulated materials of DENERG Building

The selection of materials has been rigorously informed by the Design Builder software, which factors in insulation criteria tailored to both summer and winter conditions. As depicted in the accompanying illustration, the implementation of mineral fiber wool is showcased, strategically positioned on both the interior and exterior sides of the wall. This configuration facilitates a comparative analysis between uninsulated and insulated scenarios, particularly in terms of interior temperature dynamics. The current situation of the building a layer of gypsum board, complemented by mineral fiber wool and a protective coating on the exterior surface which is showed figures 8.20 and 8.21. Such a configuration underscores a holistic approach to thermal efficiency, attuned to the nuanced insulation requisites dictated by seasonal climatic variations.

Figure 8.22. Exterior wall and interior wall layers of insulated building

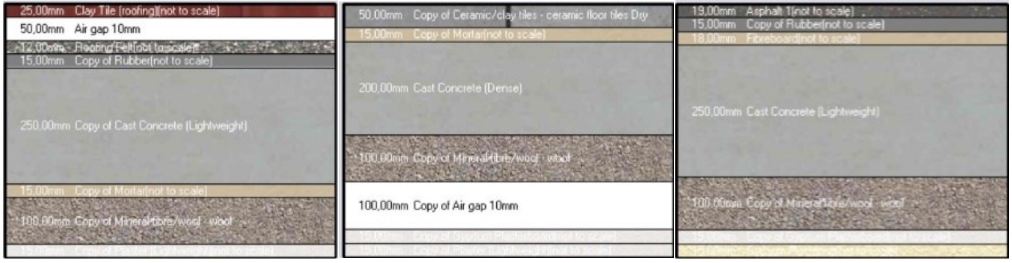


Figure 8.23. Roof, ceiling and floor material layers of insulated building

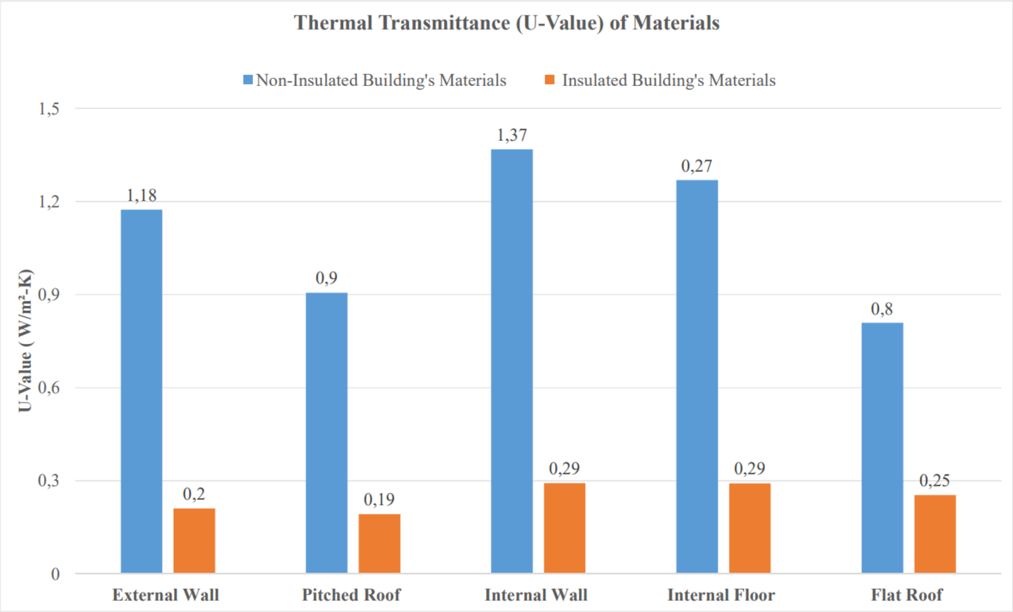


Table 8.5. Thermal Transmittance comparison of current (non-insulated) and insulated materials of Energy Department building

The U-values depicted in the graph exclusively pertain to the materials integrated into the interior of the building. It is evident from the graph that the incorporation of thermal insulation materials on the interior side yields discernible benefits for the overall energy efficiency of the structure. Notably, certain materials have remained unaltered, with their U-values registering consistently at 0.3 W/m²-K, as indicated on the graph according to the Piemonte region's law. Windows and doors have not undergone modifications or received additional insulation materials, resulting in a consistent level observed at a singular point on the graphical representation. As observed in Table 8.5, the average U-values of non-insulated materials stand at 1.1 W/m²-K. Incorporating insulation into these materials yields a notably positive effect, reducing U-values by approximately 0.3 W/m²-K to an average of around 0.25 W/m²-K.

8.3.2.1.1. Air Temperature in Winter Time

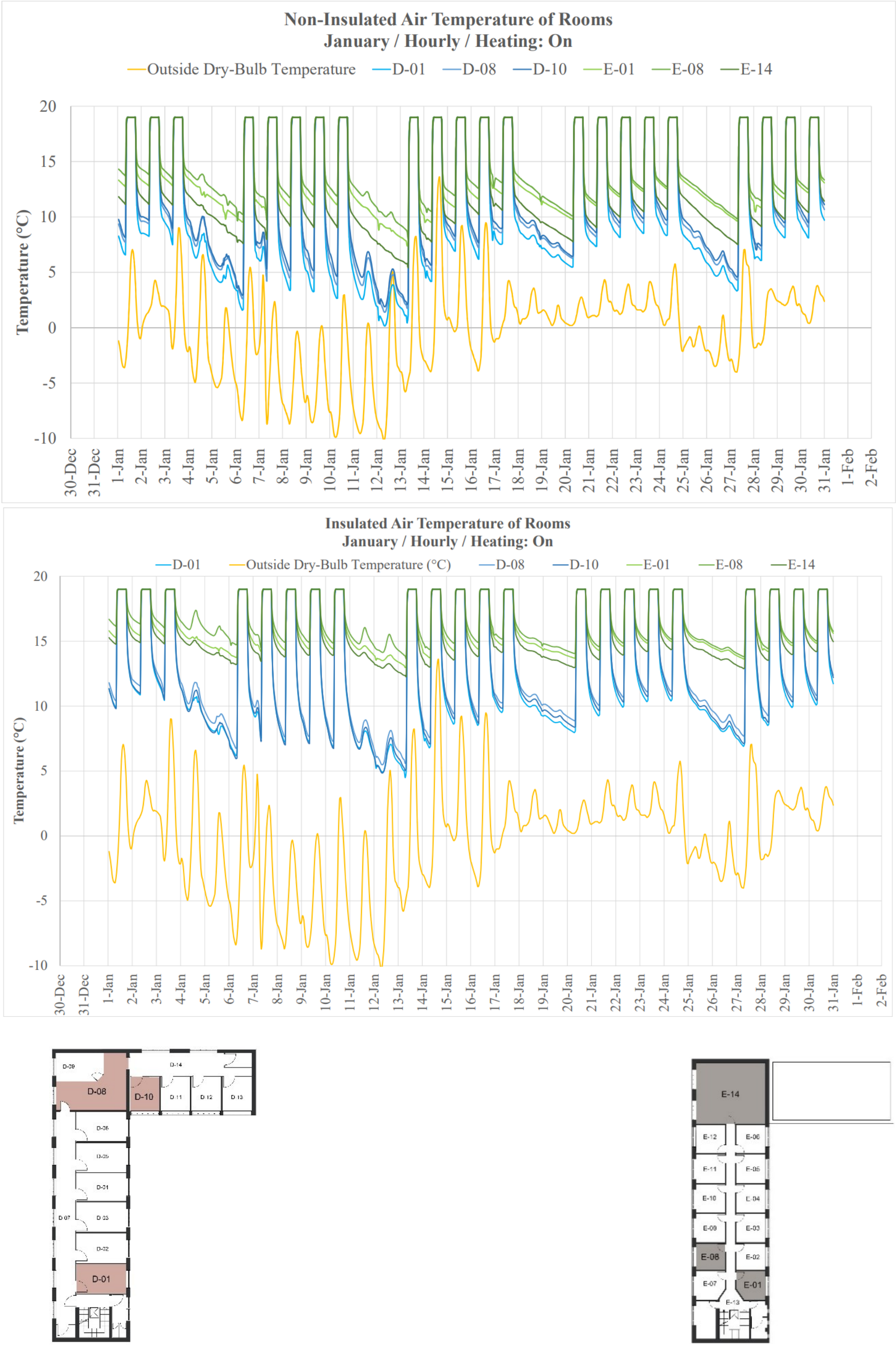


Table 8.6. Non-Insulated and Insulated materials interior air temperature of Energy Department's office rooms in January with heating on

The fan coil unit serves as the primary system for cooling and heating the office rooms within the Energy Department at Politecnico di Torino. In accordance with Politecnico di Torino regulations, the interior temperature is mandated to be maintained at 19 degrees Celsius during winter months when heating is activated. Accordingly, heating parameters were configured to achieve this set temperature of 19 degrees Celsius in January using the DesignBuilder software, under both the current non-insulated and improved U-value insulated material conditions, as depicted in Figure 8.6. Heating operations are scheduled within designated working hours, typically spanning from 8 am to 6 pm on weekdays.

Analysis of the data presented in Table 8.6 and corresponding graphs reveals noteworthy trends. Specifically, in the non-insulated building scenario, the air temperature declines below 15 degrees Celsius when heating is inactive. In the insulated building scenario, the air temperature remains above 15 degrees Celsius even when heating is not operational. This observation suggests that insulation significantly contributes to maintaining a desirable indoor temperature, particularly during working hours on weekdays, thereby facilitating compliance with the mandated 19-degree Celsius threshold for occupant comfort within the Energy Department building which this last situation can be seen from table 8.7. Therefore, it is evident that the heating system operates in both scenarios, whether insulated and non-insulated buildings.

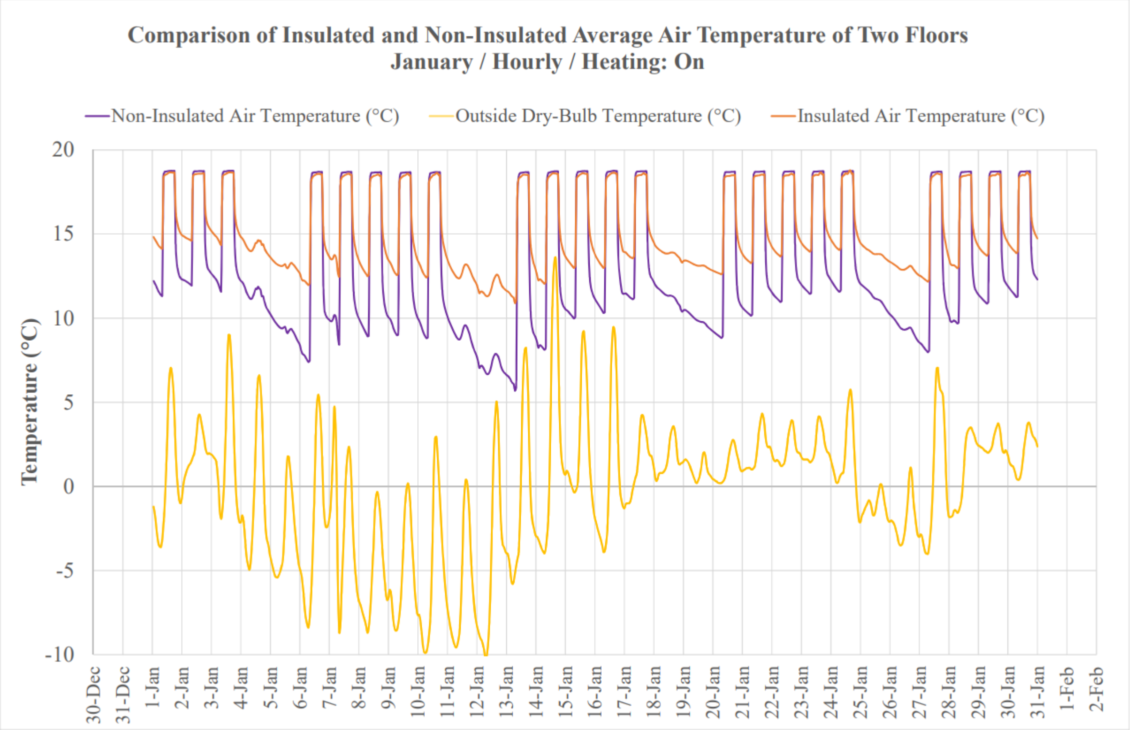


Table 8.7. Comparison of Insulated and non-Insulated materials interior average air temperature of Energy Department office rooms in January with heating on

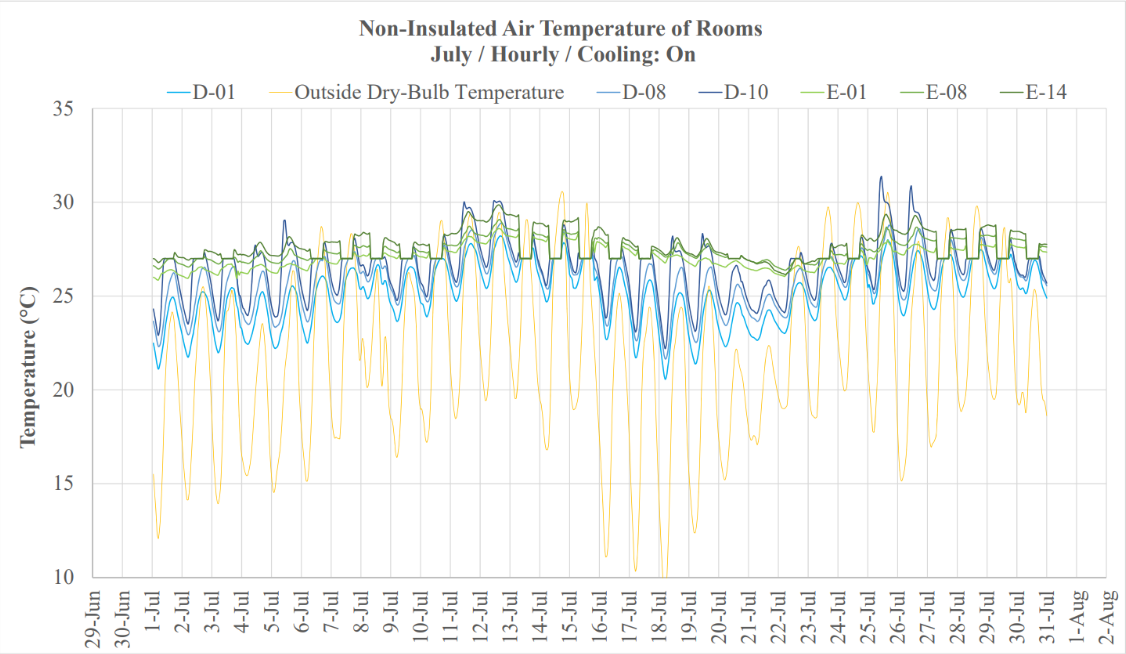
8.3.2.1.2. Natural Ventilation and Cooling in Summer Time

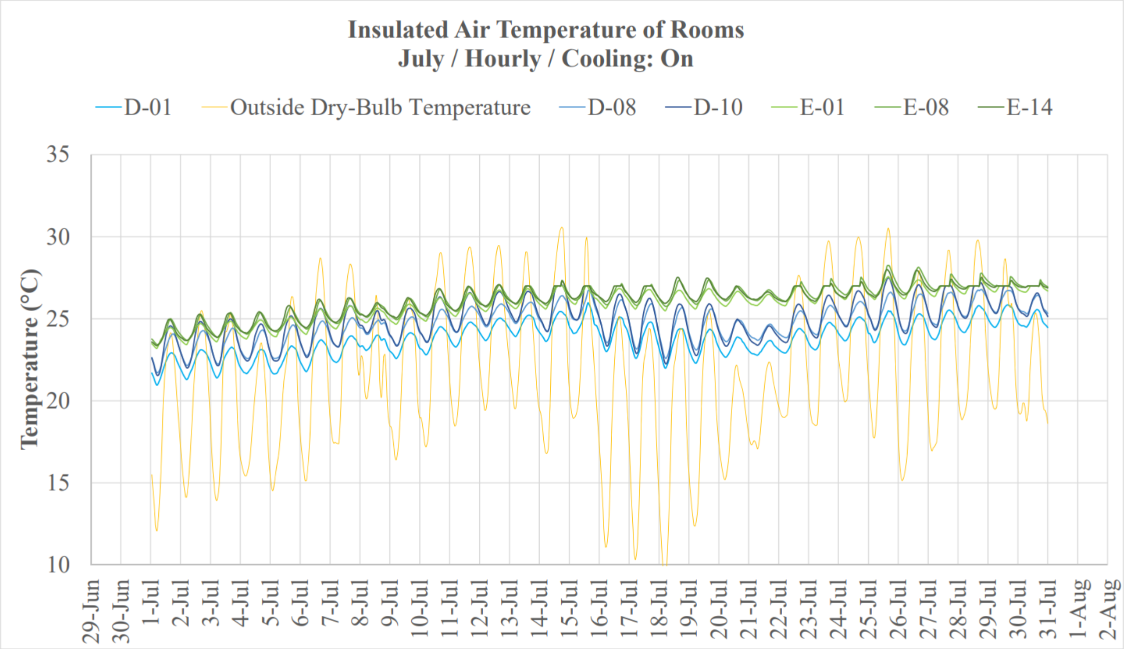
Utilizing passive strategies to introduce outdoor air into a building's interior for ventilation and cooling, without the reliance on mechanical systems, defines natural ventilation. Also, this approach contributes to the health and well-being of occupants by promoting energy savings and ensuring a fresh air supply (Natural Ventilation for Sustainable Construction - Hourigan).

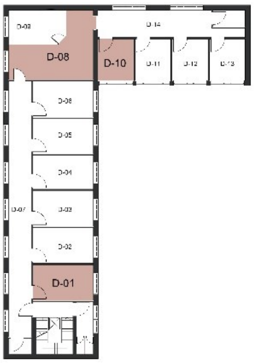
The evaluation of the natural ventilation and cooling system was undertaken throughout the month of July. It was noted that, under cooling on system conditions, the internal temperatures of the analyzed office rooms within the current non-insulated building, designated as D-01, D-08, D-10, E-01, E-08, and E-14, exceeded 30 degrees Celsius. In contrast, the internal temperatures of the office rooms in the insulated building remained at 27 degrees Celsius and did not surpass the 30-degree threshold, as illustrated in Table 8.8.

In adherence to the regulations of Politecnico di Torino campus, the interior air temperature during the summer cooling period is mandated to be set at 27 degrees Celsius. Cooling parameters were configured to maintain this specified average air temperature throughout the month of July for two floors of Energy Department building, which typically represents the peak of summer heat.

In the current non-insulated condition, room D-10 attained a temperature of 30°C in July when cooling was activated. However, with the implementation of building insulation, the air temperature in room D-10 was maintained at 27°C in July, aligning with the optimal value prescribed by regulations, as evidenced in Table 8.8.







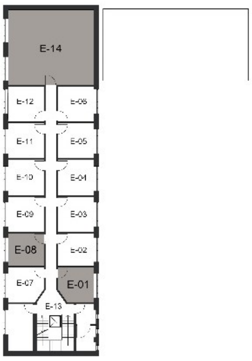


Table 8.8 Non-Insulated and Insulated materials interior air temperature of DENERG office rooms in July cooling is open

