VELUX®

Daylight, Energy and Indoor Climate Basic Book

2nd edition June 2010

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Preface & introduction

Preface

Daylight, Energy and Indoor Climate at the heart of the VELUX brand

Daylight and fresh air have been at the core of our business since the company started in 1942. By bringing daylight and fresh air into people's homes, the VELUX Group has contributed to create spaces with high quality and to increase the health and well-being of the occupants.

Today, the benefits of VELUX products are more important than ever before. Health and well-being constitute one of the most important agendas of the future and an increased focus on energy savings must not jeopardize the indoor climate.

A good indoor climate, with generous daylight levels and provision of fresh air from outside, is the key to making homes, offices, kindergartens and schools etc. healthy. Yet, there is great potential for improvement on indoor climate in the world's buildings: In the EU today, we spend 90% of our time indoors [1]. But up to 30% of the building mass neither contributes to nor provides a healthy indoor climate [2]. Can we do better then? Can we design buildings that do not compromise the global climate while providing a healthy indoor climate? With our products and the way they are used, the VELUX Group wishes to encourage and contribute to more sustainable ways of creating buildings. We call it Sustainable Living – and call for a holistic view that takes energy efficiency, healthy indoor climate and the use of renewable energy into account.

Why this Daylight, Energy and Indoor Climate Book?

Through this book, we aim to share insights and knowledge by giving specific advice and concrete documentation on the effects and benefits of VELUX products in buildings. In connection with creating new buildings – as well as by renovating existing buildings – the specific solutions need to be considered in a holistic perspective – where usage, personal needs, function, location, orientation, building geometry and window configuration play very important roles.

Daylight, Energy and Indoor Climate Basic Book
2nd edition June 2010

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Introduction

Indoor climate in a historical perspective

Daylight and ventilation by windows are inseparably connected to indoor climate. Indoor climate encompasses all the elements: temperature, humidity, lighting, air quality, ventilation and noise levels in the habitable structure.

We spend most of our time indoors. Yet the indoor environment is discussed much less than the outdoor environment. The presumption is that we are safe indoors. Buildings provide shelter, warmth, shade and security; but they often deprive us of fresh air, natural light and ventilation.

The positive health effect of light, in this case of sunlight, was acknowledged by the Egyptians, ancient Greeks and Romans, each of whom worshipped their own sun god. Much later, at the beginning of the 1900s, sunlight as a healer was put to practical use. Sanatoria were built for light therapy for people suffering from skin diseases, among other ailments.

The importance of the indoor environment, and of indoor air quality in particular, was recognized as early as the first century BC. However, it was not until the early decades of the twentieth century that the first relations between parameters describing heat, lighting and sound in buildings and human needs were established. In fact, the last hundred years have seen much effort put into management of the indoor environment with the goal of creating healthy and comfortable conditions for the people living, working and recreating in them.

In the late 19th century, the environmental factor 'thermal comfort' was introduced as being part of the overall concept of indoor comfort. It was recognized that poorly ventilated rooms, besides being responsible for poor air quality, could also result in unwanted thermal effects both through temperature and humidity.

Although we spend our time indoors, we are still "outdoor animals" [3]. The forces, which have selected the genes of contemporary man, are found in the plains, forests and mountains, not in centrally heated bedrooms or ergonomically designed workstations. We have adapted to the life indoor, but our gene code is still defined for outdoor life. Sick building syndrome, winter depressions, asthma, allergies, etc. are symptoms linked to the quality of the indoor environment as regards our biological needs. It is imperative that buildings and spaces where we spend much of our time are designed with those needs in mind; going back to nature, with natural ventilation and natural lighting.

How to evaluate the quality of the indoor climate?

There are no general methods that describe "everything" in a formula or in a single number. There are several indicators for how we can support our biological and physiological needs; ventilation rate for natural ventilation, daylight levels to be achieved, solar radiation exposure levels, comfortable temperature levels, relative humidity levels, sound levels etc. The chapters of this book will explain the individual indicators and give advice on specific levels that should be achieved to meet a good indoor climate.

It is, however, just as important to evaluate the indoor environment with our senses; do we feel well indoors? Human factors, including physiology, perception, preferences, and behavior make every individual a very accurate sensor. The indoor environment is more than the sum of its parts, and its assessment has to start from human beings.

Indoor climate and health

The human senses, "windows of the soul" [4], are basically the instruments we have to report or indicate whether we feel comfortable in the indoor environment and how we feel our health is affected by it. We judge the indoor environment by its acceptability with respect to heat, cold, smell, noise, darkness, flickering light and other factors. But in terms of health effects, it is not just the human senses that are involved, but the whole body and its systems. Indoor environmental stressors that can cause discomfort and health effects comprise both environmental and psycho-social factors, such as working and personal relationships. However, the greatest impact on our health from the indoor environment comes from the availability and quality of daylight and fresh air.

The prevalence of diseases like allergies and asthma is increasing rapidly. This trend is attributed to changes in the indoor environment, but there is still limited understanding of the specific causes. Presently, the only solid conclusion is that humid buildings are a cause.

Sunlight is a natural anti-depressant, which helps us synchronize with the natural rhythm of life and direct sun and high daylight exposure levels are shown to be effective for preventing winter depressions.

Indoor climate and energy consumption

The focus on energy savings is increasingly challenging the existing building stock as well as new and future buildings, as energy consumption is believed to result in climate changes. It is, however, important to remember that all energy in buildings is used to serve people's needs, comfort and well-being. The VELUX Group considers "Sustainable Living" as a way of making the changes to limit the environmental impact at home without compromising on the quality of the indoor environment.

Optimal use of daylight, natural ventilation during summertime, and intelligently controlled solar shading are all examples of technologies, which – in combination with intelligent building design – can be used to reduce the energy consumption of new and existing buildings.

It is all about the sun; without solar radiation there will be no light, no wind, no heat, no life. And the solar radiation reaching the ground is far larger than the energy needed. Solar energy is often viewed as a set of niche applications with a useful, but limited potential. However, it is the only supply-side energy solution that is both large enough and acceptable enough to sustain the planet's long-term requirements; the available solar energy exceeds the world´s annual energy consumption by factor 1500 [5]. Fossil fuels like oil and coal alone could fulfil our energy needs for another three or four generations, but would do so at a considerable environmental cost [5].

Environment

The production, disposal and use during the lifetime of VELUX products potentially impact the environment in other ways than through climate change, and materials like wood, glass and aluminum should be used with the environmental impact in mind. Life Cycle Assessment is used in the VELUX Group to evaluate the impact of products on the environment.

Activities and initiatives by the VELUX Group with specific focus on Daylight, Energy and Indoor Climate:

Model Homes 2020

Looking into a future perspective of how we construct and renovate buildings, it is necessary to consider climate changes, the resource situation and the health of this and coming generations. These challenges should be tackled as one.

The VELUX Group has devised a strategy to take an active part in developing sustainable buildings. Part of this strategy is the project Model Home 2020 – our vision for how we should construct future buildings that reflect the balance between energy design and livability, thus creating optimal indoor climate through a dynamic building envelope that is climate neutral and meets regulatory standards.

The vision and principles behind Model Home 2020 need to be developed and tested; from 2009 to 2011, we will build six full-scale experiments. They will all reflect and respond to three main principles – efficient energy design, high degree of livability and minimum climate impact – as well as the different climatic, cultural and architectural conditions of the countries in which they are built. The projects reflect the Active House principles, the paradigm of the next generation of building construction.

Our innovation philosophy is to be progressive by making 1:1 experiments of our vision for sustainable buildings: "You never change things by fighting the existing reality. To change something build a new model that makes the existing model obsolete." Buckminster Fuller.

http://www.velux.com/Sustainable_living

Active House – a vision of buildings that give more than they take

The VELUX Group is among the initiators of the Active House vision of buildings that create healthier and more comfortable lives for their occupants without negative impact on the climate – moving us towards a cleaner, healthier and safer world. The Active House vision defines highly ambitious long-term goals for the future building stock. The purpose of the vision is to unite interested parties based on a balanced and holistic approach to building design and performance, and to facilitate cooperation on e.g. building projects, product development, research initiatives and performance targets that can move us further towards the vision.

An Active House is evaluated on the basis of the interaction between energy consumption, indoor climate conditions and impact on the environment:

Energy – Contributes positively to the energy balance of the building

An Active House is energy efficient and all energy needed is supplied by renewable energy sources integrated in the building or from the nearby collective energy system and electricity grid.

Indoor Climate – Creates a healthier and more comfortable life

An Active House creates healthier and more comfortable indoor conditions for the occupants and the building ensures generous supply of daylight and fresh air. Materials used have a positive impact on comfort and indoor climate.

Environment – Has a positive impact on the environment

An Active House interacts positively with the environment by means of an optimized relationship with the local context, focused use of resources, and focus on its overall environmental impact throughout its life cycle.

http://www.activehouse.info/

VELUX Daylight Symposiums

The VELUX Daylight Symposiums, held every 2nd year since 2005, have created a reputable and internationally recognized platform for the exchange of knowledge, viewpoints and visions regarding daylighting. The symposiums allow ample space for discussion of theory and practice – defining a "common language" – discussing how to define daylight quality in buildings and how to achieve daylight quality in projects.