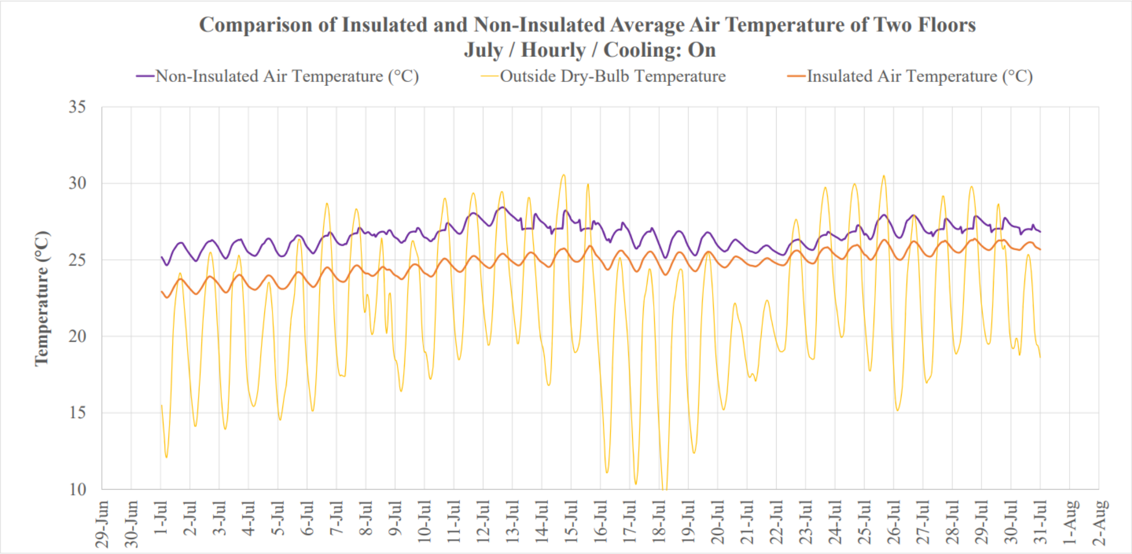
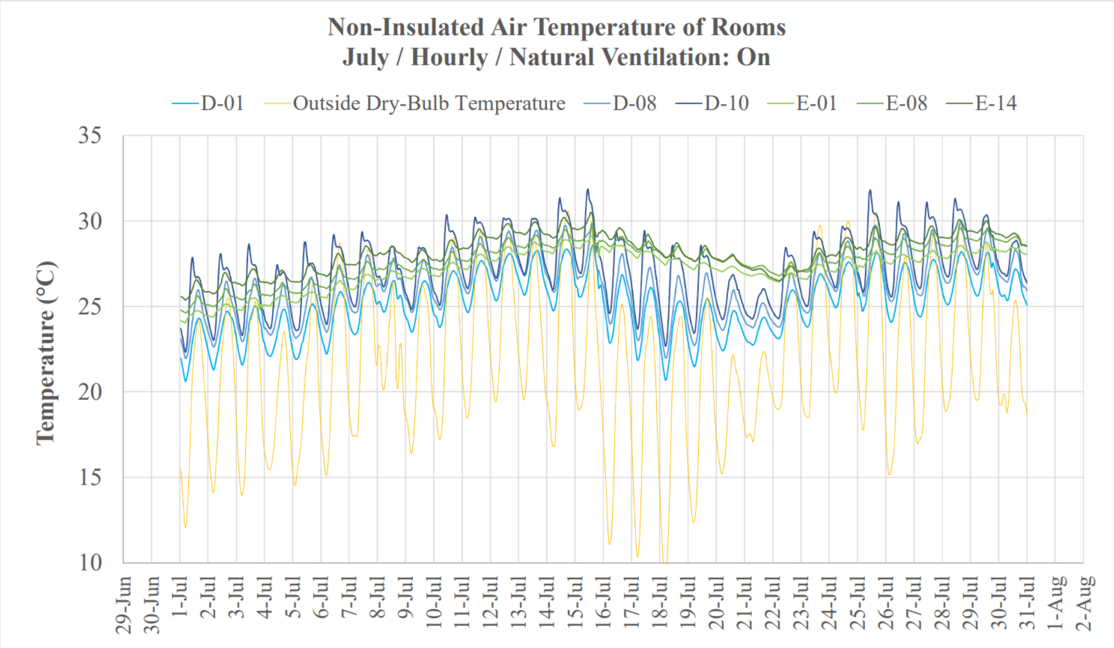
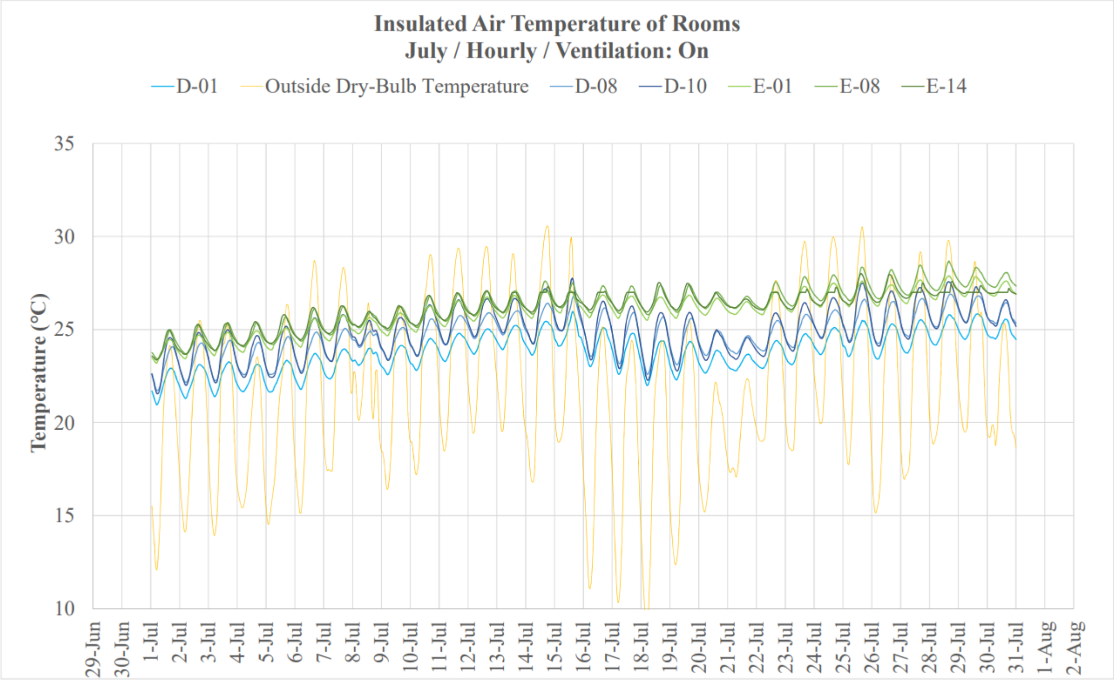
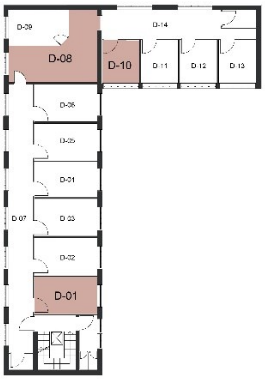


Table 8.9. Comparison of Insulated and non-Insulated materials interior average air temperature of Energy Department's office rooms in July with cooling is open

A comparative analysis of the average interior air temperatures between the insulated and non-insulated buildings across two floors as average air temperature during the cooling period reveals significant disparities which can be seen table 8.9. In the insulated building which is colored as orange, where cooling is operational, the average air temperature hovers around 27 degrees Celsius throughout July. In the non-insulated building which is colored as purple, the average air temperature tends to range between 29 and 30 degrees Celsius during the same period. This notable discrepancy underscores the efficacy of employing insulated materials within the current building structure, particularly in enhancing thermal performance and operational efficiency during summer months when cooling systems are activated. The utilization of insulated materials presents a viable solution for mitigating excessive heat infiltration, thereby promoting a more comfortable indoor environment while simultaneously optimizing energy consumption.







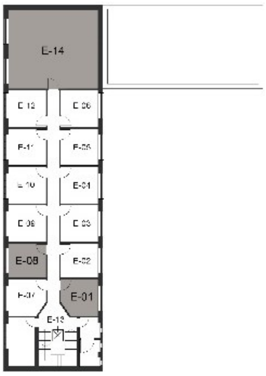


Table 8.10. Non-Insulated and Insulated materials interior air temperature of DENERG office rooms in July with natural ventilation is open

Utilizing natural ventilation in lieu of cooling systems presents an energy-saving opportunity during summer periods, particularly when augmented with superior U-value materials. A comparison between the current non-insulated state of the building and the recommended insulated configuration, focusing on the average air temperature across two floors of the Energy Department building at Politecnico di Torino campus, is elucidated through the graphical representation provided in Table 8.11. This comparison, conducted exclusively with natural ventilation in operation during July, the peak of summer heat, underscores the potential benefits of implementing insulated materials in mitigating indoor temperature fluctuations and reducing reliance on energy-intensive cooling mechanisms.

According to The National Institute for Insurance against Accidents at Work recommends maintaining office temperatures within the range of 18–22°C and during the summer, it is advised to keep the temperature difference between indoor and outdoor environments within a limit of 7 degrees (Trying temperatures | The Florentine). Hence, insulating the building under these circumstances could obviate the need for cooling during summer periods, presenting a potentially efficient solution.

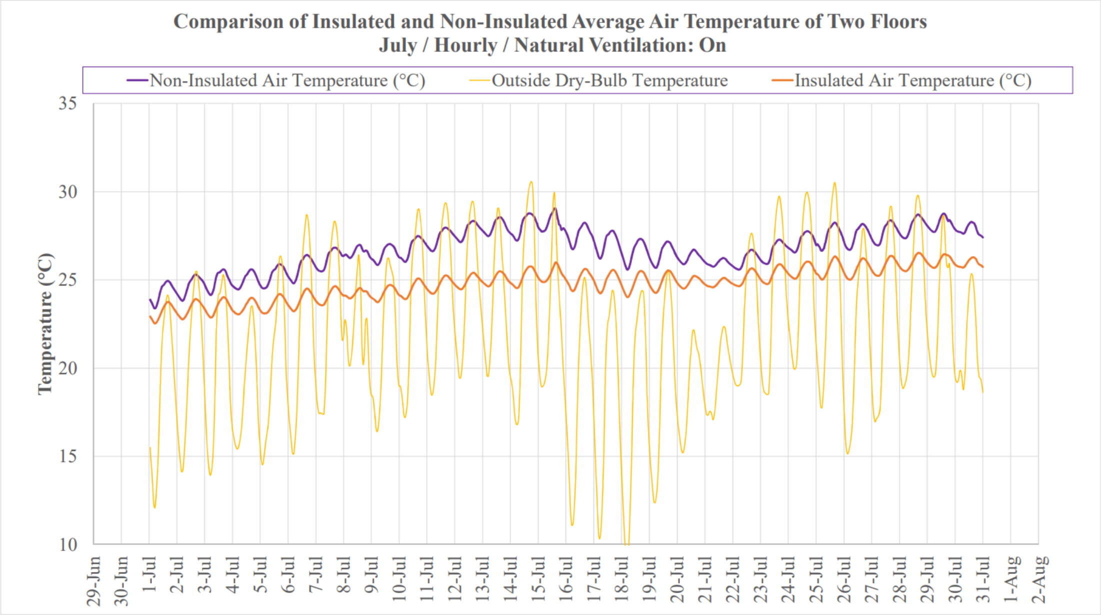
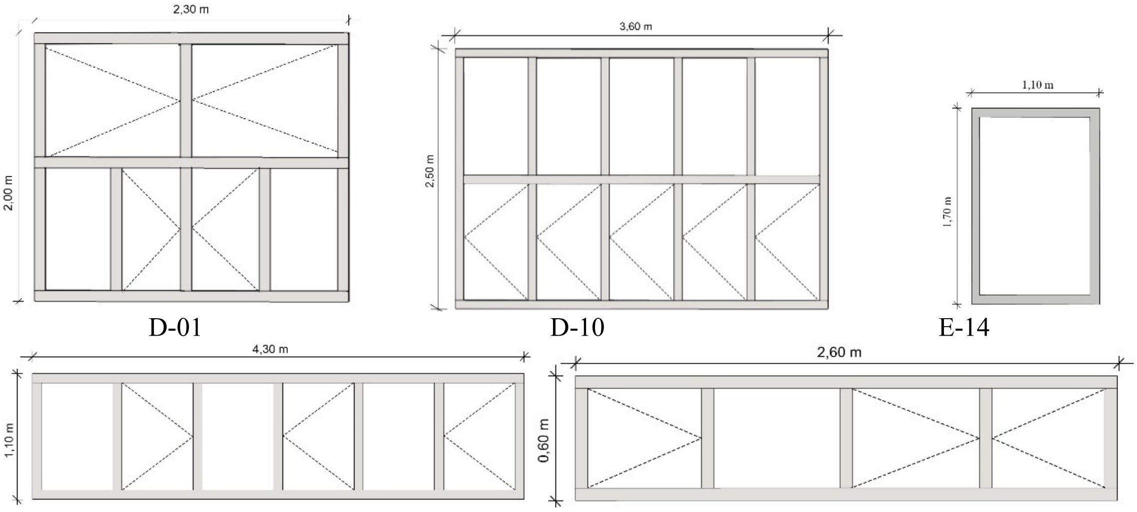


Table 8.11. Comparison of Insulated and non-Insulated materials interior average air temperature of two floors in July with natural ventilation is open

8.3.2.2.Openings of Energy Department Building

8.3.2.2.1. Window Types



D-01 D-10 E-14

D-14 Rooms from E-01 to E-12

Figure 8.24. Window types of 3rd and 4th floor

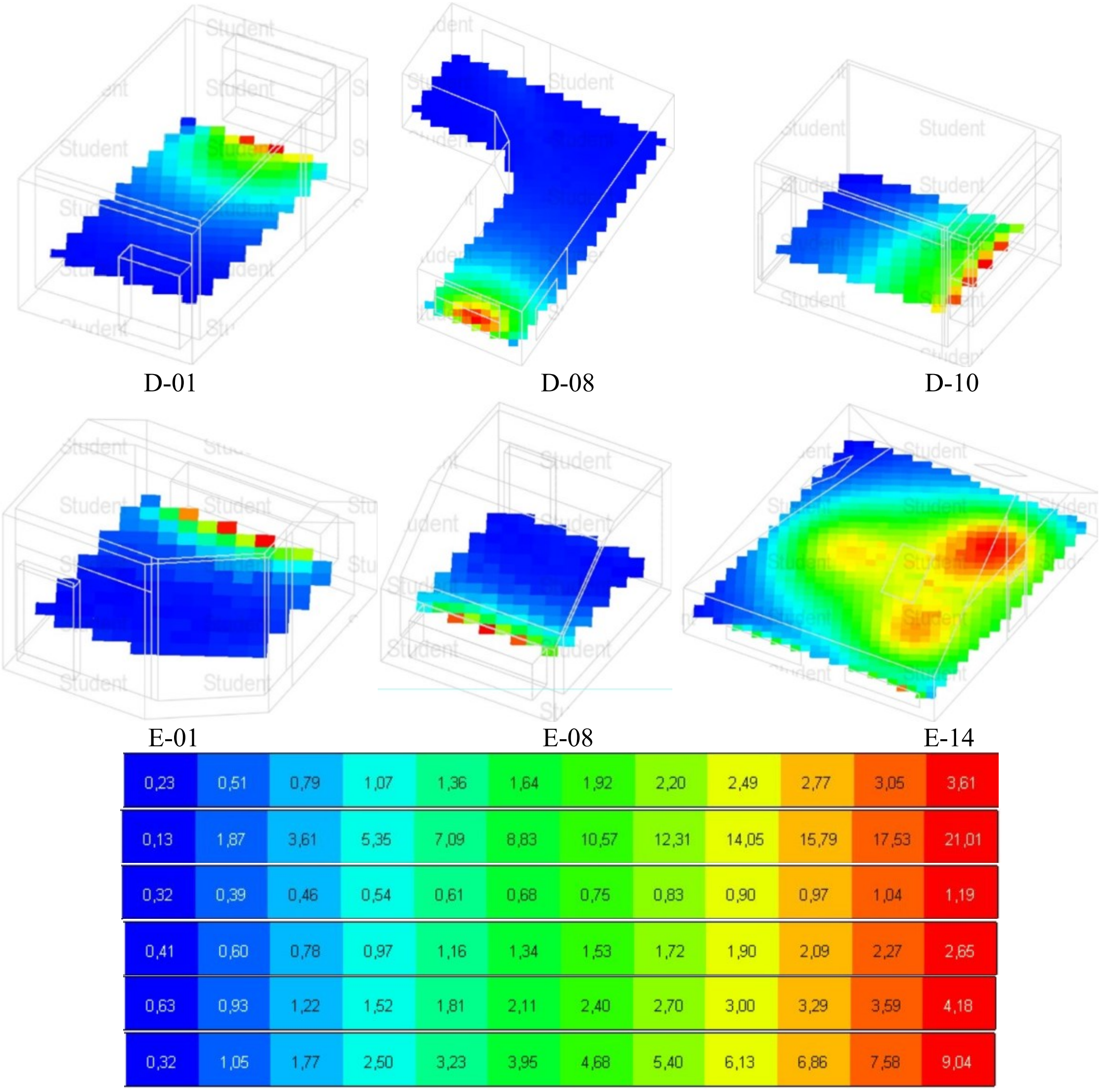
The Energy Department building encompasses five distinct window types which are represented in the accompanying figure 8.24. The glazing of these windows is double-paned, and each exhibits variations in both type and dimensions. Subsequently, calculations have been performed based on these specifications. The calculations were performed without altering the glazings, thereby utilizing the existing glazings for the analysis and there are some shadings and no-shadings for the windows.

Figure 8.25. D-07 window without shading and D-10 room window with shading

8.3.2.3.Daylight Analysis of Office Rooms

8.3.2.3.1. Average Daylight Factor in Overcast Sky

Variations in average daylight factor gains are attributed to the distinct orientations of the Energy Department building's facades so that six office rooms within the building have been meticulously chosen for the analysis and computation of daylight factors, as illustrated in figure 8.26. These six rooms have been analyzed in overcast sky mood and the results show that room D-10 has the highest average daylight factor which is 4% which is highest value than other rooms that can be seen from table 8.12.



D-01 D-08 D-10

E-01 E-08 E-14

0,23	0,51	0,79	1,07	1,36	1,64	1,92	2,20	2,49	2,77	3,05	3,61
0,13	1,87	3,61	5,35	7,09	8,83	10,57	12,31	14,05	15,79	17,53	21,01
0,32	0,39	0,46	0,54	0,61	0,68	0,75	0,83	0,90	0,97	1,04	1,19
0,41	0,60	0,78	0,97	1,16	1,34	1,53	1,72	1,90	2,09	2,27	2,65
0,63	0,93	1,22	1,52	1,81	2,11	2,40	2,70	3,00	3,29	3,59	4,18
0,32	1,05	1,77	2,50	3,23	3,95	4,68	5,40	6,13	6,86	7,58	9,04

Figure 8.26. Daylight Factors of rooms from D-01, D-08, D10, E-01, E-08 and E-14 in overcast sky

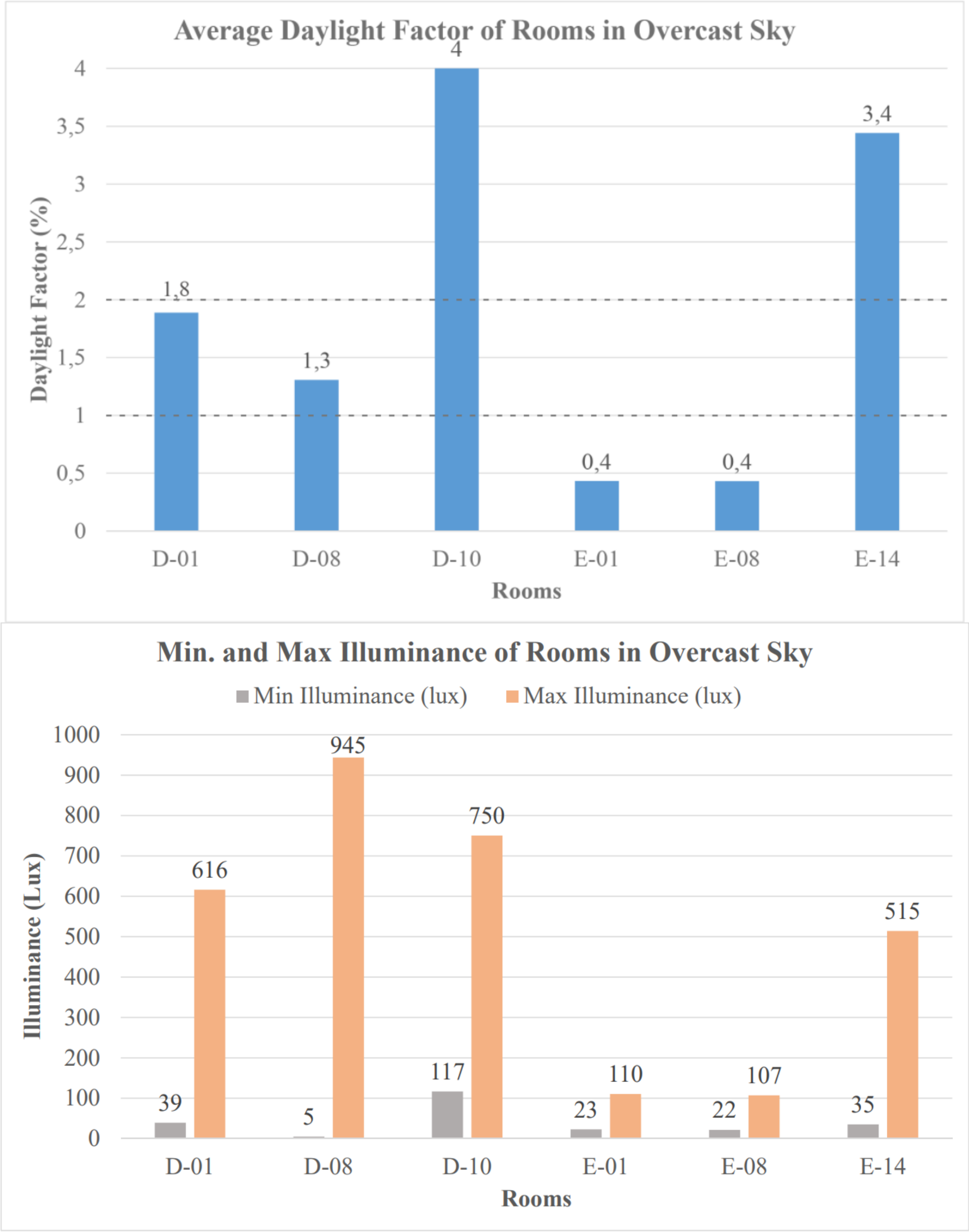
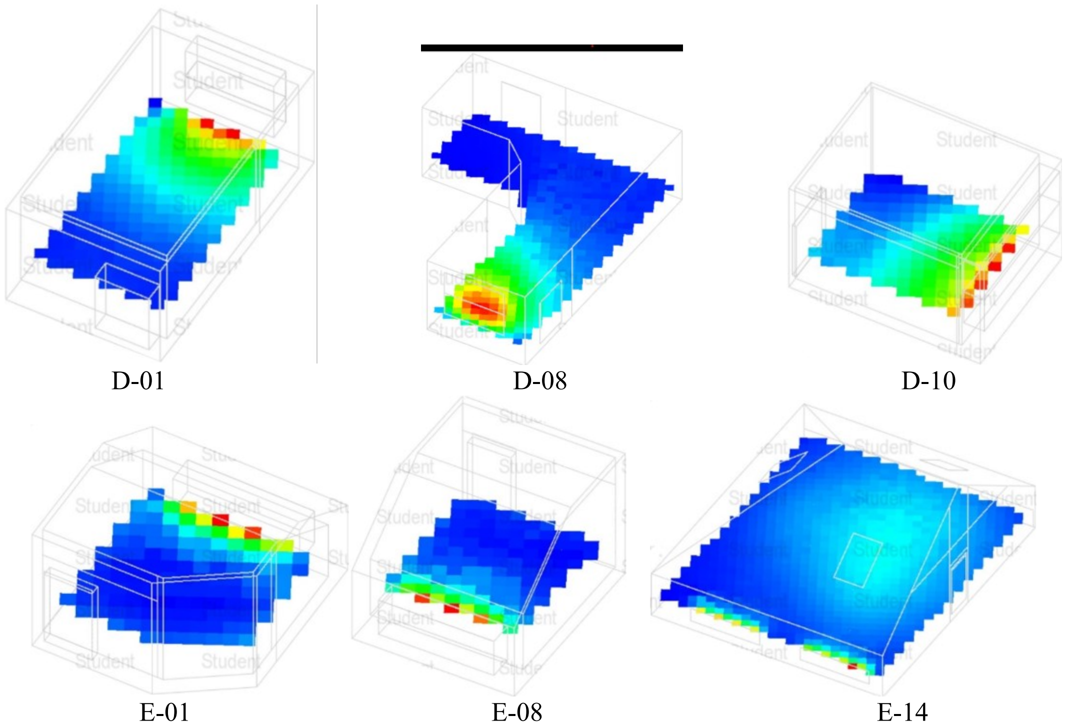


Table 8.12. Daylight illuminance and average daylight factor of rooms in overcast sky without shading

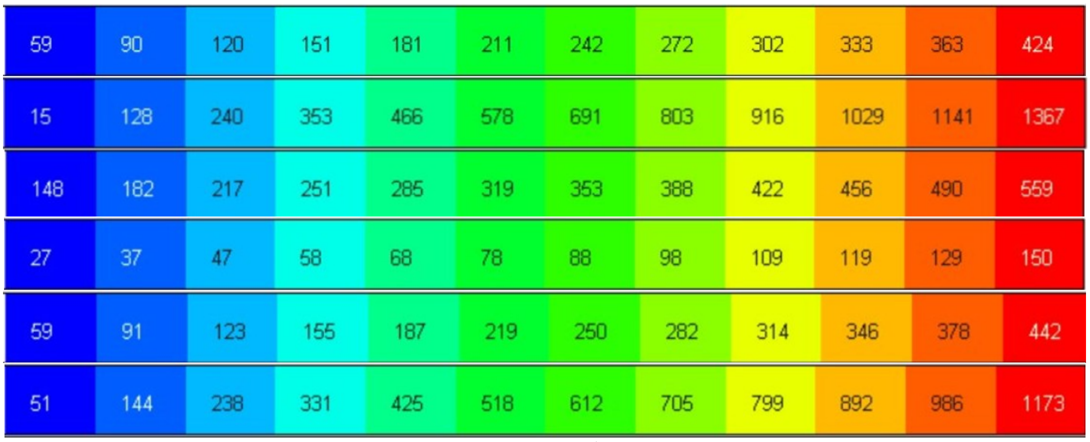
The minimum daylight factor was required to be 1% under the previous daylight regulation, the CAM 2017 regulation requires this obligation to be 2%. A daylight assessment was carried out for six rooms and the average daylight factor on cloudy days was as follows: rooms D-01, D-08, D-10 and E-14 exceeded the 1% threshold and both rooms D-10 and E - 14 exceeded the 2% threshold and met the minimum criteria specified in both regulations.