Worldwide interest in daylighting has been renewed considerably to meet future challenges in relation to energy efficiency, and a growing movement towards sustainable buildings has established a hopeful target for buildings to reach energy self-sufficiency in the near future. At the same time, medical research is focusing more on light and its effect on human health and a unified understanding of light and its impact on human beings has evolved; in general, buildings using daylight are healthier places to live in.

The programmes provide the latest updates on the scientific progress in the field as well as experiences and viewpoints from architectural practices. The programmes also include separate sessions addressing particular aspects of daylighting as well as open discussions between the speakers and the audience.

http://www.thedaylightsite.com

Daylight & Architecure – VELUX Magazine

Daylight and Architecture is the VELUX Group's magazine to architects, designers, building professionals and everyone else with interest in daylight in architecture. The magazine started in 2005 and has been published two to three times per year since then.

With the magazine we want to create a communication platform where we set up topics that are relevant for architects and bring into focus the importance of daylight when creating better living conditions for people.

The magazine features in-depth articles from internationally renowned professionals on the themes of daylight & architecture. Every issue has a specific theme depicted in articles and pictures from scientific as well as artistic angles. The red thread through the magazine relates to current strategic topics on the "VELUX agenda". This means that D&A brings into focus indoor climate, sustainability, resource efficiency and low energy consumption. This is part of the VELUX strategy to put sustainable living on the agenda.

http://da.velux.com/

The International VELUX Award for students of architecture (IVA)

The International VELUX Award took place for the first time in 2004 and since then the Award has been organized every second year. The award is open to students from all over the world and encourages students of architecture to explore the theme of sunlight and daylight in its widest sense to create a deeper understanding of this specific and ever relevant source of light and energy.

With the Award, the VELUX Group wants to pay tribute to daylight and to strengthen the role of daylight in building design according to our vision of promoting daylight, fresh air and quality of life. Within the overall theme "Light of Tomorrow" the Award seeks to foster new thinking with regard to how daylight, fresh air and quality of life can be realized through design to provide insight into the evolution of ideas and potential trends in relation to daylight and architecture.

The Award is organized in close collaboration with the International Union of Architects (UIA) and the European Association for Architectural Education (EAAE). Today the award is recognized as the most prestigious international competition for architectural students.

http://iva.velux.com/

Daylight

Daylight

Daylight has been used for centuries as the primary source of light in interiors and has been an implicit part of architecture for as long as buildings have existed. Not only does it replace electrical light during daytime, reducing energy use for lighting, but it also influences both heating and cooling loads which makes it an important parameter of an energy efficient design. Additionally, recent research has proved that daylight provides an array of health and comfort benefits that make it essential for buildings' occupants.

1.1 Daylight

Daylight is described as the combination of all direct and indirect light originating from the sun during daytime. Of the total solar energy received on the surface of the earth, 40% is visible radiation and the rest is ultraviolet (UV) and infrared (IR) wavelengths, as shown in Figure 1.1.

While certain electrical light sources can be constructed to match a certain spectrum of daylight closely, none have been made that mimic the variation in the light spectrum that occurs with daylight at different times, in different seasons, and under different weather conditions [6]. Figure 1.2 shows the spectrums of two typical electrical light sources used in dwellings which do not match the quality and richness found in the spectrum of daylight.

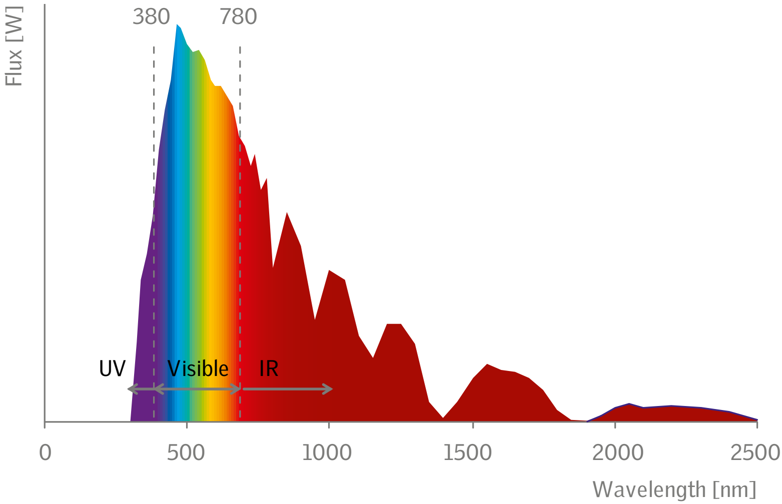


Figure 1.1. Diagram of the electromagnetic spectrum showing the location of the visible spectrum.

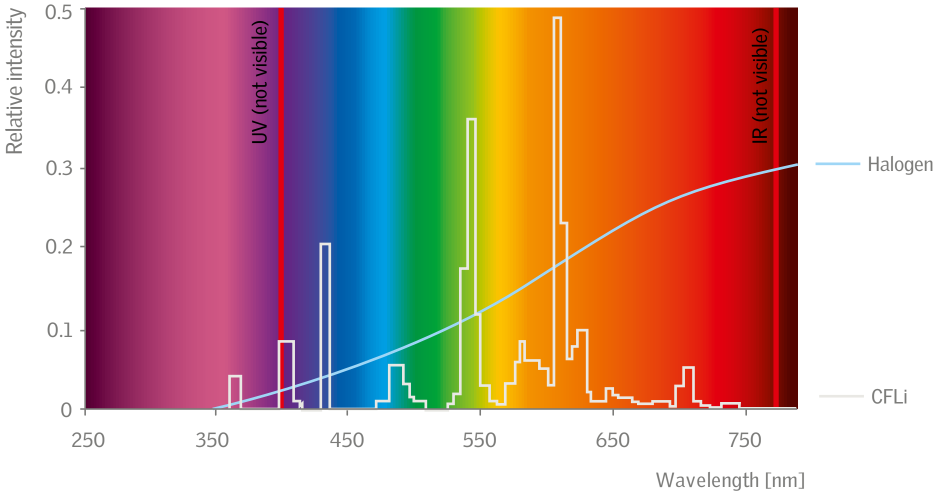


Figure 1.2. Spectral composition of two typical electrical light sources , halogen and low energy compact fluorescent lamp (CFLi) [7].

Remember

Of the solar energy received on the surface of the earth, 40% is visible light and the rest is ultraviolet (UV) and infrared (IR) wavelengths.

There are no electrical light sources which can mimic the qualities of daylight.

1.2 Daylighting

Daylighting can be defined as the practice of placing windows and reflective surfaces in buildings so that daylight provides adequate light during daytime.

The goals of room daylighting are to adequately illuminate visual tasks, to create an attractive visual environment, to save electrical energy and to provide the light needed for our biological needs. A good luminous environment is simultaneously comfortable, pleasant, relevant, and appropriate for its intended uses and users [8].

Daylight in buildings is composed of a mix – direct sunlight, diffuse skylight, and light reflected from the ground and surrounding elements.

Direct sunlight is characterized by very high intensity and constant movement. The illuminance produced on the surface of the earth may exceed 100 000 lux.

Skylight is characterized by sunlight scattered by the atmosphere and clouds resulting in a soft and diffuse light. The illuminance level produced by an overcast sky may reach 10 000 lux.

Reflected light is characterized by light (sunlight and skylight) that is reflected from the ground: terrain, trees, vegetation, neighbouring buildings etc. The surface reflectance of the surroundings will influence the total amount of reflected light reaching the building façade.

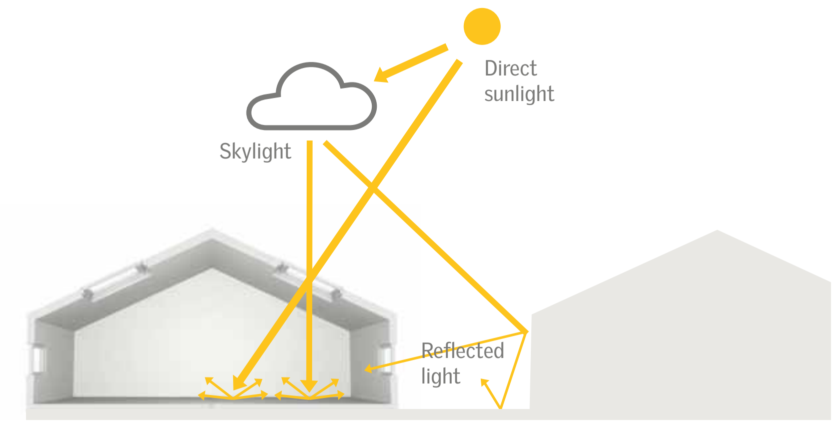


Figure 1.3. The components of daylight.

In some dense building situations, the light reflected from the ground and surroundings can contribute to a major part of the daylight provisions.

Daylighting systems can be simple - from combining window design with appropriate internal and external shading (e.g. external awning blind and internal Venetian blind) – to systems designed to redirect sunlight or skylight to areas where it is required (e.g. sun tunnels). More advanced systems can be designed to track the sun or passively control the direction of sunlight and skylight.

Daylighting is inseparably linked to the energy demand and indoor climate of a building. The size and placement of glazing should be determined together with the total energy use of the building and specific requirements for daylighting.

Remember

Daylight in buildings is composed of a mix – direct sunlight, diffuse skylight and light reflected from the ground and surrounding elements.

Light from the sun is intense and directional.

Light from the sky is soft and diffuse.

Light reflected from the ground can often account for 15% or more of the total daylight reaching a building façade.