8.3.2.3.2. Daylight Illuminance in Clear Sky of Rooms



D-01 D-08 D-10

E-01 E-08 E-14



59	90	120	151	181	211	242	272	302	333	363	424
15	128	240	353	466	578	691	803	916	1029	1141	1367
148	182	217	251	285	319	353	388	422	456	490	559
27	37	47	58	68	78	88	98	109	119	129	150
59	91	123	155	187	219	250	282	314	346	378	442
51	144	238	331	425	518	612	705	799	892	986	1173

Figure 8.27. Daylight Illuminance (lux) of rooms on 15th January at 13 pm in clear sky without shading

Daylight illuminance levels were calculated for six rooms on January 15th for winter and July 15th for summer, under clear sky conditions without shading. As depicted in Figure 8.27 and Table 8.13, each room exhibits maximum illuminance near the windows at 13:00 on both January 15th and July 15th. In January, rooms D-01, E-01, and E-08 recorded the lowest lux values (424, 150, 442 lux, respectively), falling below the targeted minimum of 500 lux for office rooms.

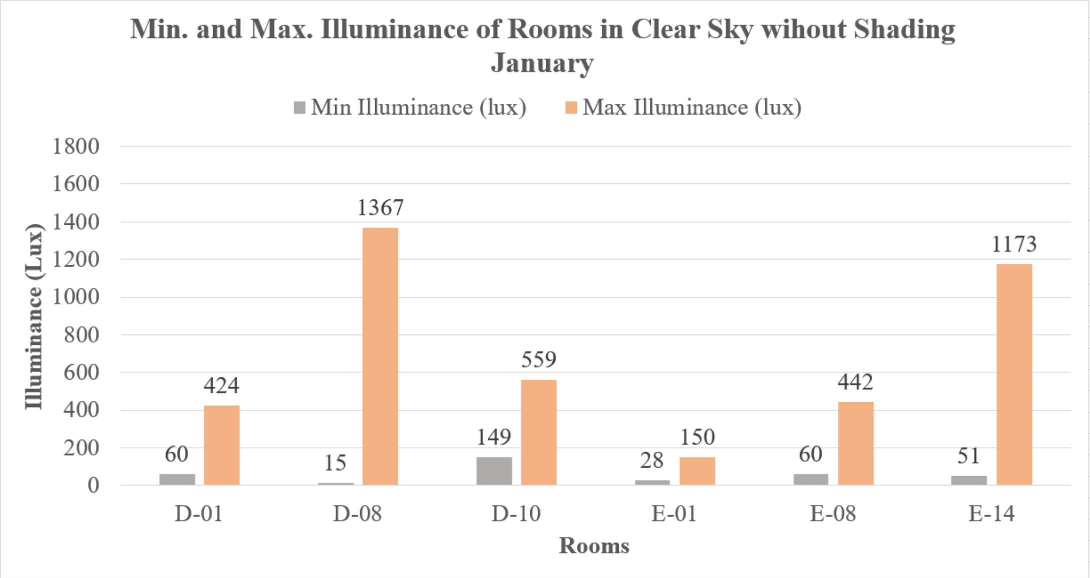
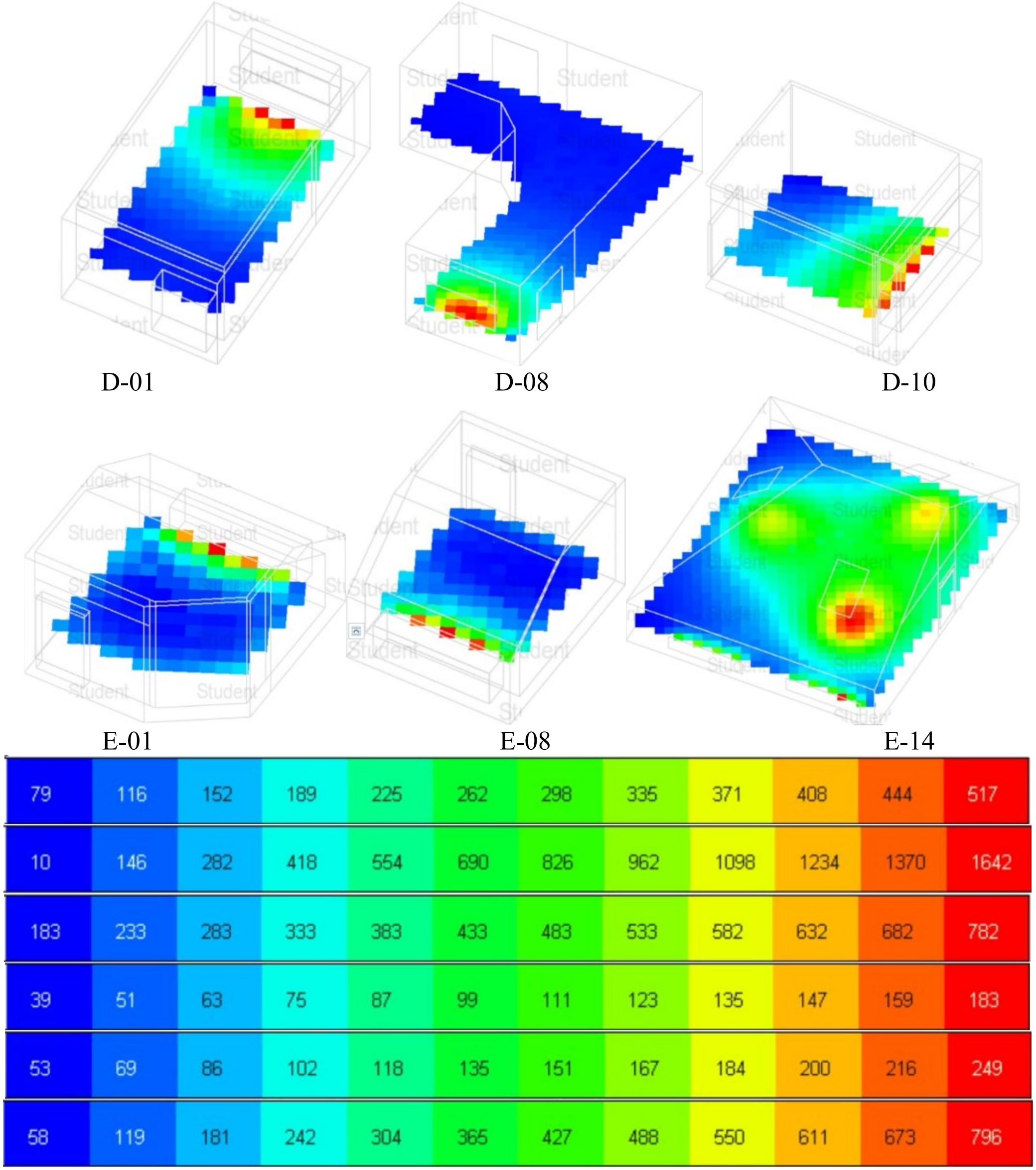


Table 8.13. Daylight illuminance of rooms on 15th January at 13pm in clear sky without shading



79	116	152	189	225	262	298	335	371	408	444	517
10	146	282	418	554	690	826	962	1098	1234	1370	1642
183	233	283	333	383	433	483	533	582	632	682	782
39	51	63	75	87	99	111	123	135	147	159	183
53	69	86	102	118	135	151	167	184	200	216	249
58	119	181	242	304	365	427	488	550	611	673	796

Figure 8.28. Daylight illuminance of rooms on 15th July at 13 pm in clear sky without shading

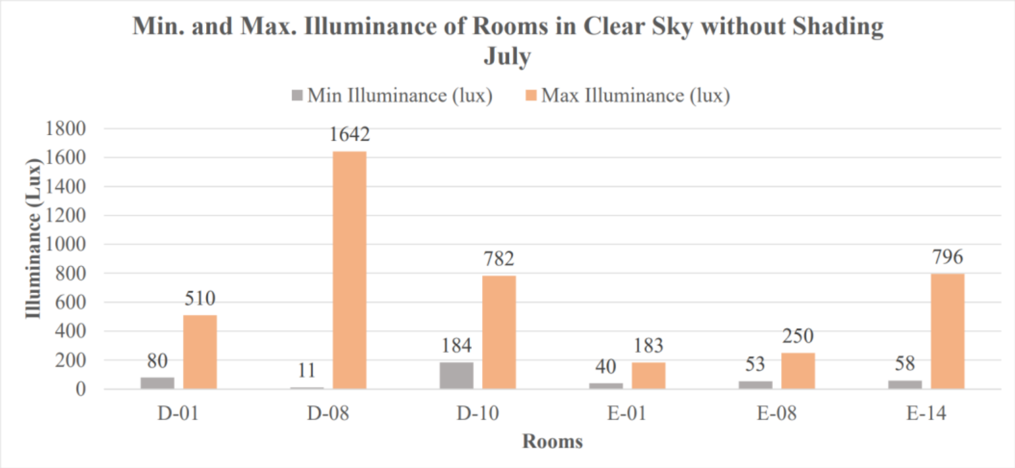


Table 8.14. Daylight illuminance of rooms on 15th July at 13pm in clear sky without shading

All rooms reached the minimum lux value of 500 lux in July at 13:00 in clear sky without shading, except for rooms E-01 and E-08 (183, 249 lux), located on the fourth floor with the shortest windows, as illustrated in Figure 8.28. On the other hand, Semi-office D-08 space which has a window on south façade has the maximum value is 1642 lux but minimum value is 11 lux. As depicted in Figure 8.28, desks situated away from the windows receive insufficient daylight, resulting in an average illuminance ranging between 280 and 400 lux and 100 lux is enough for circulation areas so while this falls below the recommended levels for an office room, it may still be deemed sufficient given the multifunctional nature of the space because this space is serving as a circulation area connecting two blocks, facilitating movement between the south-north and east-west facades, the space's primary function extends beyond that of a traditional office environment.

8.3.2.3.2.1. Daylight Illuminance and Daylight Factor with Current and New Shadings

Openings of 3rd and 4th Floor	**D-10**	**D-11**	**D-12**
Current Shading Types	Reflectivity Blind	Reflectivity Blind	Reflectivity Blind
Shading Position	Inside/Vertical	Inside/Vertical	Inside/Vertical
Shading Control Type	Scheduled	Scheduled	Scheduled
Slat Angle	60°	60°	60°
Openings of 3rd and 4th Floor	**D-13**	**D-14**	**E-14**
Current Shading Types	Reflectivity Blind	Reflectivity Blind	Diffusing Shade Roll
Shading Position	Inside/Vertical	Inside/Vertical	Inside/Light Translucent
Shading Control Type	Scheduled	Scheduled	Scheduled
Slat Angle	60°	60°	no slat

Table 8.15. Current shadings of 3rd and 4th floor

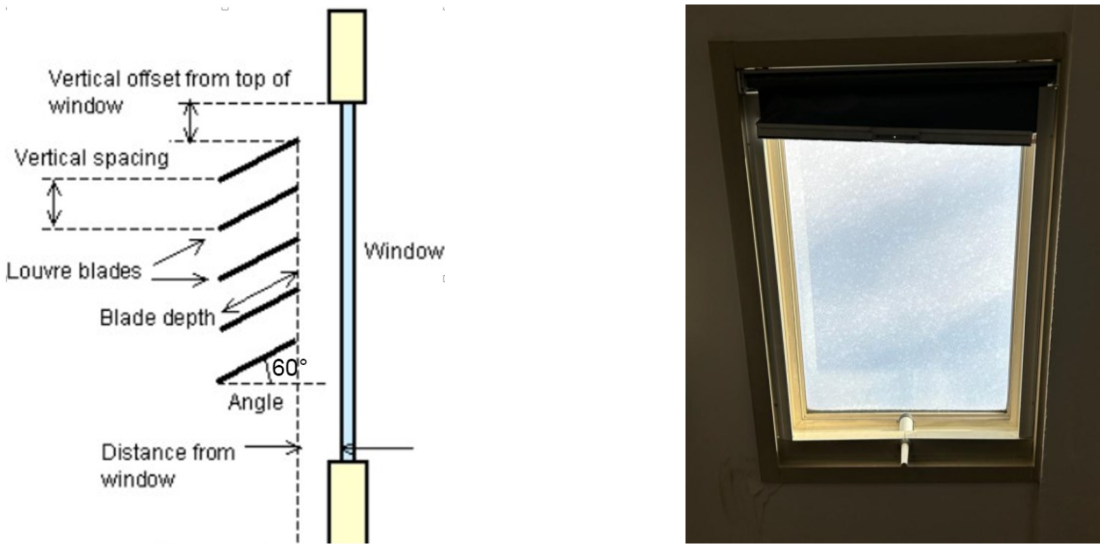

Plan of the Blind

Figure 8.29. Current shading of 3rd floor rooms from D-10 to D-13 (Design Builder) and skylight shading from room E-14

Among the six rooms examined, only rooms D-10 and E-14 are equipped with shading mechanisms. Given that the eastern and southern facades of the building experience the highest solar exposure, additional shading measures were deemed necessary to mitigate solar heat gain. Consequently, a new shading system comprising shade rolls was installed for room D-08, while the shading mechanism for the southern skylight of room E-14 was modified from shade roll to louvre blade. However, for the purpose of comparing daylight illuminance across the six rooms, the same current shading system, consisting of reflectivity vertical blinds from room D-10, was installed in rooms D-01, D-08, D-10, E-01, and E-08, as illustrated in the plan depicted in Figure 8.29. Window-to-floor (WFR) and window-to-wall ratios were computed for each of the six rooms, as detailed in Table 8.15. Regulation stipulates a minimum WFR of 0.125, prompting the analysis of these rooms. With the exception of rooms D-08 and E-14, all rooms exhibit adequate WFR values. However, rooms D-08 and E-14 fall below the specified threshold, recording a WFR of 0.10.

Rooms	**D-01**	**D-08**	**D-10**	**E-01**	**E-08**	**E-14**
Window Area (m²)	4.6 m²	4.6 m²	9 m²	2.65 m²	2.65 m²	7.16 m²
Floor Area (m²)	25 m²	38 m²	17 m²	14.6 m²	14.6 m²	75 m²
Wall Area (m²)	12,3 m²	12,6 m²	15,3 m²	8,15 m²	8,15 m²	134 m²
Window / Floor (WFR)	0.185	0.120	0.530	0.180	0.180	0.095
Window / Wall (WWR)	0.40	0.37	0.60	0.33	0.34	0.057

Table 8.15. Window to floor (WFR) ratio and window to wall (WWR) ratio of rooms on 3rd and 4th floors

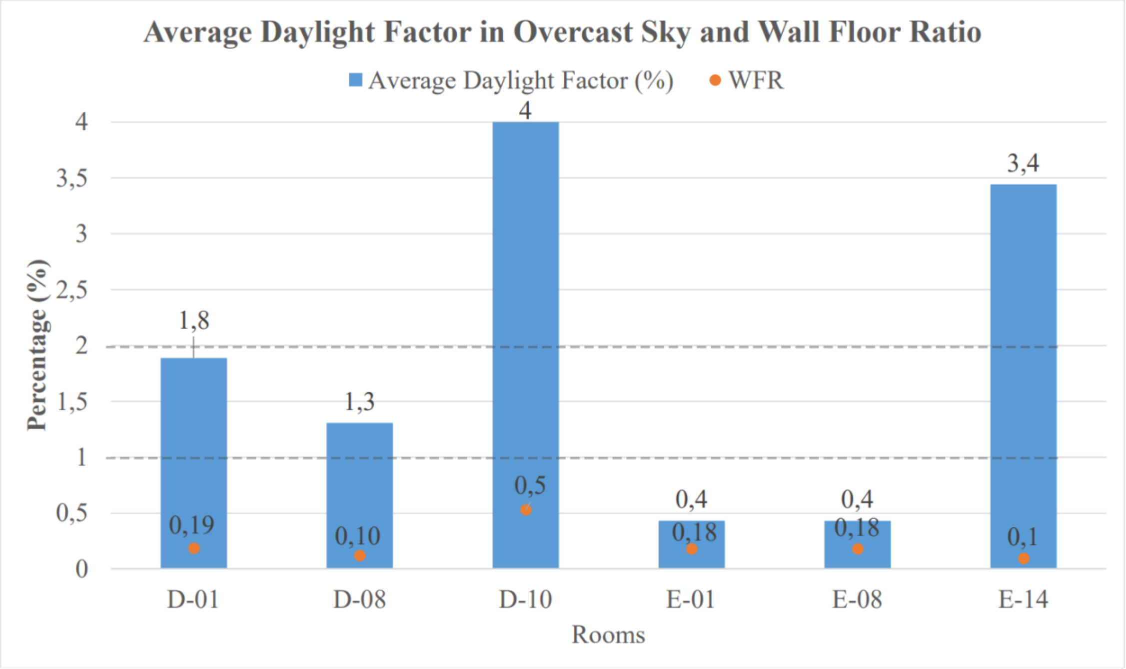


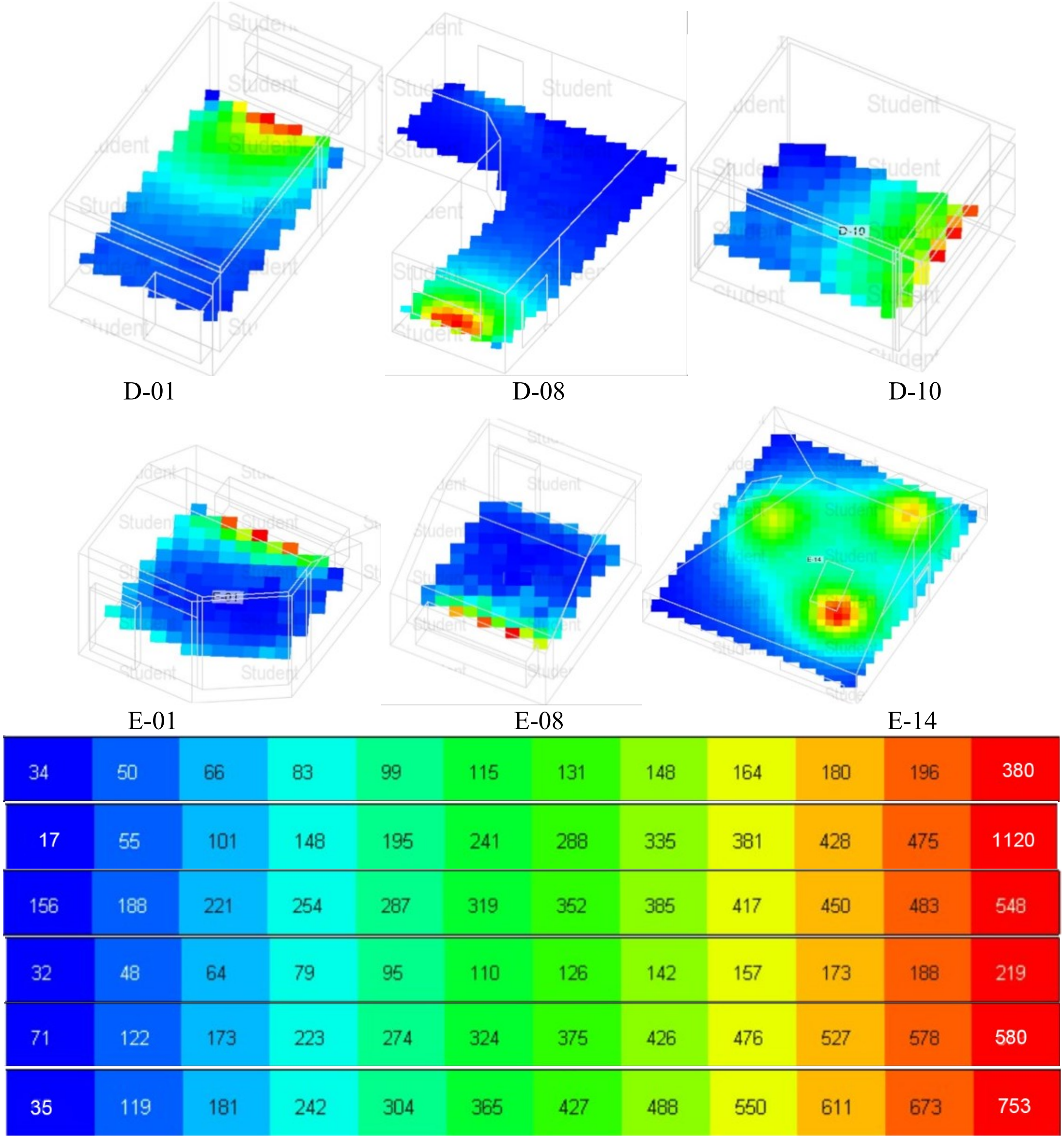
Table 8.16. Window to floor ratio (WFR) and Daylight Factor (%) of rooms on 3rd and 4th floors

The average daylight factor and window-to-floor ratio (WFR) are presented jointly in Table 8.16. Despite rooms E-01 and E-08 failing to achieve the target daylight factor of 1%, their WFR values reach 0.18, surpassing the required minimum of 0.125. Room E-14 exhibits a daylight factor of 3.4%, yet its WFR stands at 0.1. This discrepancy arises from the room's large floor area coupled with inadequate window coverage, despite receiving significant solar gain from the southern skylight.