» Good quality lighting should include lighting for health, in parallel with meeting the other needs of people who will occupy the space «

1.3 Daylighting quality

Until the late 1990s, lighting recommendations were based primarily on lighting needs for vision. In the recent years, the lighting community has adopted a broader definition of lighting quality including human needs, architectural integration, and economic constraints, as illustrated on Figure 1.4.

1.3.1 Visual needs

A good daylighting design will deliver high amounts of light without glare. Whereas a poor daylighting design will deliver either inadequate amounts of light so that electric lighting has to be used frequently, or high amounts of light together with glare [6].

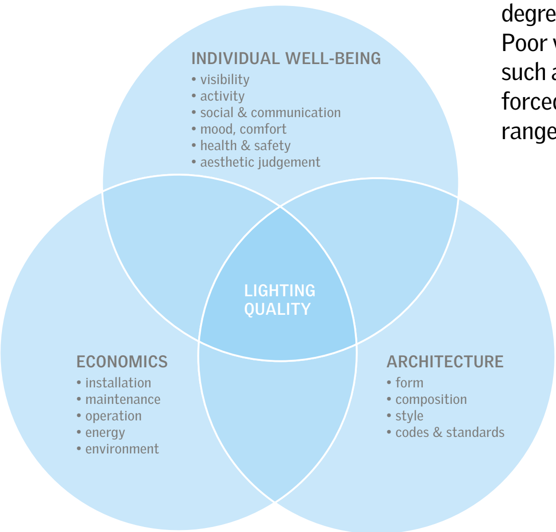


Figure 1.4. Lighting quality model [9].

Daylight availability

Daylighting should be designed to provide adequate light levels in the room and on the work plane so that daylight is the main/or only source of light (autonomous) during daytime.

Requirements for daylighting are still missing in terms of specific illuminance levels, but there is enough evidence in literature to indicate that illuminances in the range of 100 to 2500 lux are likely to result in significant reduction of electrical lighting usage [10].

Visual comfort

The light variation within your field of view can influence visual comfort and performance. For good visibility, some degree of uniformity of light is desirable. Poor visibility and visual discomfort, such as glare, may occur if the eye is forced to adapt too quickly to a wide range of light levels.

Too high or too low contrasts can also result in tiredness, headaches, discomfort etc. While specific guidelines for dwellings are not available, it is believed that luminance variations around 10:1 are suitable for daylighting design. Generally, the human eye can accept greater luminance variations when spaces are lit by daylight than when they are artificially lit.

The sensation of glare can occur when luminance variations exceed 20:1 to 40:1 [11]. In the case of glare, the eye adapts to the high level of the glare source, which makes it hard to perceive details in the now "too dark" work area. The Figure 1.5 below shows a situation where glare is controlled by external solar shading (awning blind).

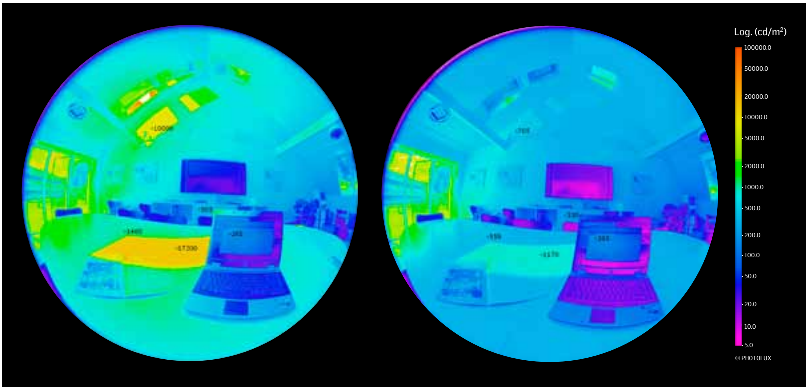


Figure 1.5. Luminance map of a task area showing sun patches causing glare.

Luminance map of task area showing glare control with external solar shading.

Remember

Daylight should provide enough light in the room and on the work plane to be the main or only source of light during daytime.

Occupants can accept greater luminance variations in spaces lit by daylight than if artificially lit.

Luminance variations around 10:1 are suitable for daylighting design.

The sensation of glare can occur when luminance variations exceed 20:1 to 40:1.

» Our body uses light as a nutrient for metabolic processes similar to food and water «

1.3.2 Non-visual needs

Daylight has a wide range of influences on humans which go far beyond our need of vision. When we speak about health, balance and physiological regulation, we are referring to the functions of the body's major health keepers: the nervous system and the endocrine system. These major control centres of the body are directly stimulated and regulated by light [12].