Openings of 3rd and 4th Floor	**D-01 to D-14**	**E-01 to E-14**
New Shading Type	Reflectivity Blind	Diffusing Shade Roll
Shading Position	Inside	Inside/Light Translucent
Shading Control Type	Scheduled	Scheduled
Slat Angle	60°	no slat

Table 8.17. Current and adding new shadings of 3rd and 4th floor rooms

Illuminance levels were calculated for each of the six rooms on July 15th at 1pm under clear sky conditions with shading, as detailed in Table 8.17. All rooms experienced a reduction in illuminance due to the chosen shading configurations. Room D-10 utilized the current shading of reflectivity vertical blinds set at a 60° angle during working hours, while room E-14 employed a diffusing shade roll positioned inside the light translucent. New shadings were introduced for rooms D-01, D-08, E-01, and E-08. The results revealed that rooms D-08 and E-14 exhibited the highest daylight lux values, measuring 1120 and 753 lux, respectively. Conversely, rooms D-01 and E-01 recorded the lowest illuminance levels, with values of 380 and 219 lux, respectively, indicating poor daylight conditions, as shown in Table 8.18.



34	50	66	83	99	115	131	148	164	180	196	380
17	55	101	148	195	241	288	335	381	428	475	1120
156	188	221	254	287	319	352	385	417	450	483	548
32	48	64	79	95	110	126	142	157	173	188	219
71	122	173	223	274	324	375	426	476	527	578	580
35	119	181	242	304	365	427	488	550	611	673	753

Figure 8.30. Daylight illuminance of rooms on 15th July at 13 pm in clear sky with current and adding shading

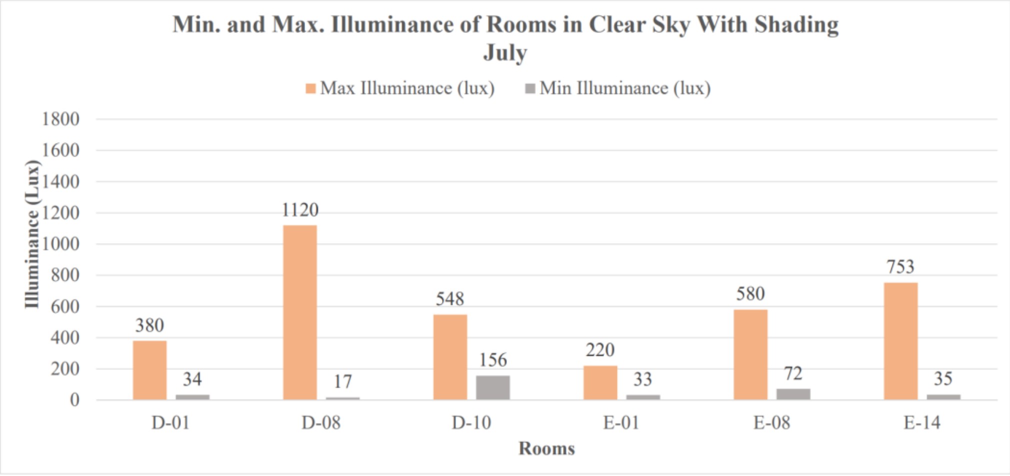
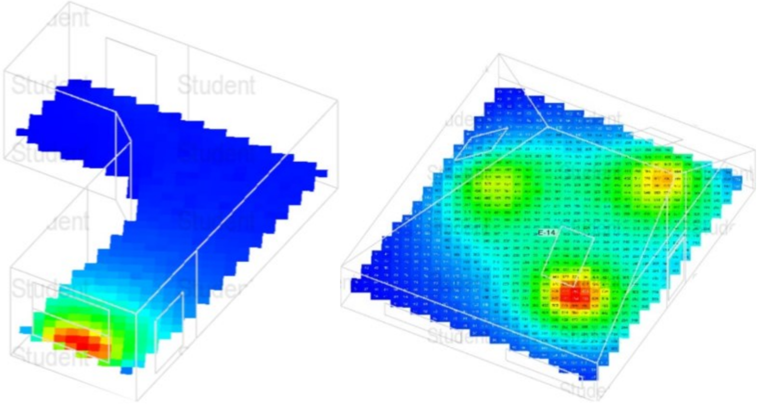


Table 8.18. Daylight illuminance of rooms on 15th July at 13pm in clear sky with current and adding shading

Based on the results of daylight illuminance for each of the six rooms, it is recommended to install a diffusing shade roll for room D-08 and to replace the shading of room E-14's southern skylight with a closed high-reflectivity blind, similar to that of room D-10, as indicated in Table 8.19 and Figure 8.31. The calculations were conducted on July 15th at 1pm under clear sky conditions. The maximum illuminance recorded for room D-08 was 220 lux, while for room E-14, it was 745 lux, as shown in Table 8.20. The results indicate that employing shading for room D-08 is highly effective. However, for room E-14, although the illuminance value decreased with shading, it may still be insufficient to warrant its use.

Openings of 3rd and 4th Floor	**D-08**	**E-14 Skylight**
New Suggested Shading Type	Diffusing Shade Roll	High Reflectivity Blind
Shading Position	Inside/Light Translucent	Inside/Horizontal
Shading Control Type	Scheduled	Scheduled
Slat Angle	no slat	Closed

Table 8.19. Suggested new shadings of 3rd and 4th floor



D-08 E-14

Figure 8.31. Daylight illuminance of room D-08 and E-14 on 15th July at 13pm in clear sky with suggested shadings

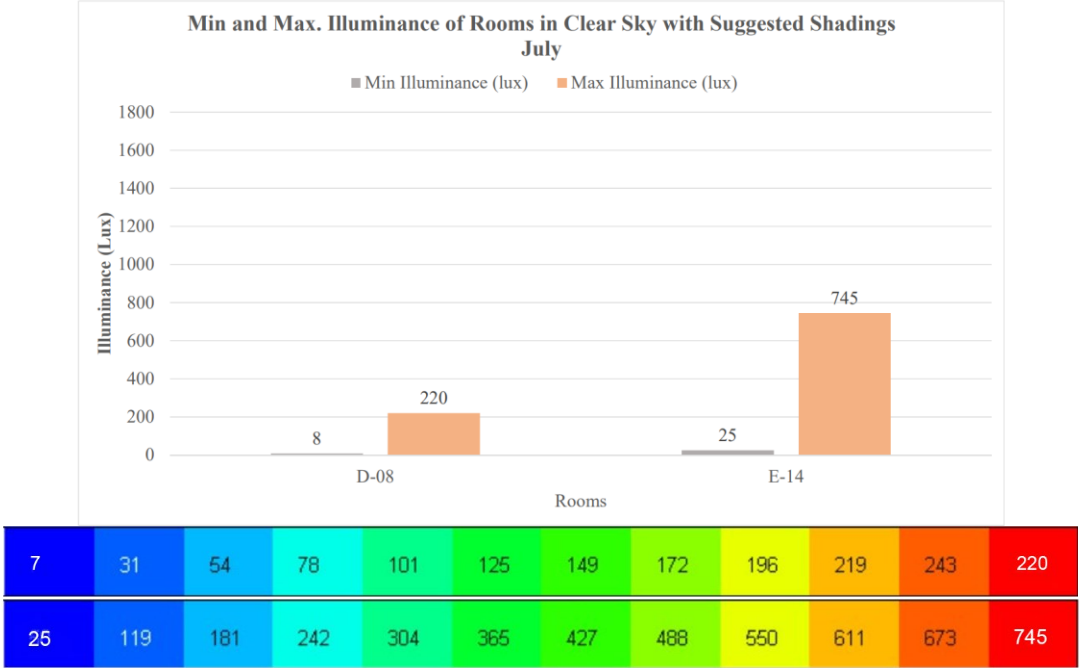


Table 8.20. Daylight illuminance of rooms D-08 and E-14 on 15th July at 13pm in clear sky with suggested shading

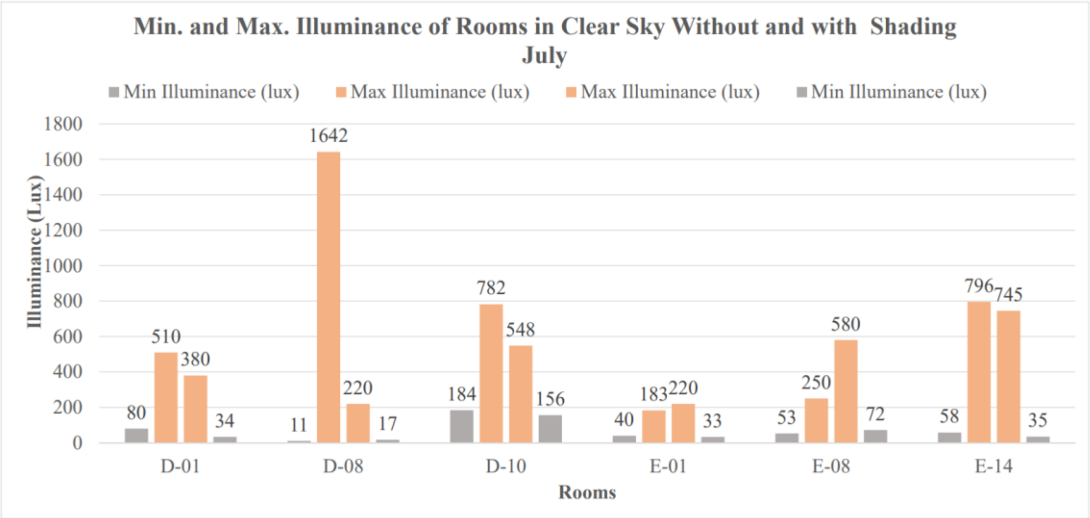


Table 8.21. Daylight illuminance comparison of rooms on 15th July at 13pm in clear sky without shading and with shading

The impact of shading on the daylight illuminance of the six rooms is evident from Table 8.21. The maximum daylight illuminance levels have decreased as follows:

- Room D-01: from 510 lux to 380 lux
- Room D-08: from 1642 lux to 220 lux
- Room D-10: from 782 lux to 548 lux
- Room E-01: from 220 lux to 183 lux
- Room E-08: from 580 lux to 250 lux
- Room E-14: from 796 lux to 745 lux

8.3.2.3.2.2. Spatial Daylight Autonomy, Annual Sunlight Exposure and Useful daylight Illuminance

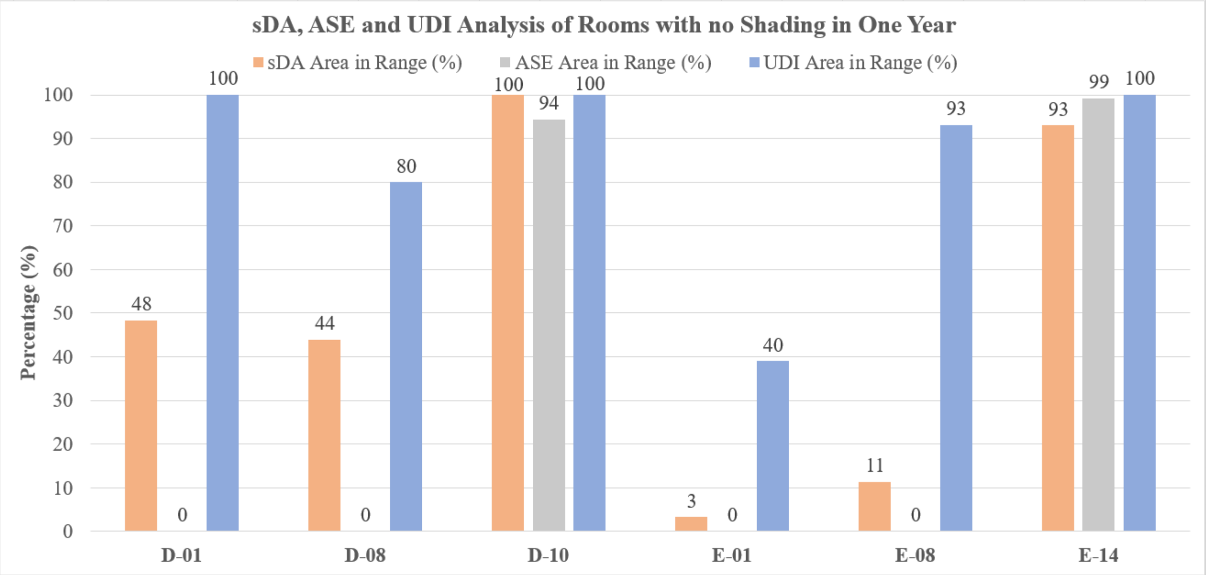


Table 8.22. Spatial daylight autonomy, annual sunlight exposure and useful daylight illuminance of rooms in one year

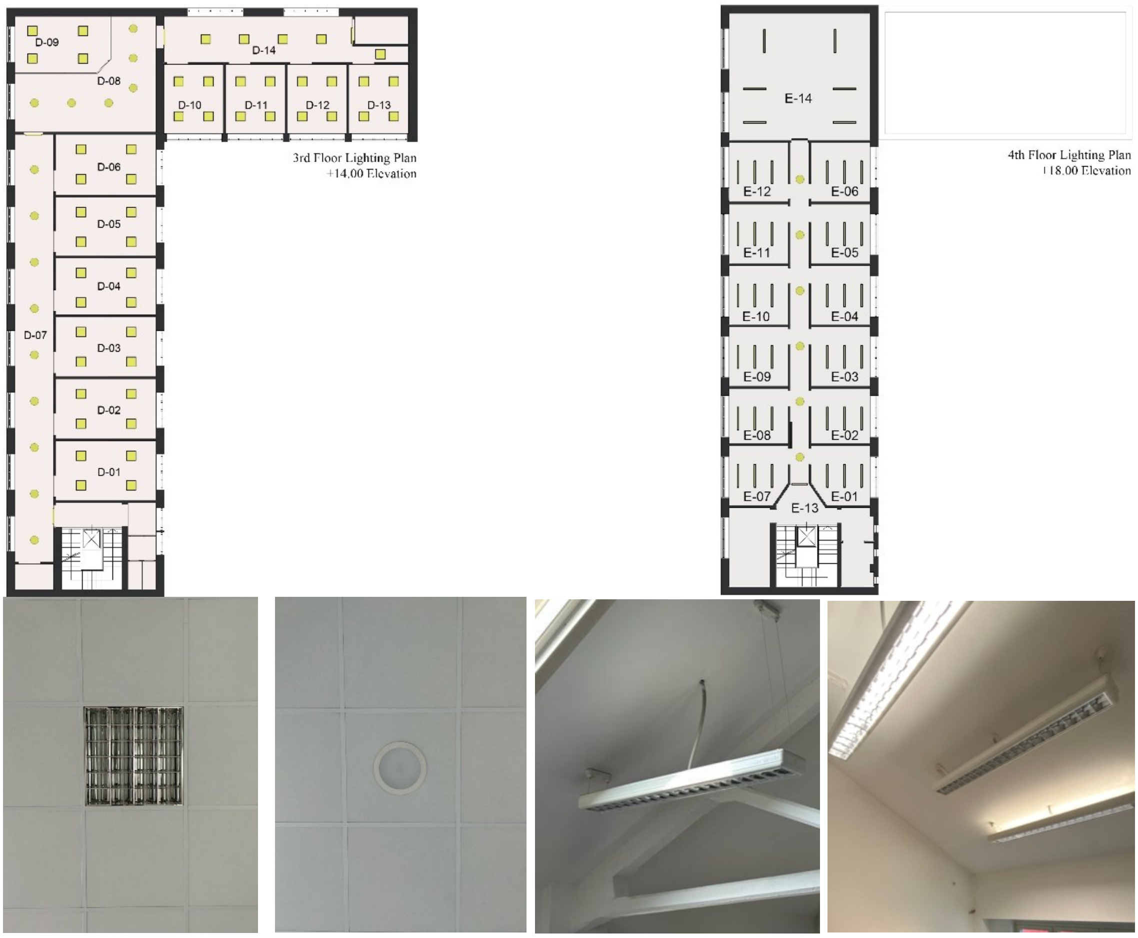
The term "sDA300/50%" refers to Spatial Daylight Autonomy, representing the percentage of the area receiving a minimum illuminance level of 300 lux for 50% of the operational hours per year. Based on this criterion, the Spatial Daylight Autonomy for rooms D-01 and D-08 is deemed average, while for rooms D-10 and E-14, it is classified as high. However, rooms E-01 and E-08 exhibit poor Spatial Daylight Autonomy due to the window heights. Notably, all rooms, except for room E-01, meet the required threshold for Useful Daylight Illuminance (UDI). Room E-01 falls short at 40%, as indicated in Table 8.20.

8.3.2.4.Artificial Lighting of Energy Department Building

The lighting systems in the Energy Department building comprise fluorescent and LED fixtures installed across the 3rd and 4th floors. The specifications and properties of these artificial lighting systems have been established and documented, as in Table 8.23.

Lighting Template	**Fluorescent**
General Lighting / Target Illuminance (lux)	On / 500 lux
Default Display Lighting Density (W/m²)	2,5
Normalised Power Density (W/m²-100)	2,5
Radiant Fraction	0,37
Visible Fraction	0,18
Working Plane Height (m)	0,76 m
Control Type of Lighting	Linear/Off
Max Allowable Glare	22

Table 8.23. Artificial lighting properties



Room D-01, D-10 Room D-08 Room E-14 Room E-01, E-08

Figure 8.32. Artificial lighting plans and artificial lightings of third and fourth floor

The analysis of artificial lighting across six rooms on the 3rd and 4th floors of the Energy Department at Politecnico di Torino reveals varying types of lighting fixtures, as illustrated in Figure 8.32. Room D-01 and D-10 are equipped with recessed fluorescent lighting, while room D-08 features LED fixtures. On the other hand, rooms E-01, E-08, and E-14 are illuminated by suspended fluorescent lights, with room E-14 also featuring wall-mounted fluorescent fixtures. Calculations of the rooms' lighting power densities (LPD) indicate that D-10 exhibits the highest value at 17,000 W/m², whereas D-08 has the lowest value at 3000 W/m² as illustrated in table 8.25.

Rooms	**D-01**	**D-02**	**D-03**	**D-04**	**D-05**	**D-06**	**D-07**
Area (m²)	25 m²	25 m²	25 m²	25 m²	25 m²	25 m²	70 m²
Lighting Type	Fluorescent	Fluorescent	Fluorescent	Fluorescent	Fluorescent	Fluorescent	Fluorescent
Lighting Quantity	4	4	4	4	4	4	11
Lighting Position	Recessed	Recessed	Recessed	Recessed	Recessed	Recessed	Recessed and Wall
LPD (W/m²)	11.522	11.522	11.522	11.522	11.522	11.522	7.522
Rooms	**D-08**	**D-09**	**D-10**	**D-11**	**D-12**	**D-13**	**D-14**
Area (m²)	38 m²	15 m²	17 m²	17 m²	17 m²	17 m²	40 m²
Lighting Type	LED	LED	Fluorescent	Fluorescent	Fluorescent	Fluorescent	LED
Lighting Quantity	4	4	4	4	4	4	7
Lighting Position	Recessed	Recessed	Recessed	Recessed	Recessed	Recessed	Recessed and Wall
LPD (W/m²)	3.150	12.800	17.000	17.000	17.000	17.000	5.285

Rooms	**E-01**	**E-02**	**E-03**	**E-04**	**E-05**	**E-06**	**E-07**
Area (m²)	14.00 m²	14.00 m²	14.60 m²	14.60 m²	14.60 m²	14.60 m²	14.60 m²
Lighting Type	Fluorescent	Fluorescent	Fluorescent	Fluorescent	Fluorescent	Fluorescent	Fluorescent
Lighting Quantity	3	3	3	3	3	3	3
Lighting Position	Recessed	Recessed	Recessed	Recessed	Recessed	Recessed	Recessed
LPD (W/m²)	10.285	10.285	9.863	9.863	9.863	9.863	9.863
Rooms	**E-08**	**E-09**	**E-10**	**E-11**	**E-12**	**E-13**	**E-14**
Area (m²)	14.60 m²	14.60 m²	14.60 m²	14.60 m²	14.60 m²	34.60 m²	34.30 m²
Lighting Type	Fluorescent	Fluorescent	Fluorescent	Fluorescent	Fluorescent	LED and Fluorescent	LED and Fluorescent
Lighting Quantity	3	3	3	3	3	8	7
Lighting Position	Recessed	Recessed	Recessed	Recessed	Recessed	Recessed and Wall	Suspended and Wall
LPD (W/m²)	9.863	9.863	9.863	9.863	9.863	3.468	13.644

Table 8.24. Artificial lighting Properties of 3rd and 4th Floor

Table 8.25. Artificial lighting power density LPD (W/m²) and LPD (W/m²-500 and 750 lux) of six rooms

The prescribed illuminance level for office workspaces falls within the range of 700 - 1000 lux, as stipulated by the International Commission on Illumination (CIE) guidelines from 1990.

Hence, the calculations were executed with careful adherence to this standard, resulting in the determination of a 750 lux illuminance level for the office rooms, alongside the existing 500 lux level within the building, as depicted in Table 8.25. The transition from 500 lux to 750 lux yields the following illuminance ranges for the respective rooms:

- Room D-01: 2,300 to 1,500 lux
- Room D-08: 630 to 420 lux
- Room D-10: 3,400 to 2,270 lux
- Room E-01: 2,000 to 1,400 lux
- Room E-08: 2,000 to 1,300 lux
- Room E-14: 2,700 to 1,800 lux.

Solar gains from exterior windows and artificial lighting for each of the six rooms were analyzed over the course of a year, monthly, using DesignBuilder software. The results indicated that in January, room D-01 exhibited the lowest solar gain at approximately 10 kWh, while room D-08 recorded the highest solar gain at approximately 48 kWh. Conversely, in July, room E-01 registered the lowest solar gain at approximately 46 kWh, whereas room E-14 displayed the highest solar gain at approximately 300 kWh. Consequently, based on these solar gain values, the artificial lighting systems are adjusted accordingly, whether to remain open or closed, as outlined in Tables 8.26 and 8.27.

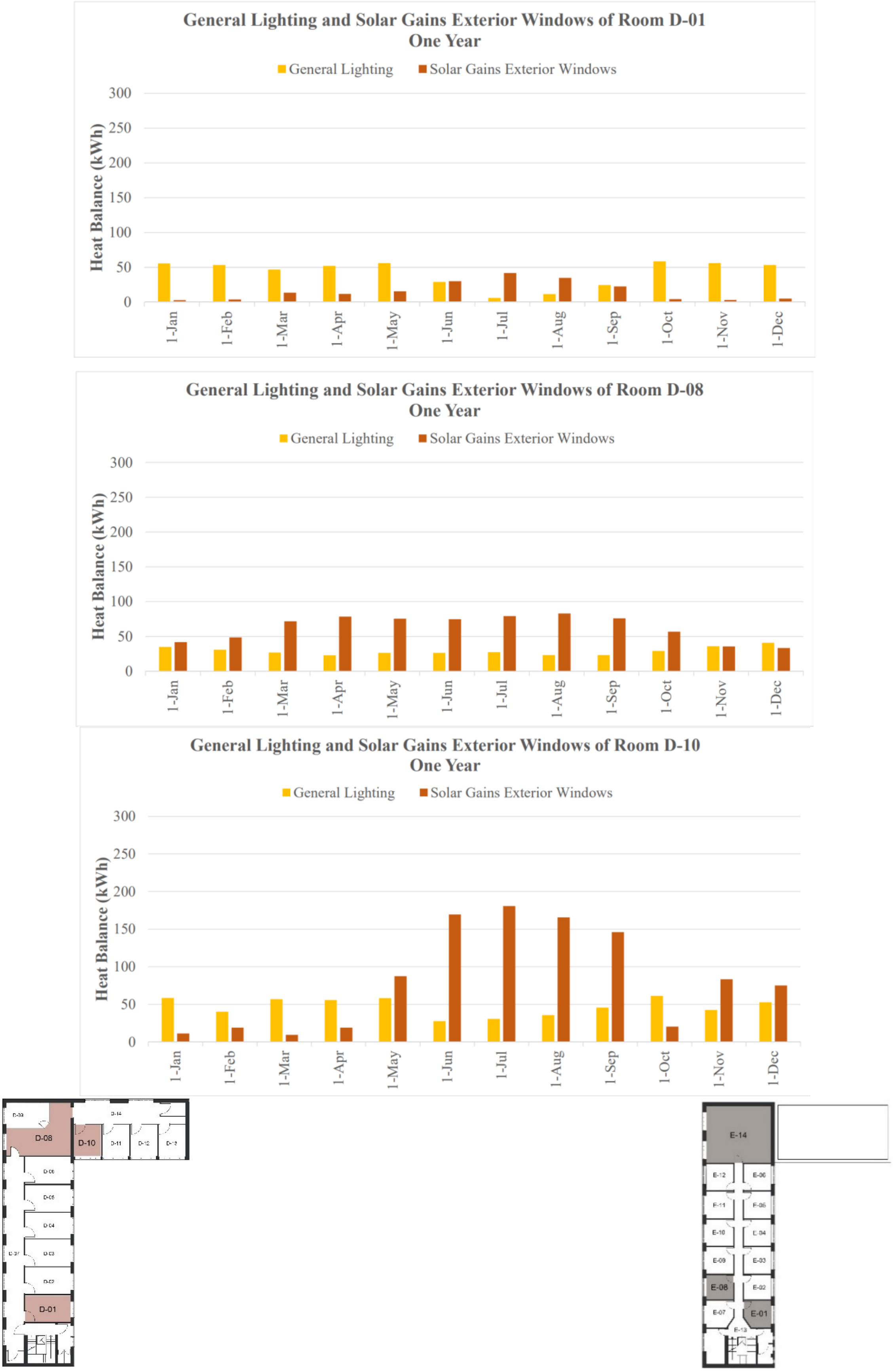
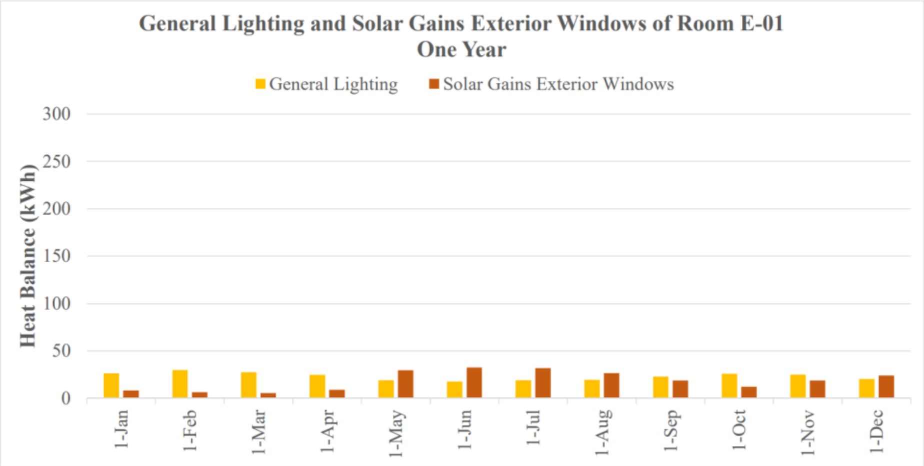
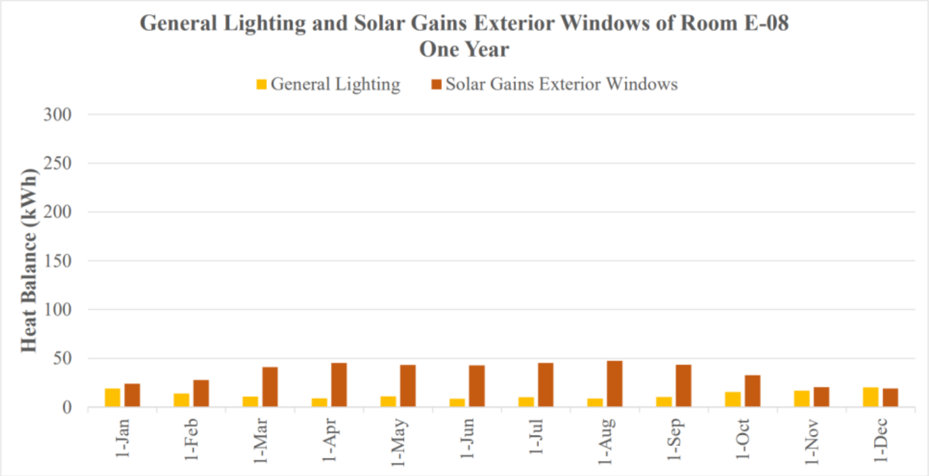
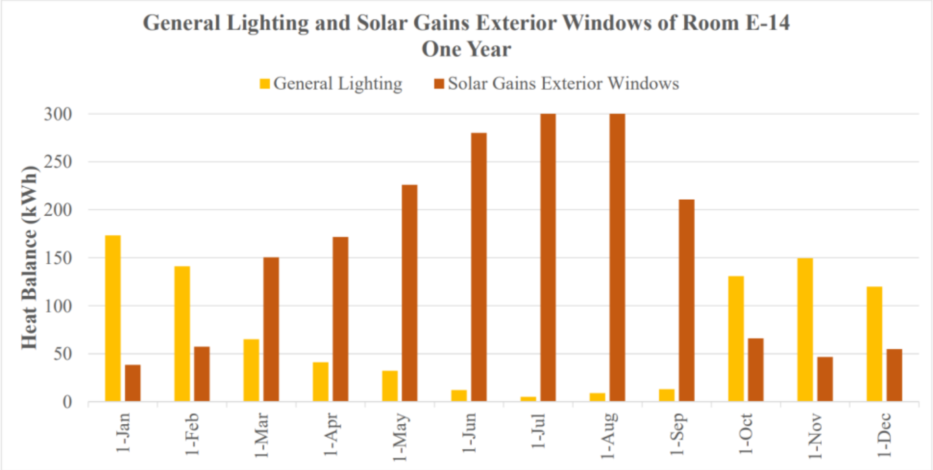
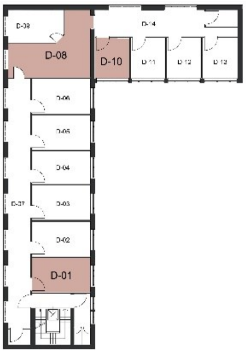


Table 8.26. General lighting and solar gains exterior windows of rooms on 3rd floor in one year


General Lighting and Solar Gains Exterior Windows of Room E-01 One Year


General Lighting and Solar Gains Exterior Windows of Room E-08 One Year


General Lighting and Solar Gains Exterior Windows of Room E-14 One Year



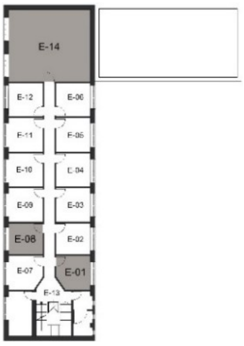


Table 8.27. General lighting and solar gains exterior windows of rooms on 4th floor in one year

Heating and Cooling Design

8.3.2.4.1. Heating Design

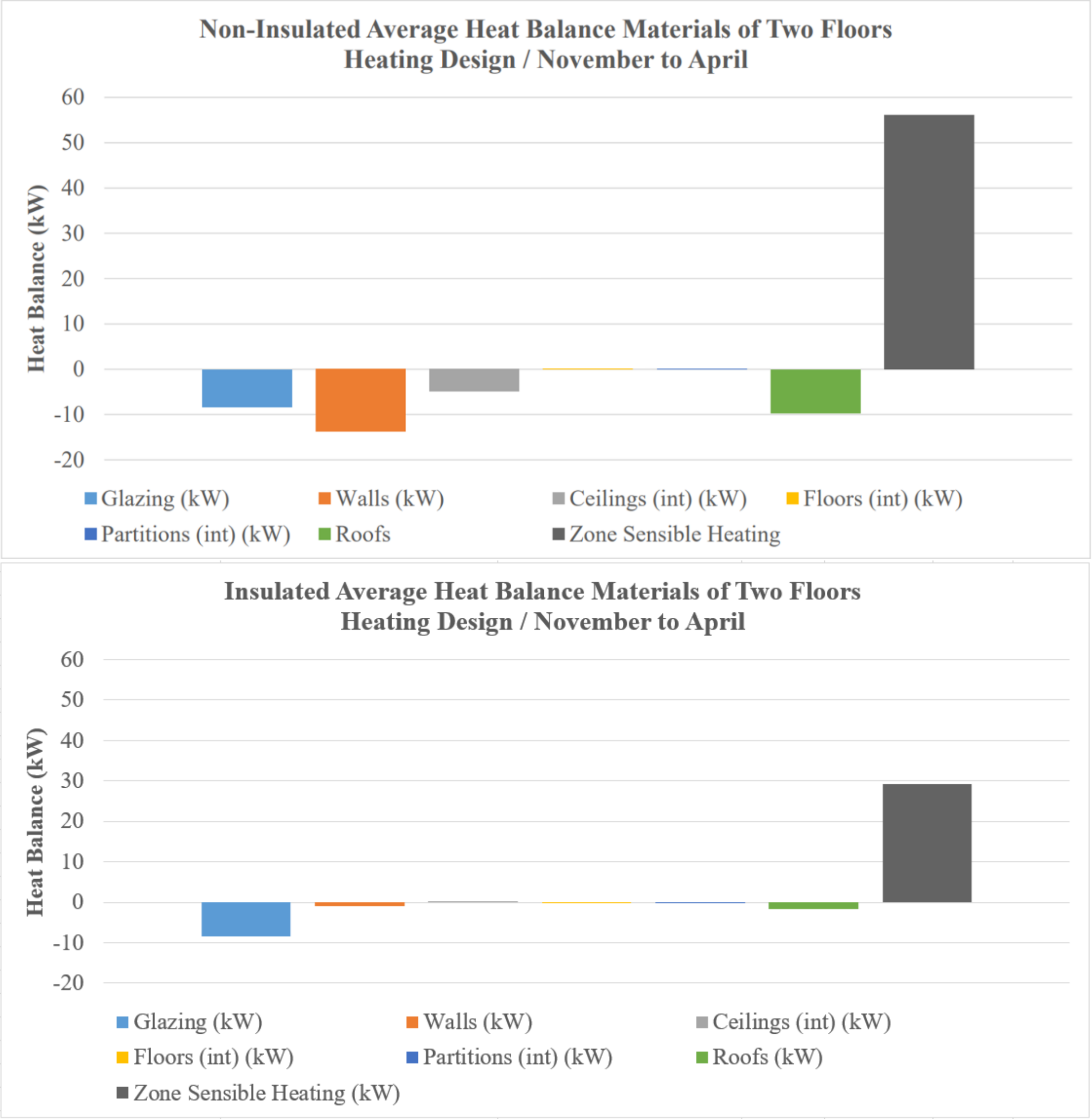


Table 8.28. Non-Insulated and insulated heating design heat balance of materials

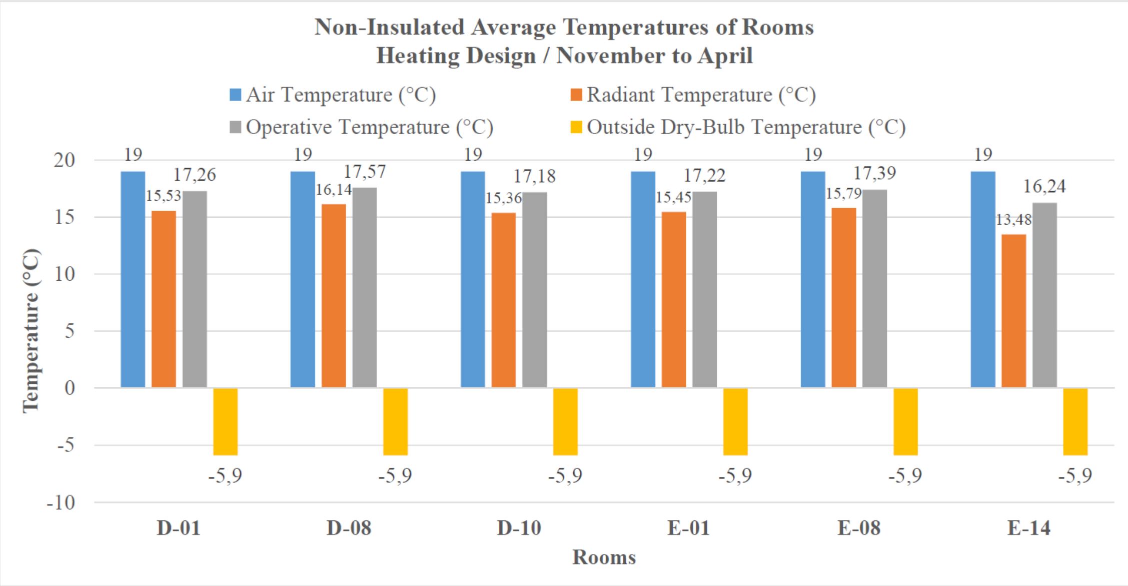
Heat balance refers to the equilibrium between heat gains and losses within a building. In the context of comparing non-insulated and insulated buildings, heat balance analysis involves evaluating how heat flows into and out of each type of building's two floors' glazings, floors, exterior walls, interior walls, roofs and ceilings.

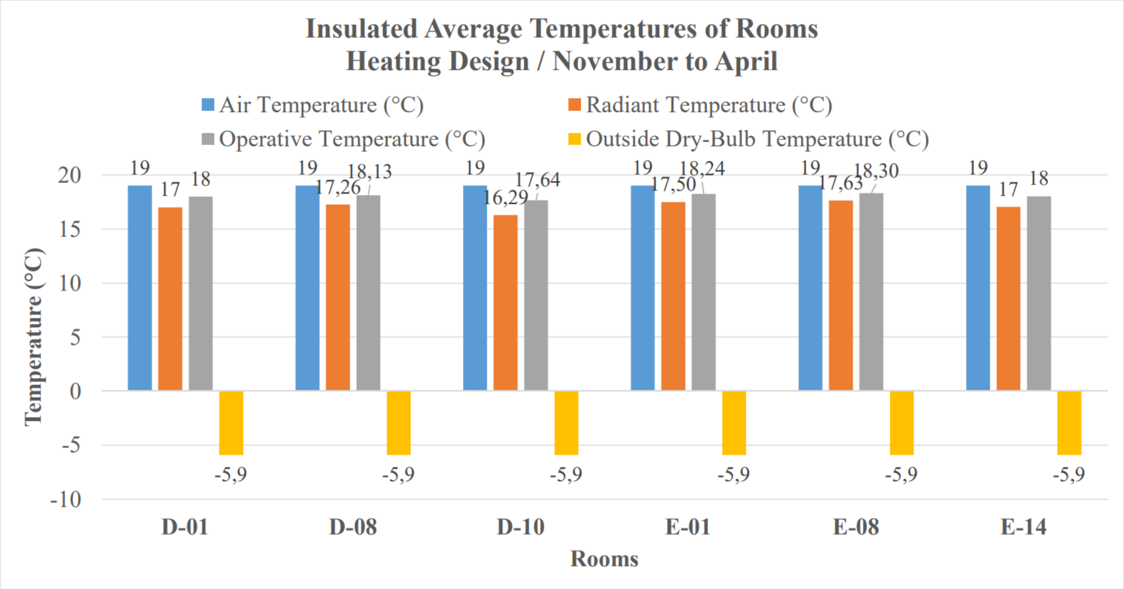
For a non-insulated building, heat transfer occurs more freely through the walls, roof, and windows due to the absence of insulation. During the winter months, heat loss through conduction, convection, and radiation can be significant, leading to higher heating demands.

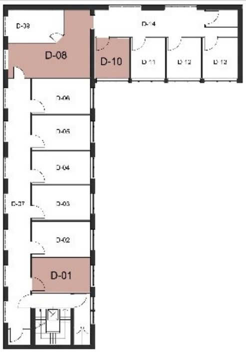
In contrast, an insulated building is designed to reduce heat transfer through the building envelope. Insulation materials such as mineral wool has been added for interior and exterior side of the external wall. Insulation materials have been added for new design building except glazing. The windows remained as current way as it can be seen from table 8.28. As a result, insulated buildings experience lower heat loss in winter and reduced heat gain in summer compared to non-insulated buildings.

The recorded interior's air temperature from November to April which are winter months have been calculated as both the non-insulated and insulated buildings for six office rooms remained consistent at 19°C when the heating system was activated, as indicated in Table 8.29. This observation suggests that the heating system effectively operates irrespective of the insulation status of the building, maintaining the designated heating design temperature in both scenarios.

Furthermore, the heat balance of each material comprising the six rooms was assessed for both insulated and non-insulated conditions during winter. Table 8.30 illustrates that the current non-insulated materials of the rooms exhibit a heat loss balance of -0.5 kW, with the most significant heat loss occurring through the roofs. Conversely, the utilization of insulation in the building yielded notable benefits, particularly for the exterior walls, where the heat loss approached zero. However, for the roof, insulation did not entirely mitigate heat loss, as it failed to achieve a positive impact.







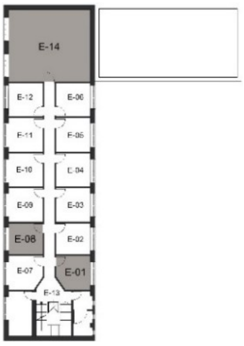
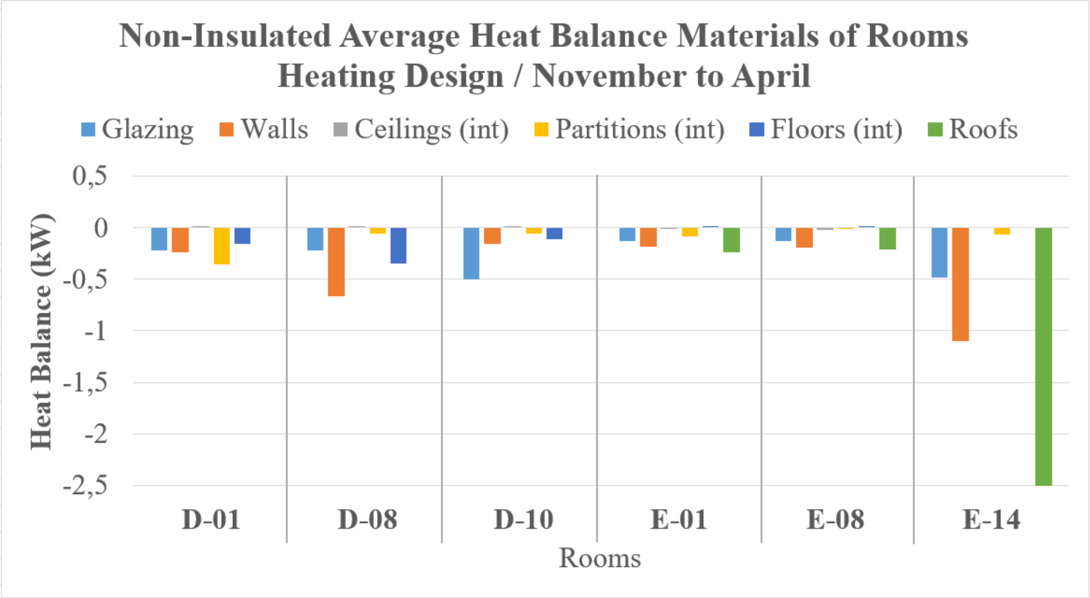
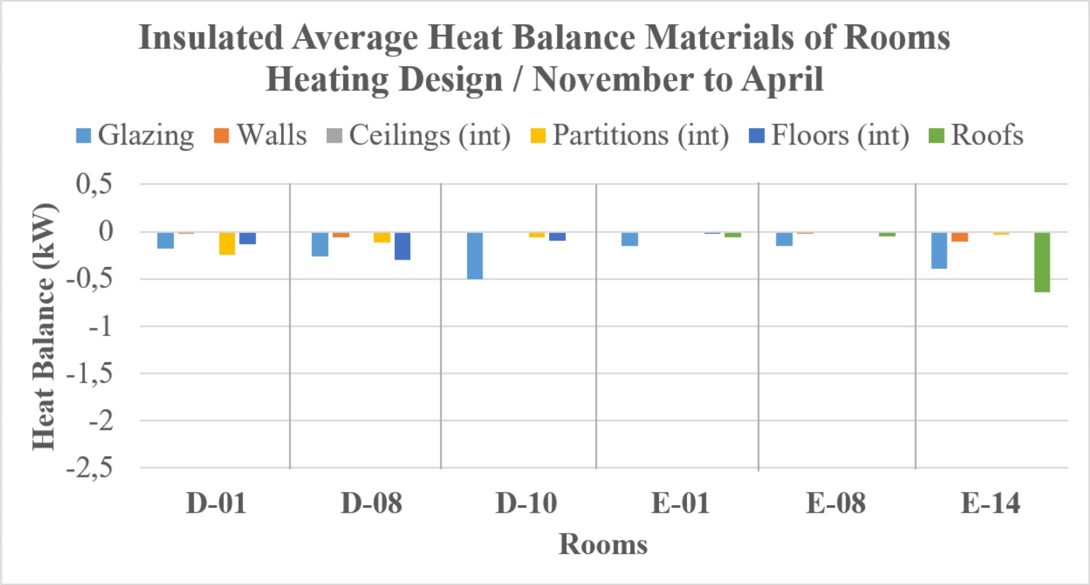
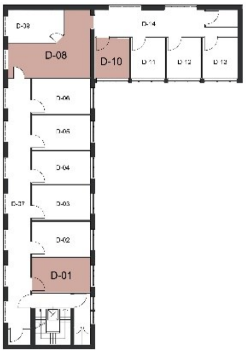


Table 8.29. Non-Insulated and Insulated heating design air temperatures of rooms D-01, D-08, D-10, E-01, E-08 and E-14







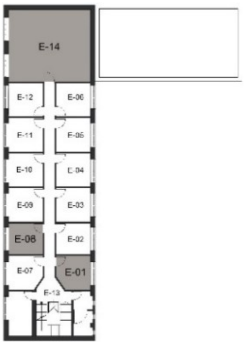


Table 8.30. Non-Insulated and insulated heating design heat balance of rooms' materials

8.3.2.4.2. Cooling Design

Cooling design analysis, heat balances of materials and interior air temperatures for each of the six rooms were calculated for a single day, specifically on July 15th. This analysis was conducted to compare the effects of insulation versus non-insulation, representing the current situation. Additionally, the analysis served to complement the previous daylighting assessment conducted in July, offering insights into the overall thermal performance of the rooms under consideration.