Circadian rhythms

Many aspects of human physiology and behaviour are dominated by 24-hour rhythms that have a major impact on our health and well-being. For example, sleep/wake cycles, alertness and performance patterns, core body temperature rhythms, as well as the production of the hormones melatonin and cortisol [13]. These daily rhythms are called the circadian rhythms and their regulation depends very much on the environment we live in. Figure 1.6 shows the production rhythms of the hormones melatonin and cortisol.

Daily light dose and timing

The non-visual effects of light are dependent on the intensity, spectrum, and timing of the light exposure. These characteristics are used as a first step towards prescriptions of healthy lighting in buildings [14].

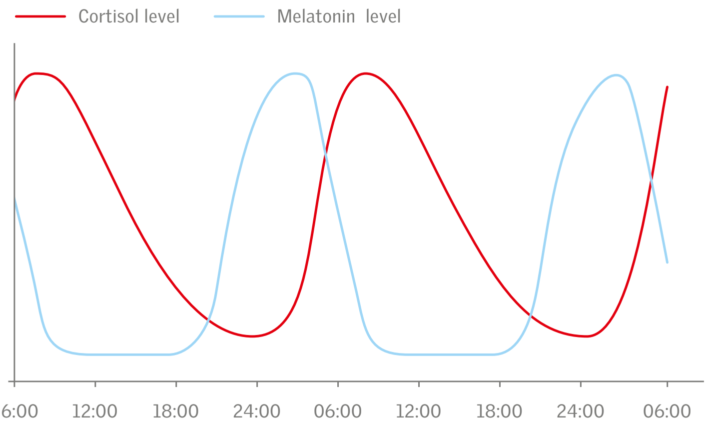


Figure 1.6. Production of the hormones melatonin and cortisol [15].

Specific requirements for different age groups also need to be taken into account. Adolescent and young adults have a somewhat delayed biological clock and need more light in the morning (bedroom, breakfast room, class room...), whereas older persons have a biological clock that has shifted earlier (often resulting in falling asleep in the evening and early morning awakening) [16].

Daylighting can deliver much higher levels of illumination than electrical lighting and can help significantly to increase the light dose received by people spending most of their time indoors.

Spectrum

Daylight is recognized to have the highest levels of light needed for the biological functions [17] compared with typical electrical light sources.

The circadian system (C(λ)) is most affected by the wavelength region 446 to 488 nm, whereas the visual system (V(λ)) is most affected by the wavelength around 555 nm, as shown in Figure 1.7. Figures 1.1. and 1.2 presented earlier shows that the spectral composition of daylight is much richer in these regions of the electromagnetic spectrum than typical electrical light sources.

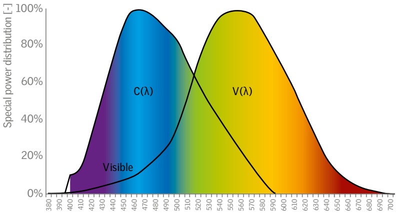


Figure 1.7. Circadian (C(λ)) and visual (V(λ)) systems response to light [13].

Light and darkness

The circadian system is linked to the light and dark cycles of nature (day and night). It is believed that healthy light is inseparably linked to healthy darkness which basically means that we need a high intensity of light during the day and a dark, blackout, room when we sleep.

Remember

People in modern societies do not receive enough light on a daily basis and need to be exposed to higher levels of illumination for longer durations.

We need a daily daylight exposure, because daylight is rich in the spectrum to which the non-visual system is most sensitive.

Daylit environments are preferred to electrically lit environments and facilitate better performance, productivity and learning.

Healthy light is linked to healthy darkness.

1.3.3 Need for a view

Meeting the need for contact with the outside living environment is an important psychological aspect linked to daylighting [19], and the provision of daylight alone is not enough to satisfy user desires for views including sky, horizon and ground [6]. Building interiors should be designed in a way, which permits to satisfy the human needs, linked to the natural environment by minimizing overshadowing and allowing distant views [16]. The size and position of window systems need to be considered carefully in relation to the eye level of the building occupants.

Figure 1.8. View from the living room of Atika, a concept house by VELUX.

Remember

The size and position of window systems need to be considered carefully in relation to the eye level of the building occupants.

1.3.4 Effects on building occupants

Performance and productivity

Daylighting has been associated with improved mood, enhanced morale, less fatigue, and reduced eyestrain [19]. Many studies show that the performance and productivity of workers in office, industrial, and retail environments can increase with the quality of light. Companies have recorded an increased productivity of their employees in the area of 15% after moving to a new building with better daylight conditions which resulted in considerable financial gains [12].

Studies also show that learning in daylit environments results in more effective learning. It was found that students in classrooms with the most window area or daylighting had 7% to 18% higher scores on the standardized tests than those with the least window area or daylight [20].

User satisfaction

Windows are highly valued by office workers in their workplace [12]. Surveys have shown that more than 60% of office workers wish to have direct sunlight in their offices at least one season during the year [21] and believe that working under natural daylight is better for health and well-being than electrical lighting [22]. Employees working in offices highly value access to a window and value it more than privacy in their office [23].

Seasonal Affective Disorder (SAD)

Seasonal affective disorder is a depression-related illness linked to the availability and change of outdoor light in the winter. Reports suggest that 0.4% to 9.7% of the world population may suffer from SAD, with up to three times that number having signs of the affliction without being classified as a major depression (primarily in Northern America and Northern Europe) [24]. Light therapy with exposure levels at the eye of between 2500 lux (for 2 hours) or 10 000 lux (for 30 minutes) has shown to be an effective cure against SAD [25]. Light therapy can also be used to treat other depression-related symptoms (non-seasonal depression, premenstrual, bulimia etc).

Remember

Daylit environments facilitate better performance, productivity and learning.

Light therapy with exposure levels at the eye of between 2500 lux (for 2 hours) and 10 000 lux (for 30 minutes) has shown to be an effective cure for SAD and other depression-related symptons.

1.4 Parameters influencing daylighting performance

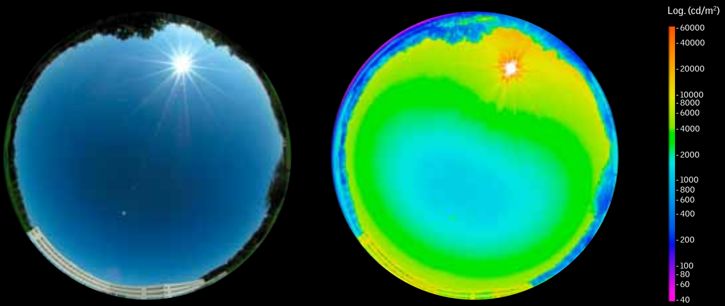
1.4.1 Location

Prevailing climatic conditions

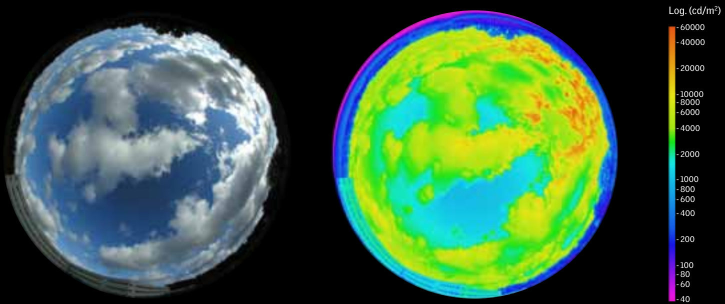
The prevailing climatic conditions of a building site define the overall preconditions for the daylighting design with regard to visual comfort, thermal comfort and energy performance. Figures 1.9 to 1.11 show the effect of climatic conditions on the sky luminous distribution and intensity.

Solar altitude

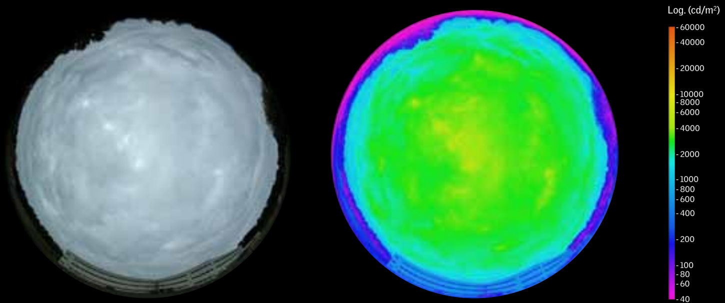
The location on earth determines the solar altitude for a given time of day and year. The summer and winter solar altitude properties for a specific location are important inputs for the design, especially with regard to control of direct solar radiation.



1) Figure 1.9. Luminance map of a clear sunny sky. The image above describes a clear sky luminance distribution. Under clear sky conditions, the sky luminance is about 10 times brighter at the horizon than the zenith. In addition to the sky luminance is the sun luminance. The sun acts as a dynamic light source of very high intensity.



2) Figure 1.10. Luminance map of an intermediate sky. The image above describes an intermediate sky luminance distribution. In this particular case, the sun energy has been scattered by the clouds, which results in a softer transition between the very intense luminance of the sun and the luminance of the sky. It's possible to observe that the clouds (illuminated by the sun) have higher luminance values than the sky.



3) Figure 1.11. Luminance map of an overcast sky. The image above describes an overcast sky luminance distribution. Under perfect overcast sky conditions, the sky luminance is the same in all orientations and the zenith is about 3 times brighter than the horizon.