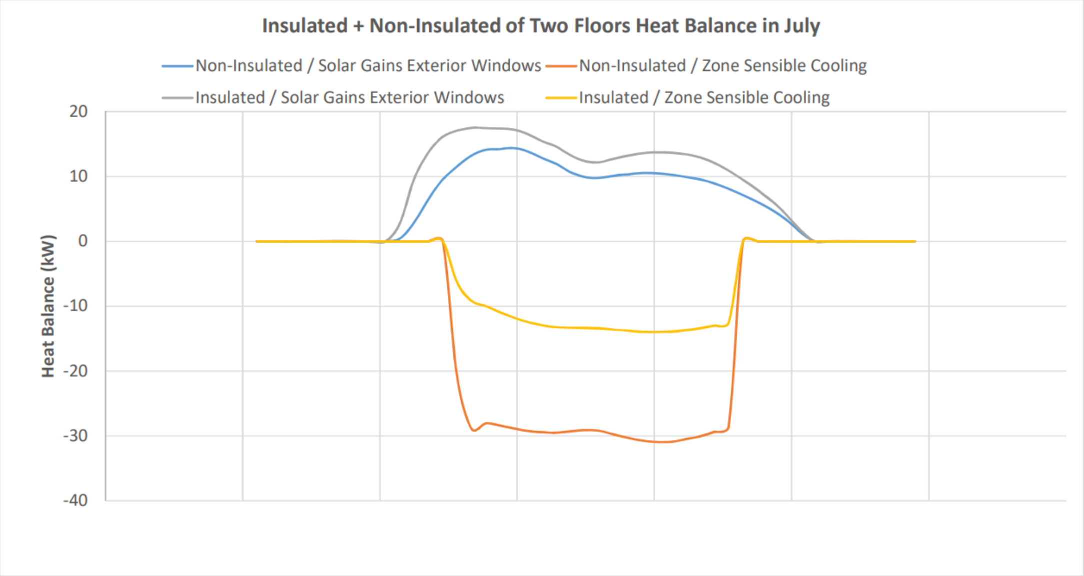
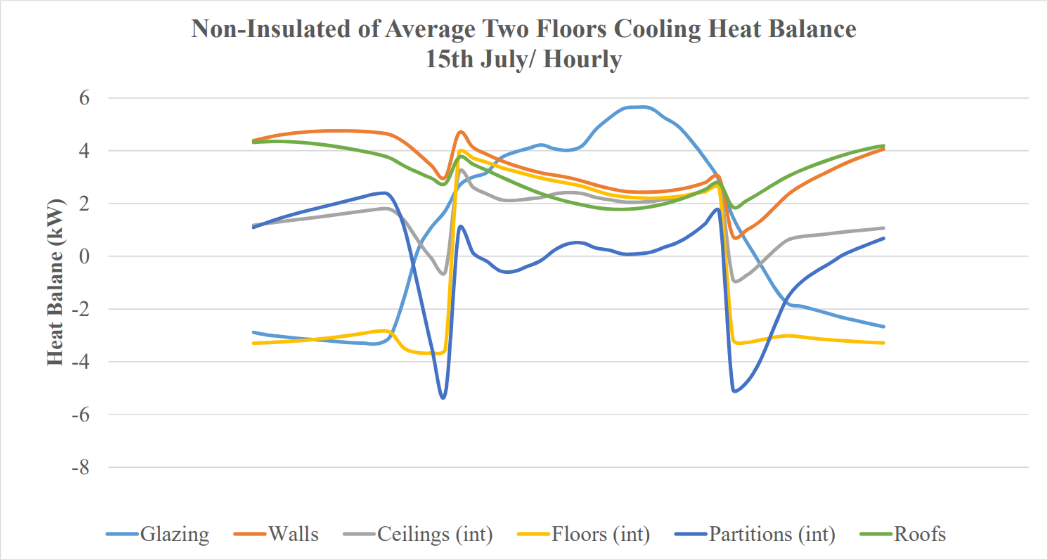


Table 8.31. Cooling design heat balance for Insulated and non-Insulated building's solar gains and sensible cooling

During summer, particularly in July, the combined effects of solar radiation and outdoor temperatures often lead to heightened cooling demands. The average sensible cooling value for the insulated zones, as depicted in Table 8.31, registers lower at approximately -12 kW compared to the non-insulated building. The cooling system operates to maintain an interior temperature of 27°C, in accordance with the regulations of the Politecnico di Torino campus, both in the current non-insulated and insulated scenarios for the analyzed six rooms, as evidenced by Tables 8.33 through 8.38.



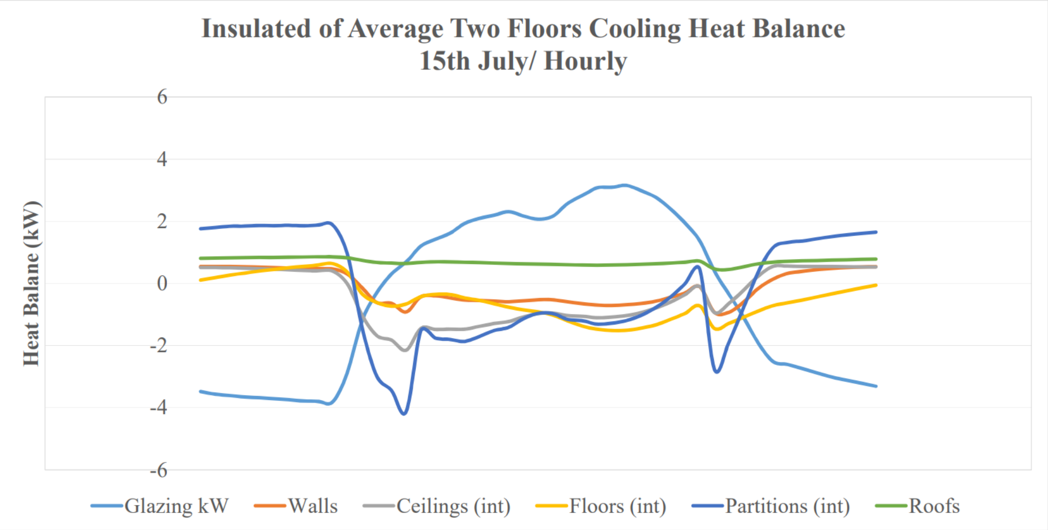


Table 8.32. Cooling design heat balance for non-Insulated and Insulated building’s materials

The heat balances of materials for the non-insulated and insulated situations generally exhibit minimal disparity across most rooms, a notable exception is observed in meeting room E-14. In the current non-insulated scenario, the heat balance for the roof of meeting room E-14 is approximately 1.2 kW. However, upon the implementation of insulation material, this value undergoes a significant reduction to approximately 0.2 kW, as illustrated in Table 8.44.

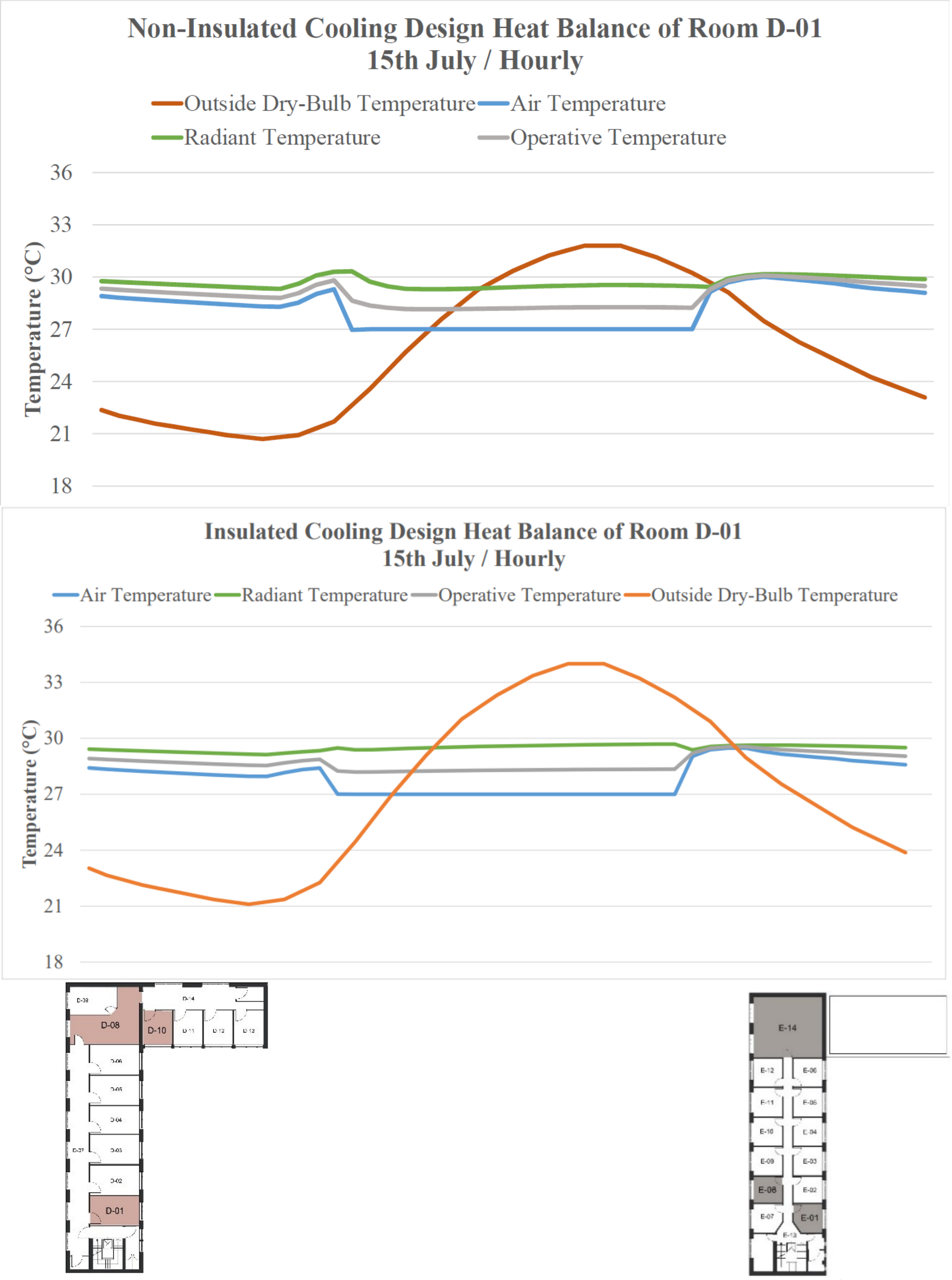


Table 8.33. Non-Insulated and Insulated cooling design heat balance of room D-01 in 15th of July

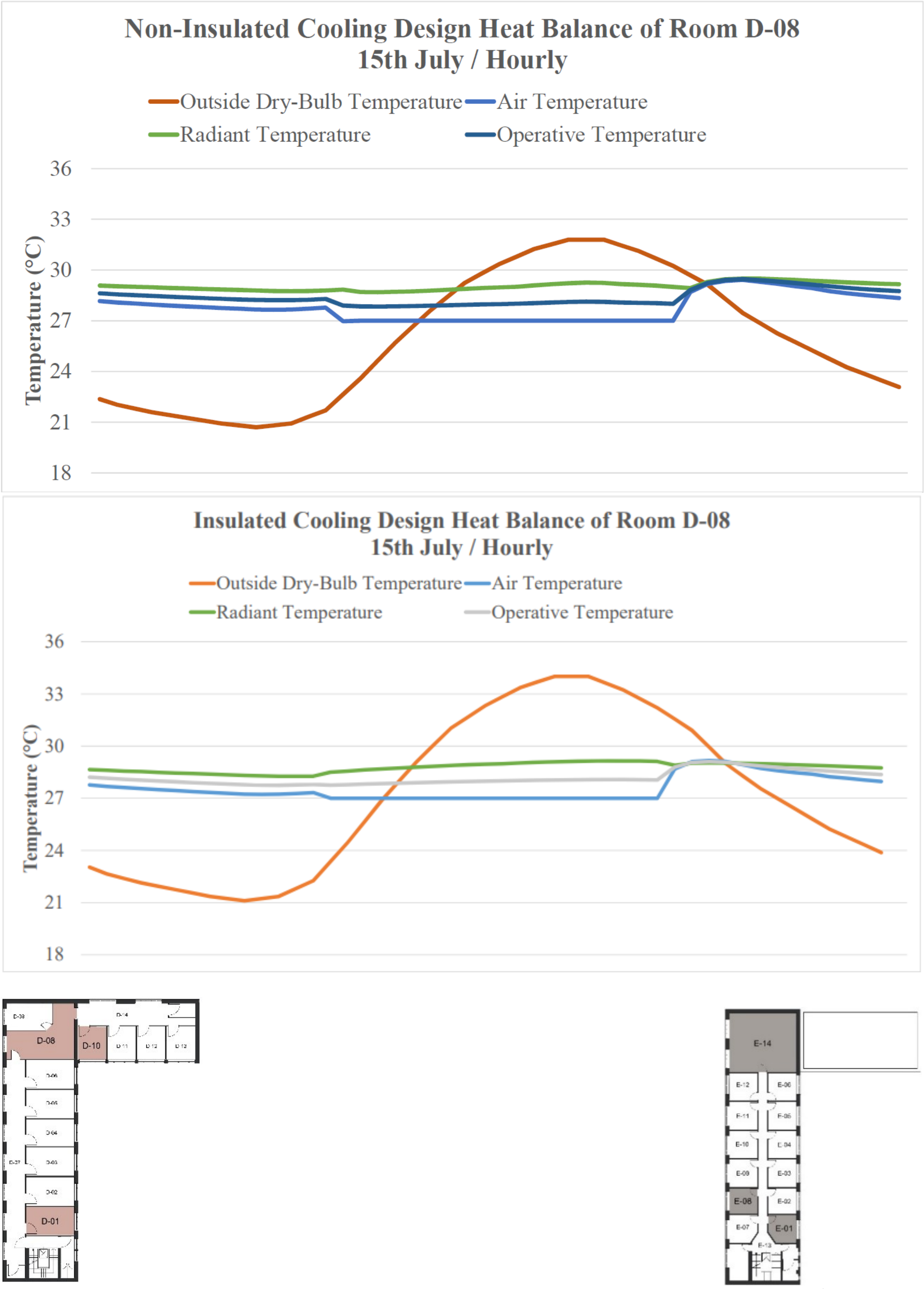
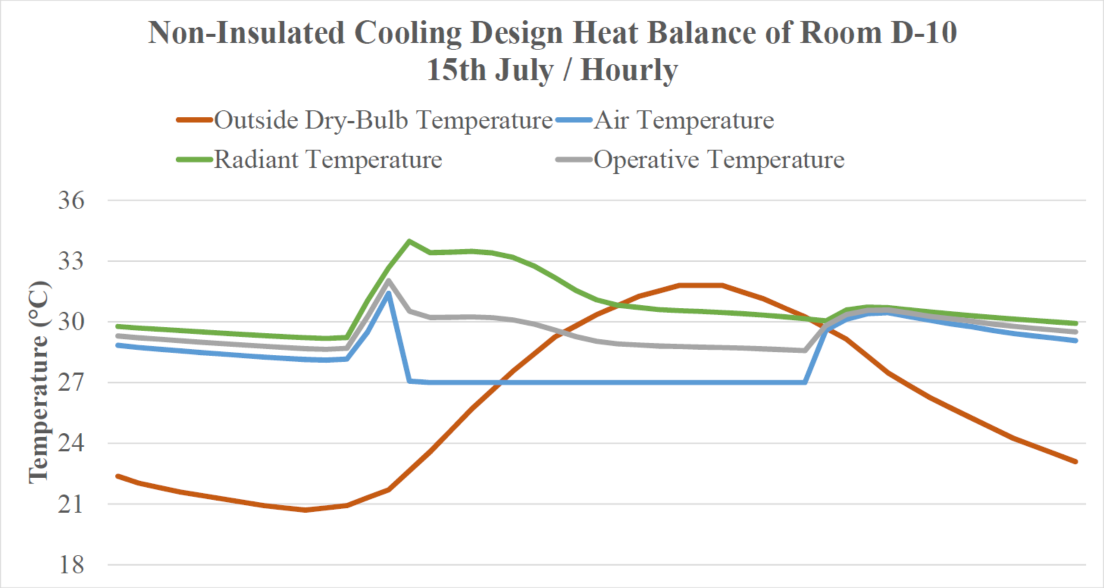
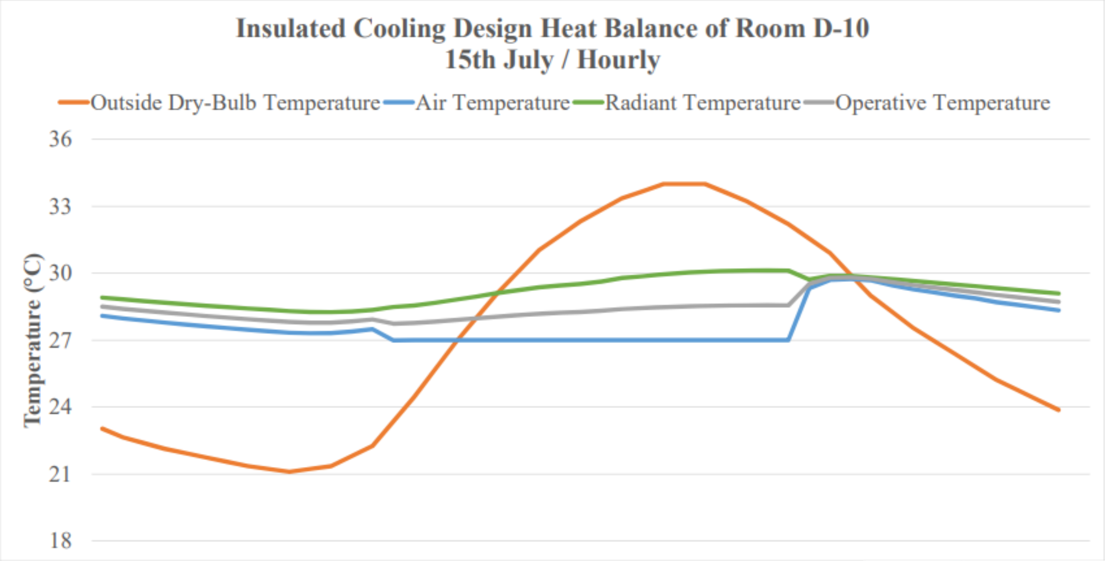
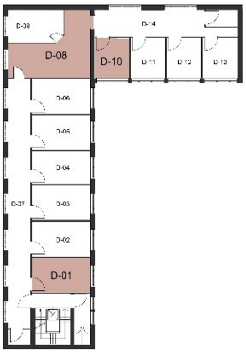


Table 8.34. Non-Insulated and Insulated cooling design heat balance of room D-08 in 15th of July







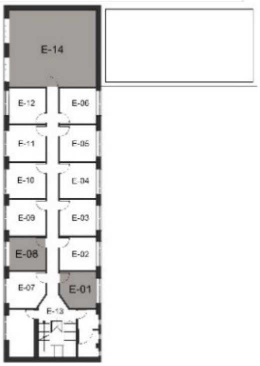
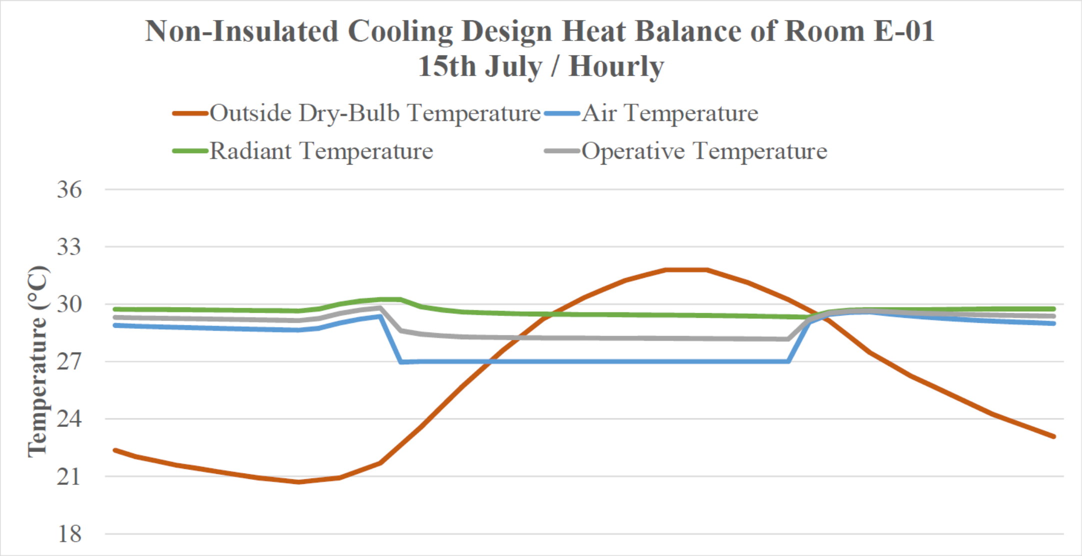
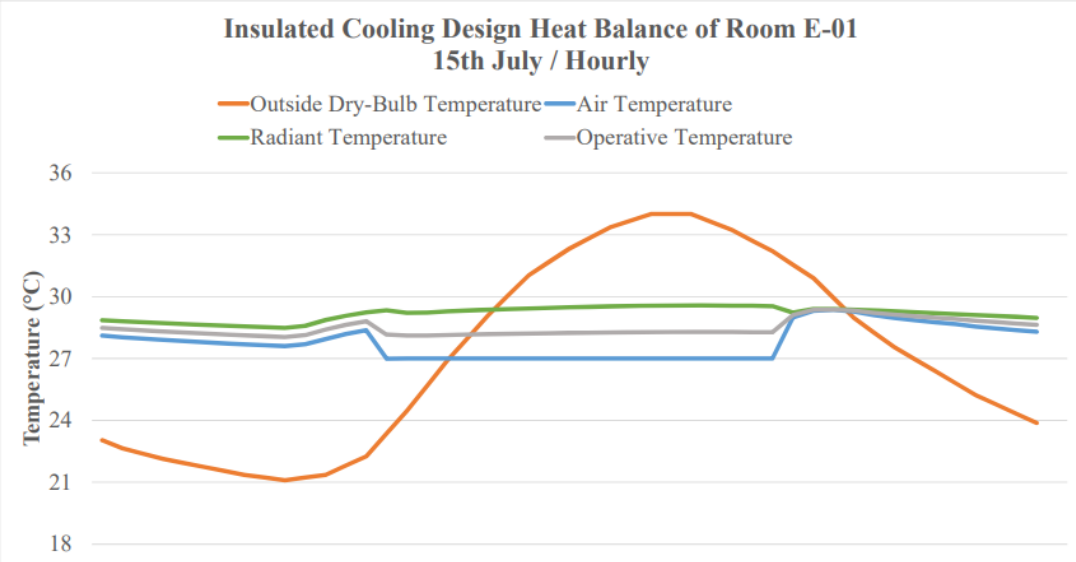
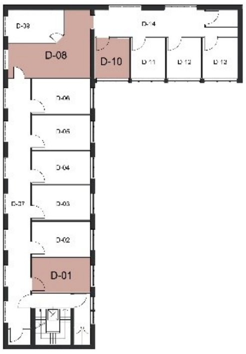


Table 8.35. Non-Insulated and Insulated cooling design heat balance of rooms D-10 in 15th of July







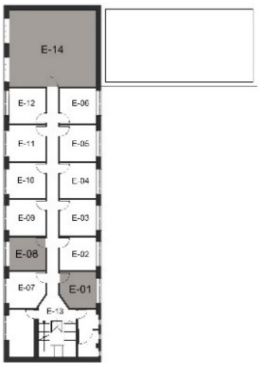
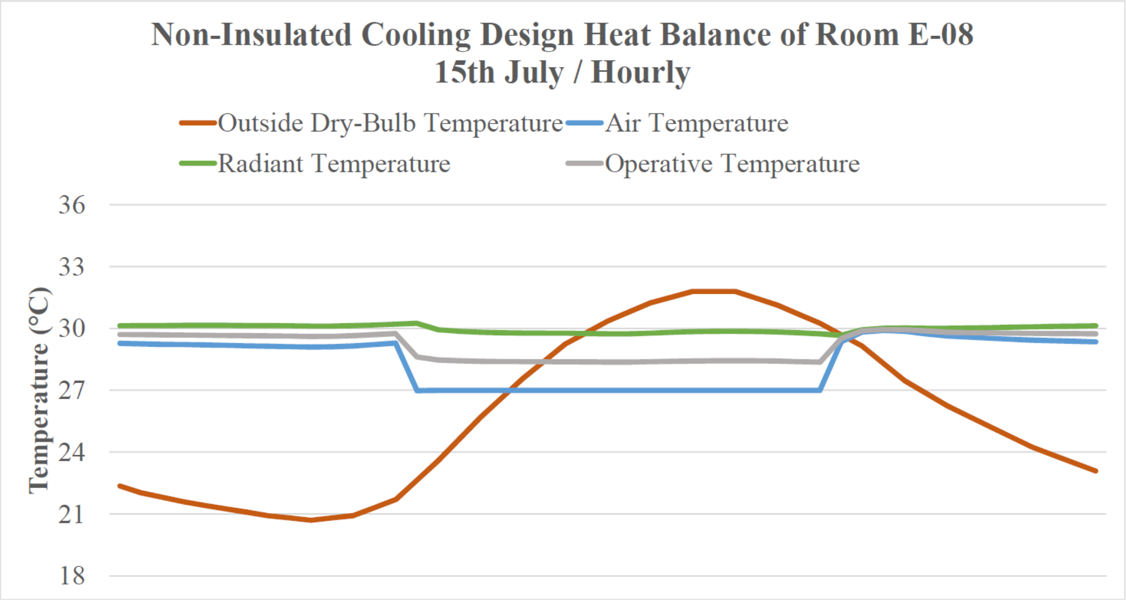
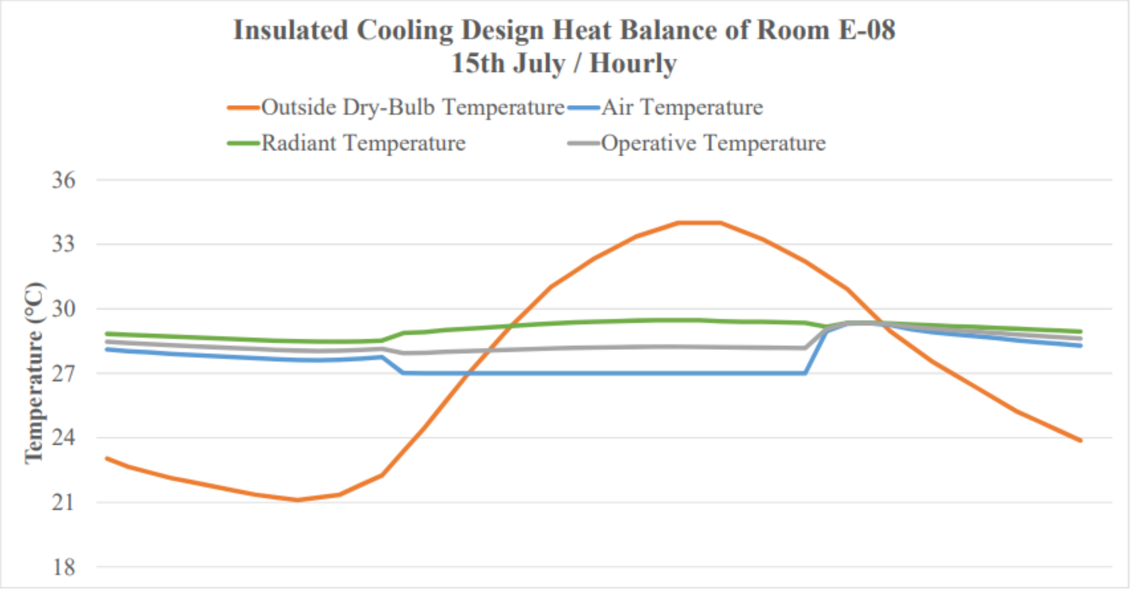
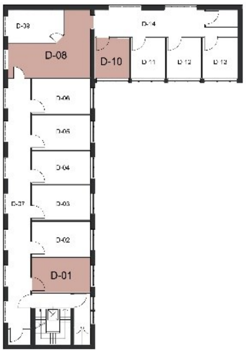


Table 8.36. Non-Insulated and Insulated cooling design heat balance of rooms E-01 in 15th of July







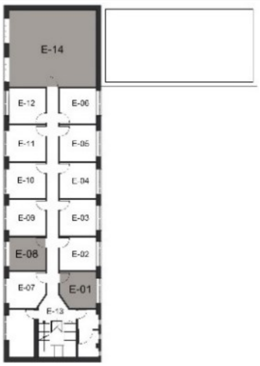


Table 8.37. Non-Insulated and Insulated cooling design heat balance of rooms E-08 in 15th of July

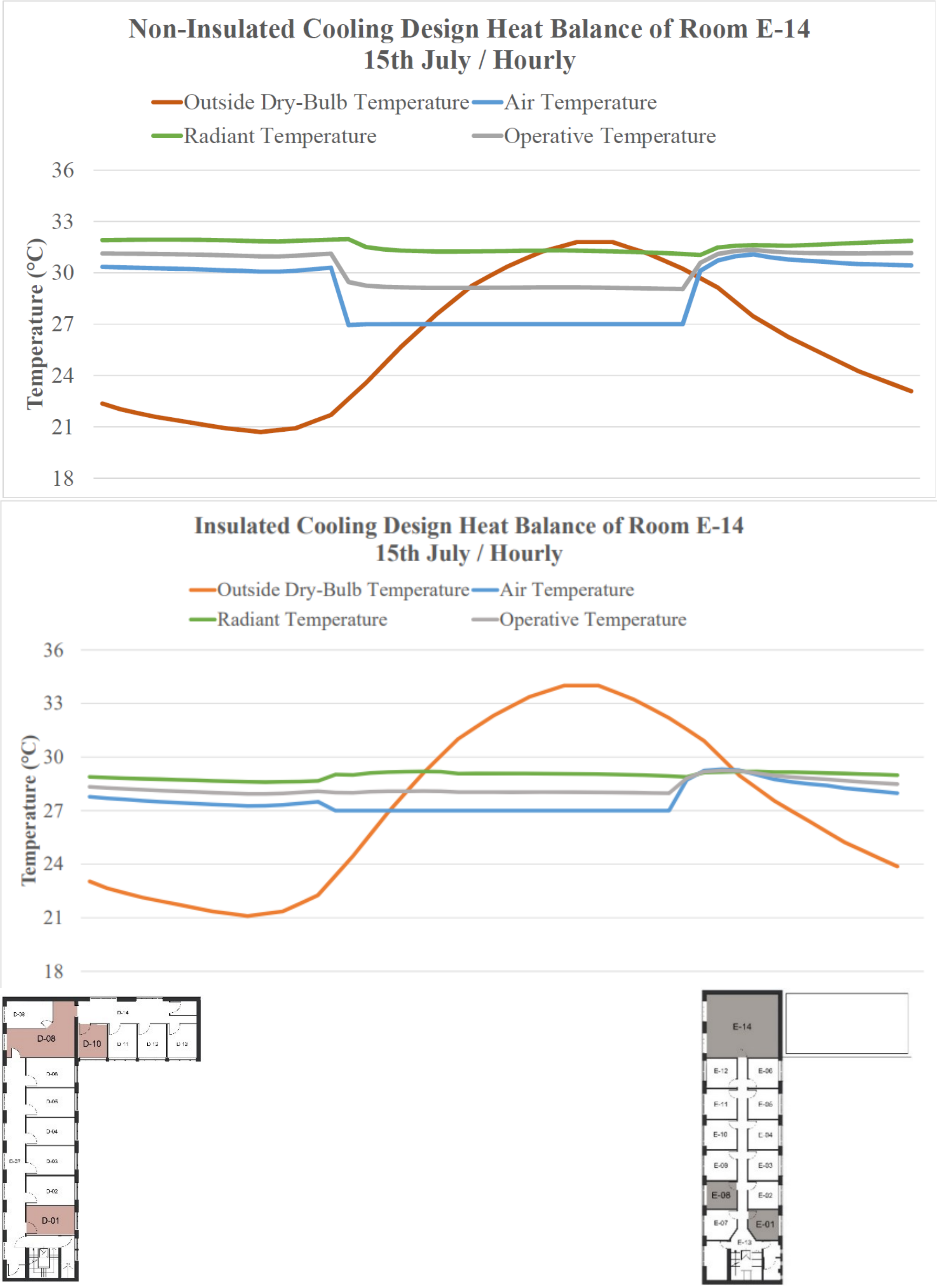
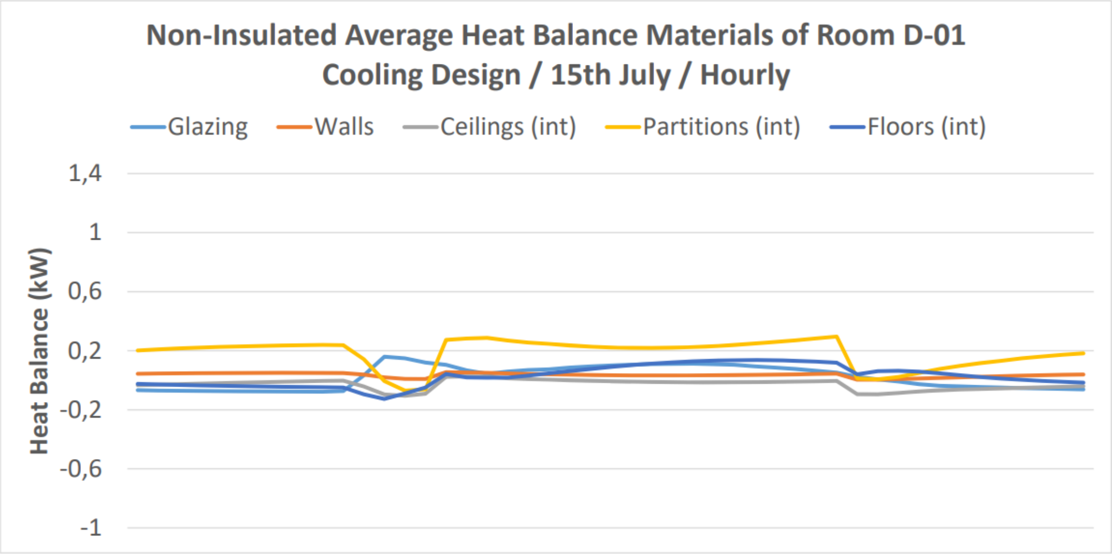
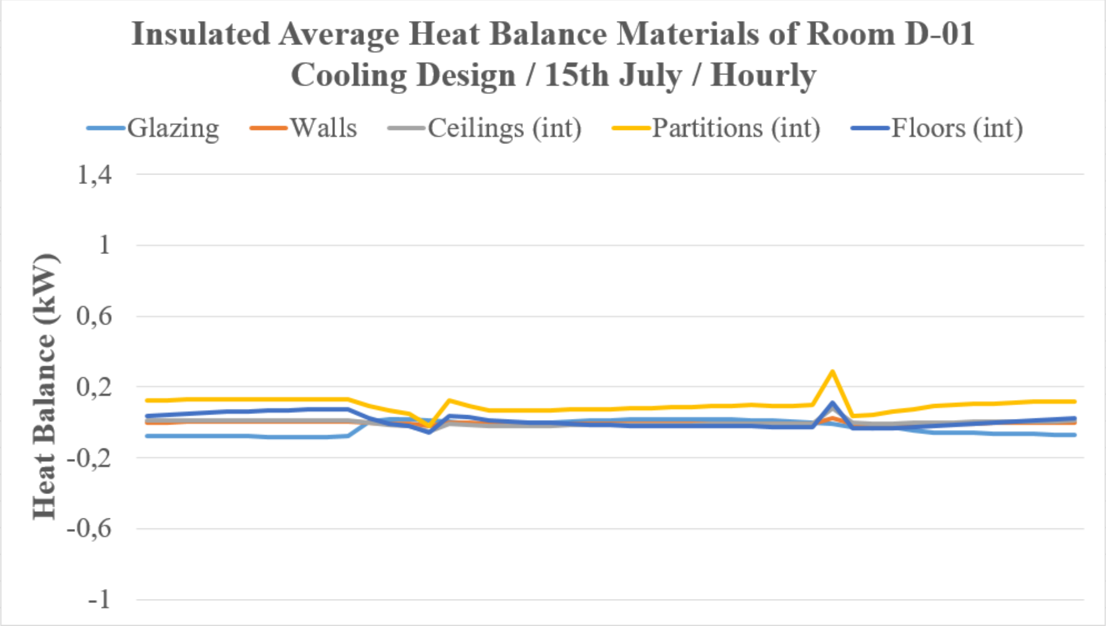
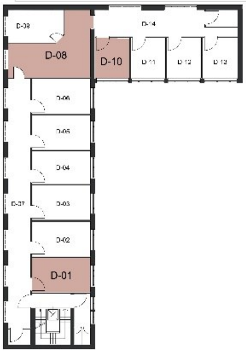


Table 8.38. Non-Insulated and Insulated cooling design heat balance of rooms E-14 in 15th of July







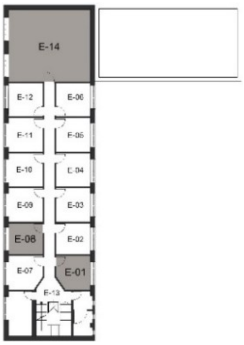
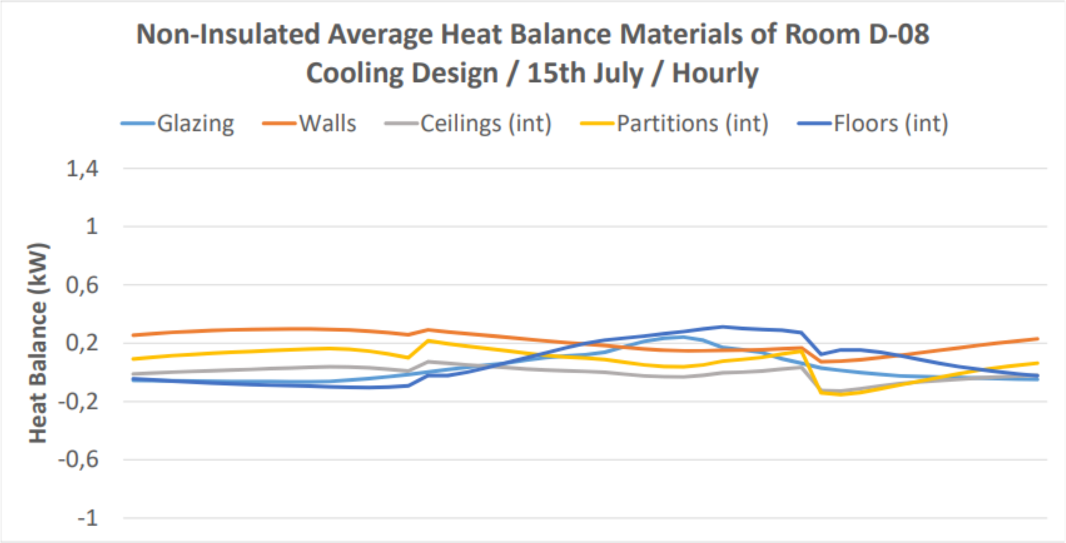
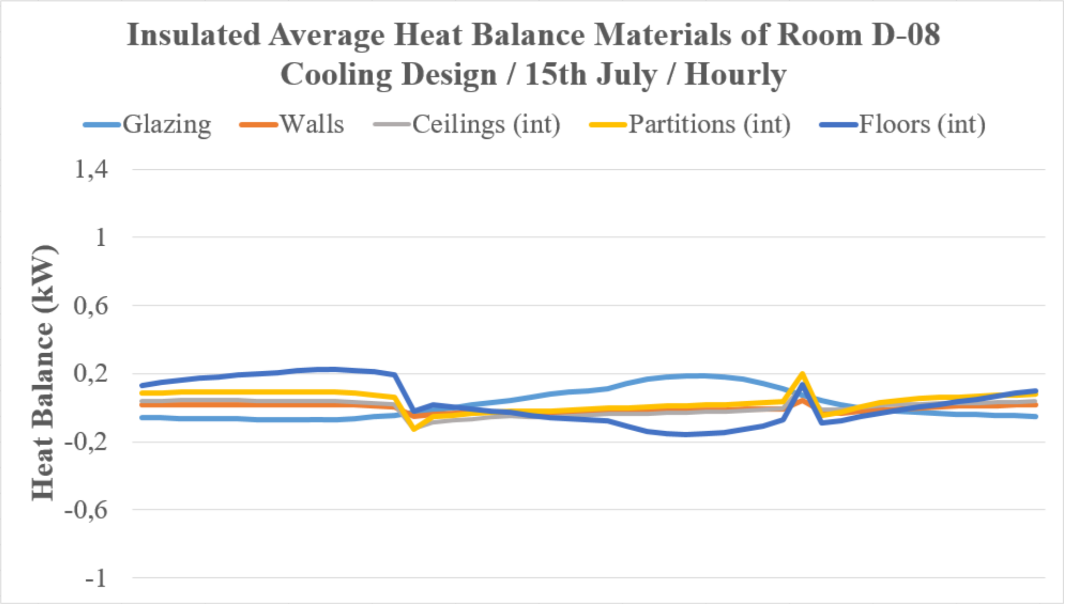
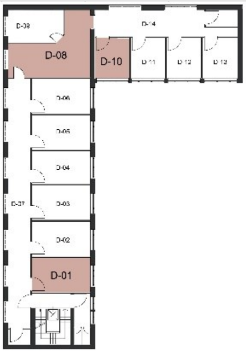


Table 8.39. Non-Insulated and Insulated cooling design heat balance materials of room D-01 in 15th of July







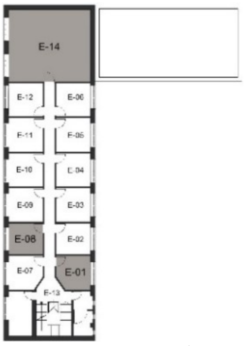


Table 8.40. Non-insulated and Insulated cooling design heat balance materials of room D-08 in 15th of July

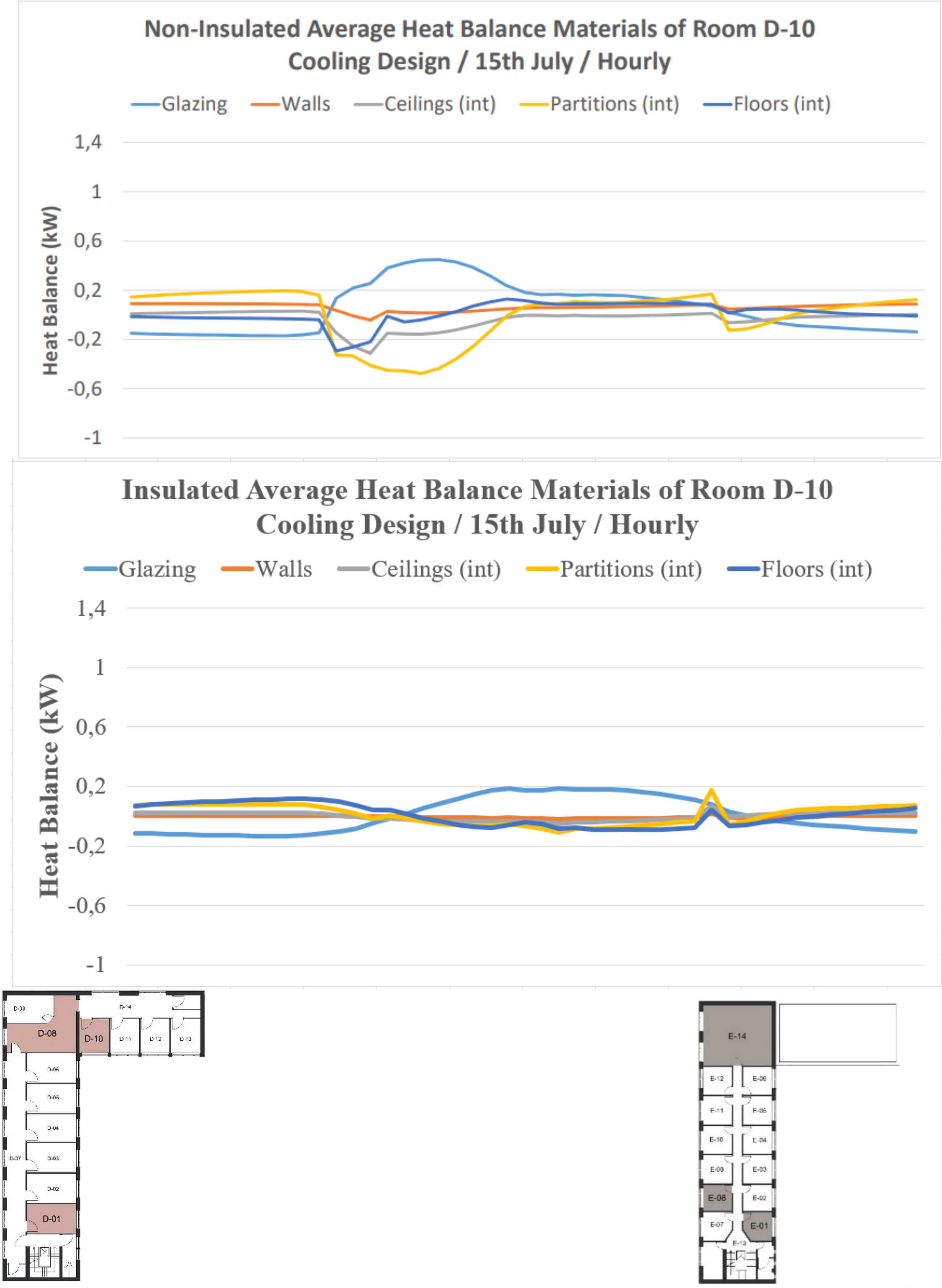


Table 8.41. Non-insulated and Insulated cooling design heat balance materials of room D-10 in 15th of July

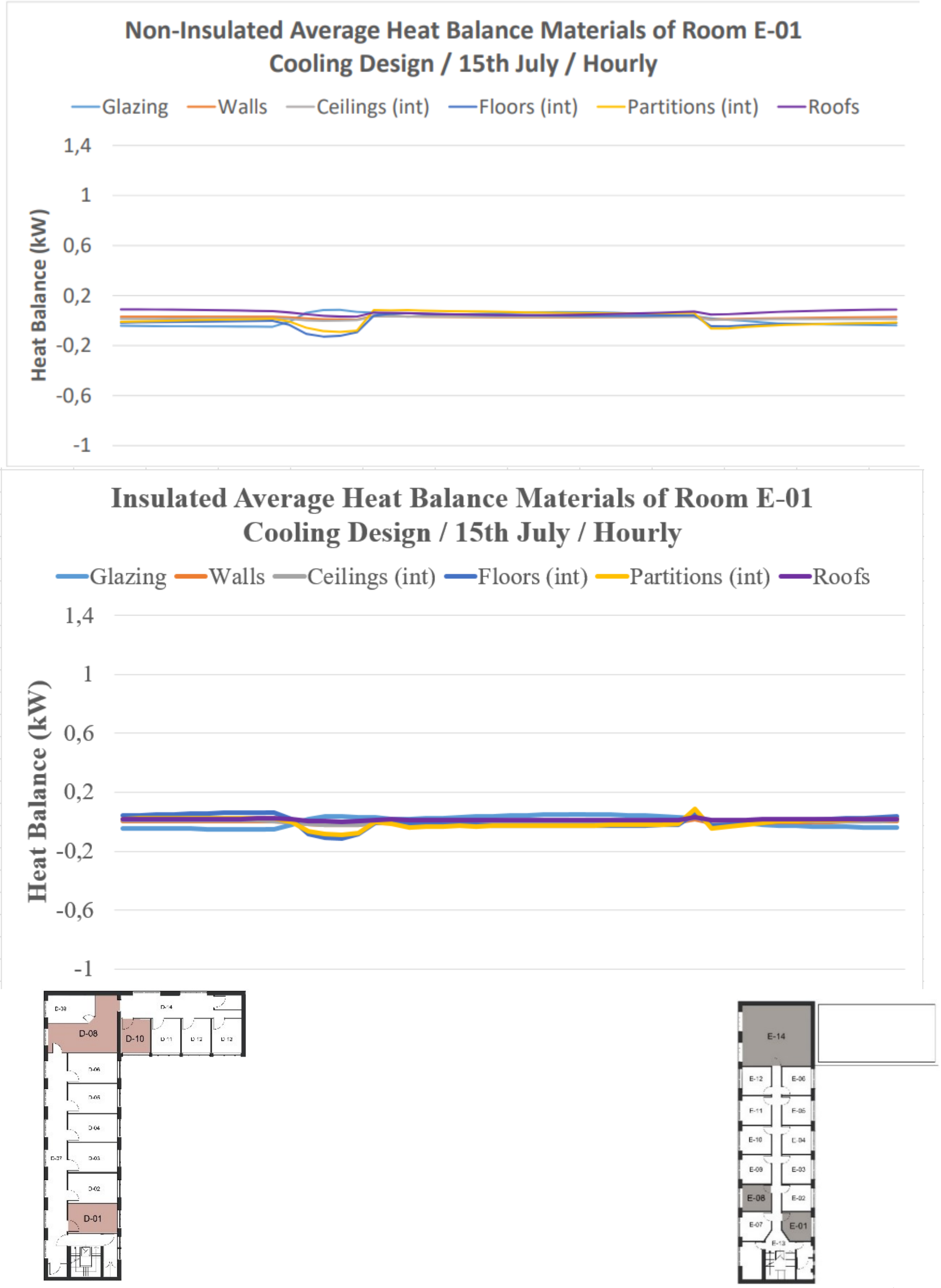
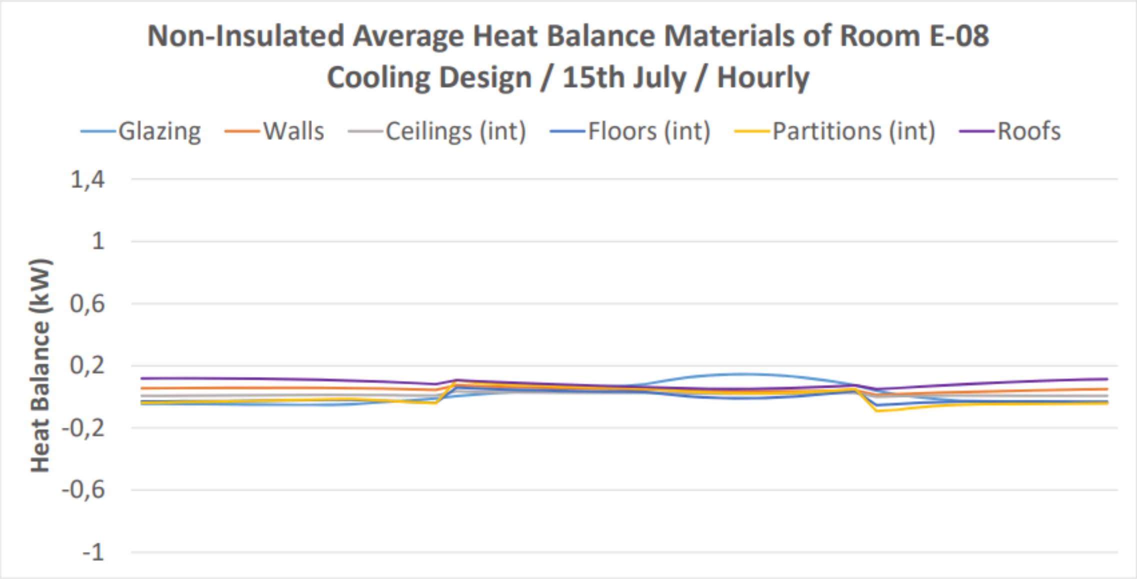
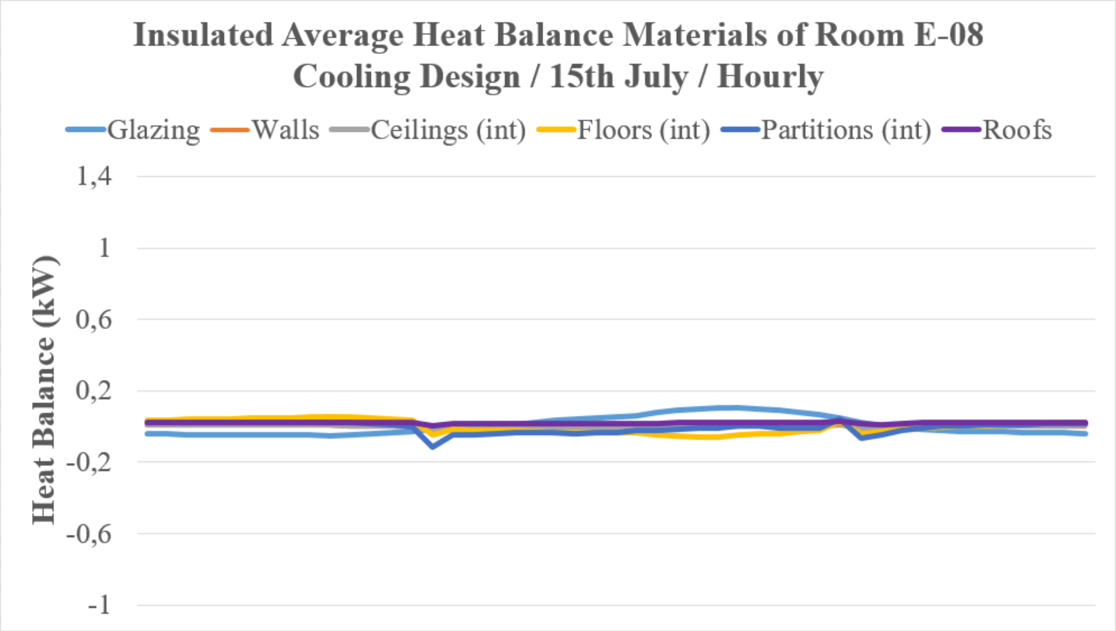
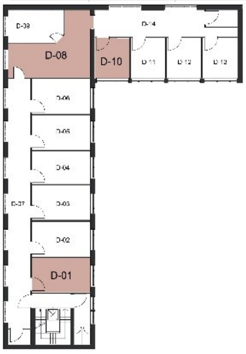


Table 8.42. Non-Insulated and Insulated cooling design heat balance materials of room E-01 in 15th of July







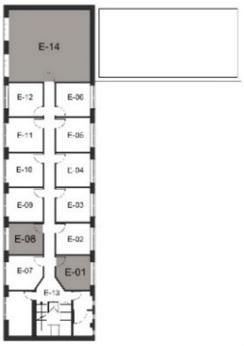
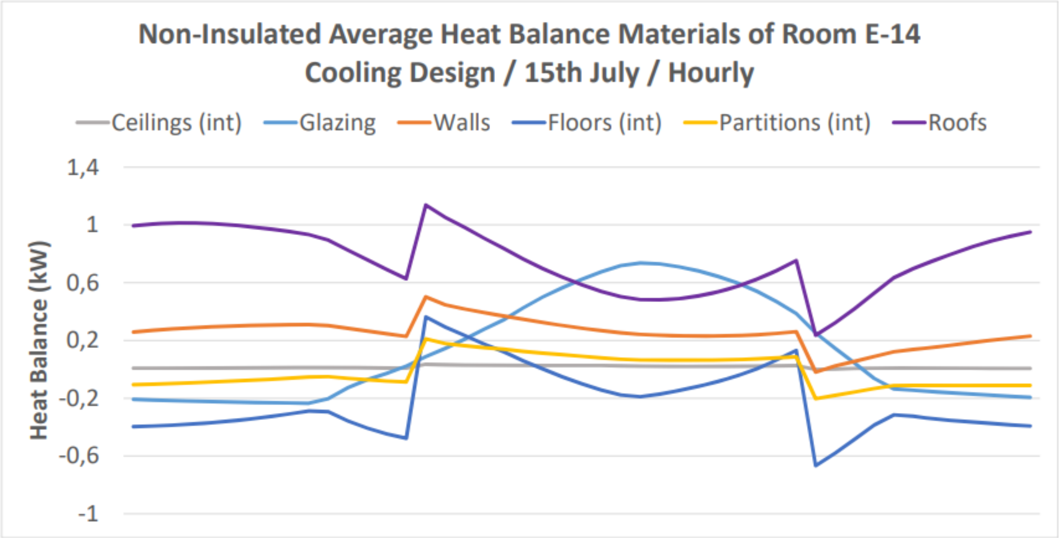
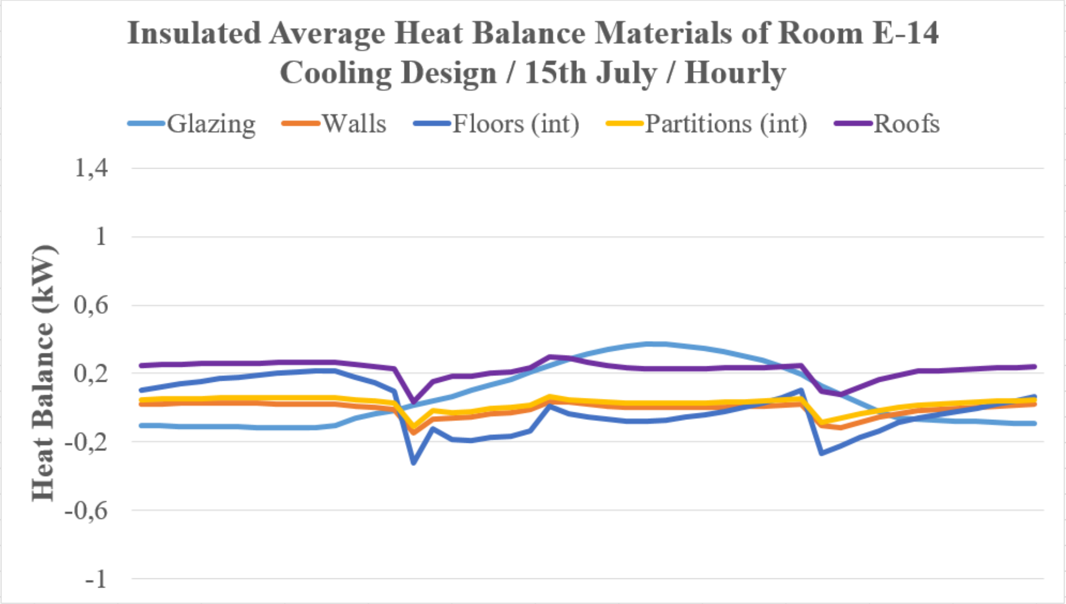
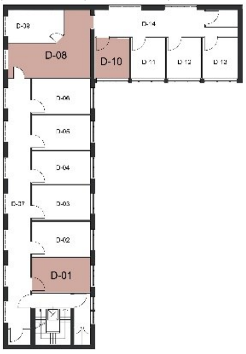


Table 8.43. Non-Insulated and Insulated cooling design heat balance materials of room E-08 in 15th of July







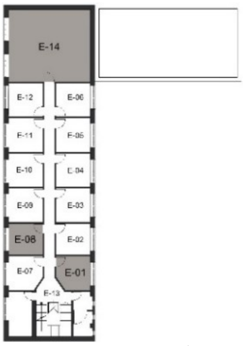


Table 8.44. Non-Insulated and Insulated cooling design heat balance materials of room E-14 in 15th of July

9. Result of Case Study of Energy Department Building

In this particular case study, the HVAC systems, daylighting, artificial lighting of the office rooms situated on the top two floors (3rd and 4th floor), comprising six rooms within the Energy Department of Politecnico di Torino, have been subject to analysis, as evidenced by figure 8.6. The investigation spanned the coldest month of January and the hottest month of July, encompassing both the current non-insulated configuration and a prospective insulated scenario, evaluating heating, natural ventilation, and air conditioning dynamics. Additionally, daylight and artificial lighting were scrutinized across six office rooms situated on various facade orientations, accounting for differing densities in both summer and winter conditions. The analyses revealed that during the summer months, especially in July, the cooling system maintains an optimal air temperature of 27 degrees Celsius in both insulated and uninsulated buildings. In the non-insulated state, room D-10 reached 30°C in July with cooling activated. However, with insulation, the temperature was maintained at 27°C, meeting regulatory standards as shown in Table 8.8.Nonetheless, as indicated in Table 8.8, the incorporation of newly insulated materials facilitates a quicker attainment of the desired air temperature within the building. Moreover, as illustrated in Tables 8.11 and 8.12, the utilization of insulation in the building enables natural ventilation to achieve the desired interior temperature of 27 degrees Celsius, while ensuring it remains below 30 degrees Celsius. Therefore, while insulated structures demonstrate notable energy savings during summer due to the efficacy optimal interior temperature with natural ventilation, necessitating the activation of the heating system throughout the winter months. The seasonal dynamics of thermal conditions and emphasize the importance of building materials in maintaining a consistent and comfortable temperature for occupants throughout the year.

The minimum daylight factor was required to be 1% under the previous daylight regulation, the CAM 2017 regulation requires this obligation to be 2%. A daylight assessment was carried out for six rooms and the average daylight factor on cloudy days was as follows: rooms D-01, D-08, D-10 and E-14 exceeded the 1% threshold and both rooms D-10 and E - 14 exceeded the 2% threshold and met the minimum criteria specified in both regulations. On the contrary, as shown in Table 8.12, it was observed that rooms E-01 and E-08 remained below these thresholds and the values did not reach the sufficient point, remaining below 0.4%. The analyses were carried out in the absence of shading and shading systems that are presently utilized on the windows. Subsequently, conclusions were drawn based on these analyses, as outlined in Table 8.14. and according to the findings presented in the table, it is suggested to introduce a new diffusing shade roll in the semi-office corridor of room D-08, in addition to the shading already employed in room D-10 because of the high illuminance (lux) in July which was from 1640 lux with no shading to 220 lux with closed shading for room D-08 and E-14 meeting room's skylight which is located on the south façade's shading result was from 796 lux to 745 lux which the value is still too much for an office room because it is suggested 300-500 lux for an office room according to the average light level for offices, while it is a minimum of 500 lux and 100 lux for circulation areas. D-08 is a semi-office space so it could be suggested shade roll. Therefore, it is recommended to replace the existing diffusing shade roll with a high reflectivity blind in the ceiling windows of the E-14 meeting room, based on the observed results.

The impact of shading on the daylight illuminance of the six rooms is evident from Table 8.21. The maximum daylight illuminance levels have decreased as follows:

- Room D-01: from 510 lux to 380 lux
- Room D-08: from 1642 lux to 220 lux
- Room D-10: from 782 lux to 548 lux
- Room E-01: from 220 lux to 183 lux
- Room E-08: from 580 lux to 250 lux
- Room E-14: from 796 lux to 745 lux.

Per the regulation, the Window-to-Floor Ratio (WFR) must be a minimum of 0.125. The average daylight factor and window-to-floor ratio (WFR) are presented jointly in Table 8.16. Despite rooms E-01 and E-08 failing to achieve the target daylight factor of 1%, their WFR values reach 0.18, surpassing the required minimum of 0.125. Room E-14 exhibits a daylight factor of 3.4%, yet its WFR stands at 0.1. This discrepancy arises from the room's large floor area coupled with inadequate window coverage, despite receiving significant solar gain from the southern skylight.

The term "sDA300/50%" refers to Spatial Daylight Autonomy, representing the percentage of the area receiving a minimum illuminance level of 300 lux for 50% of the operational hours per year. Based on this criterion, the Spatial Daylight Autonomy for rooms D-01 and D-08 is deemed average, while for rooms D-10 and E-14, it is classified as high. However, rooms E-01 and E-08 exhibit poor Spatial Daylight Autonomy due to the window heights. Notably, all rooms, except for room E-01, meet the required threshold for Useful Daylight Illuminance (UDI). Room E-01 falls short at 40%, as indicated in Table 8.20.

Three types of artificial lighting of six office rooms at the Energy Department of Politecnico di Torino. The findings revealed that in January, room D-01 experienced the least solar gain, approximately 10 kWh, while room D-08 had the highest, reaching around 48 kWh. Room D-08 had the lowest Lighting Power Density (LPD) at 300W/m². The recommended illuminance range by the International Commission on Illumination (CIE) for optimal workspace conditions is 700 to 1000 lux. Illuminance levels of 500 lux and 750 lux were calculated. Solar gains from exterior windows and artificial lighting during working hours were examined, revealing that room E-14 had the highest solar gain, while rooms E-01 and E-08 had lower gains. Consequently, artificial lighting schedules were adjusted based on these observations.

The transition from 500 lux to 750 lux yields the following illuminance ranges for the respective rooms:

- Room D-01: 2,300 to 1,500 lux
- Room D-08: 630 to 420 lux
- Room D-10: 3,400 to 2,270 lux
- Room E-01: 2,000 to 1,400 lux
- Room E-08: 2,000 to 1,300 lux
- Room E-14: 2,700 to 1,800 lux.

The analysis indicates that incorporating insulation positively impacts the overall heat balance in the building. While the unchanged windows maintain a consistent effect, improvements are noted in other materials. Activating the heating system ensures a satisfactory interior temperature of 19 degrees Celsius, while insulation enhances cooling effectiveness, achieving temperatures of up to 27 degrees Celsius. Insulated materials facilitate energy conservation in summer through natural ventilation, without cooling system, but may not suffice for winter conditions when heating is off. The heat balances of materials for meeting room E-14 as current non-insulated scenario, the heat balance for the roof of meeting room E-14 is approximately 1.2 kW. However, upon the implementation of insulation material, this value undergoes a significant reduction to approximately 0.2 kW therefore it can be suggested to put insulation material for roof.

10. Conclusion

Office rooms play a pivotal role in the well-being of workers, both physically and psychologically. Physically, the design and environment of office spaces significantly impact factors such as posture, ergonomics, and overall comfort, which can directly influence employees' physical health and reduce the risk of musculoskeletal issues. Furthermore, factors like air quality, temperature, and lighting within office rooms can affect workers' concentration, productivity, and mood. Psychologically, office environments can impact stress levels, motivation, and job satisfaction. A well-designed office space that promotes collaboration, provides access to natural light, and incorporates elements of biophilic design can foster a sense of well-being and connection to the workspace, ultimately enhancing employee morale and performance. Therefore, creating conducive office environments that cater to the physical and psychological needs of workers is essential for optimizing productivity and promoting overall workplace satisfaction.

The case study of Energy Department of Politecnico di Torino comprising six rooms within the HVAC systems, daylighting, artificial lighting, of the office rooms situated on the top two floors (3rd and 4th floor). While the study reveals satisfactory outcomes in some office rooms, indicating successful implementation of sustainable practices, discrepancies persist in others, highlighting areas for further improvement. It highlights the need for thoughtful design considerations, including the use of insulated materials, optimization of natural daylight, and strategic deployment of artificial lighting, to create a conducive and balanced office environment that positively impacts the occupants both physically and psychologically. Moving forward, continued examination and refinement of these systems serve as the foundational steps towards achieving sustainable, occupant-centric building environments.

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