1.4.2 Site properties

Reflections and obstructions outside the building

External reflections and obstructions from neighbouring buildings, vegetation, ground surface etc. will influence the amount of daylight reaching the interior. Reflections and obstructions from the building itself (volume, overhang, permanent shading etc.) will also affect daylighting performance. Roof windows are generally less affected by obstructions than facade windows, as illustrated in Figures 1.12 and 1.13.

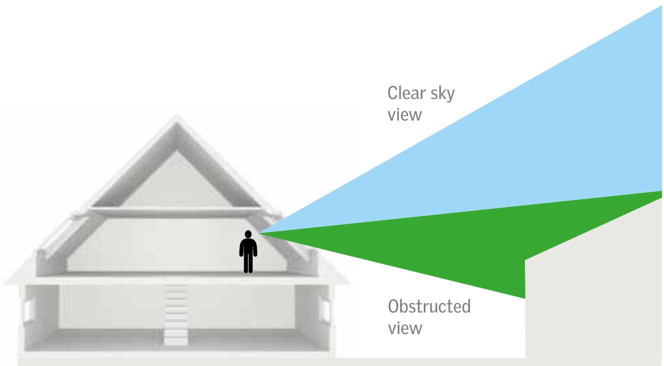


Figure 1.12. Components of view. Roof window situation.

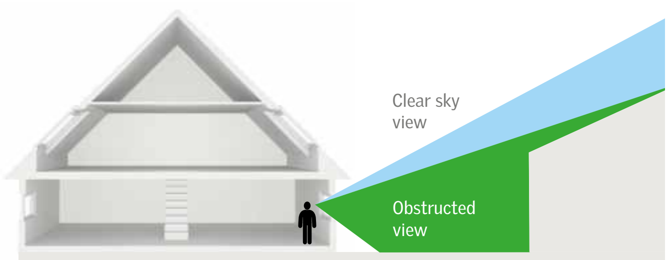


Figure 1.13. Components of view. Façade window situation.

Example: Effect of external obstruction on indoor daylight levels

The following example demonstrates the effect of external obstruction on daylight factor levels inside a residential building located in an urban environment. The figures below present the 3D models used for simulation in the VELUX Daylight Visualizer, in which the daylight factor (DF) levels were calculated for each storey.

Model properties
Glazing to floor area ratio: 20%
Pane visual transmittance τ_v: 0.78
Surface reflectance: internal walls 0.65, external walls 0.50, floor 0.30, ceiling 0.90, roof 0.30, pavement 0.25, grass 0.20.

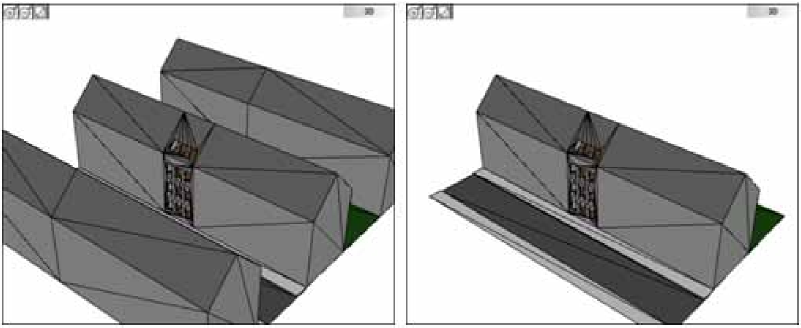


Figure 1.14. View of the 3D model used for simulations, with obstruction (left) and without obstruction (right).

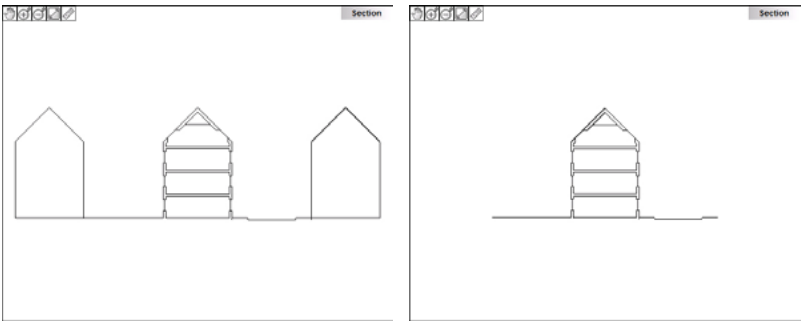


Figure 1.15. Section of the 3D model used for simulations, with obstruction (left) and without obstruction (right).

Results

The simulation results, presented in Figure 1.16, show that an external obstruction will diminish the average DF on each storey of the building, but the effect is much stronger on the lower storey of the building where the daylight availability is reduced by half. It is, therefore, very important to consider external obstructions in daylighting analyses. Results also demonstrate that external obstructions had little effect on the daylight availability in the attic lit by the roof windows. Even in urban environments roof windows can provide generous amounts of daylight since they are less influenced by external obstructions.

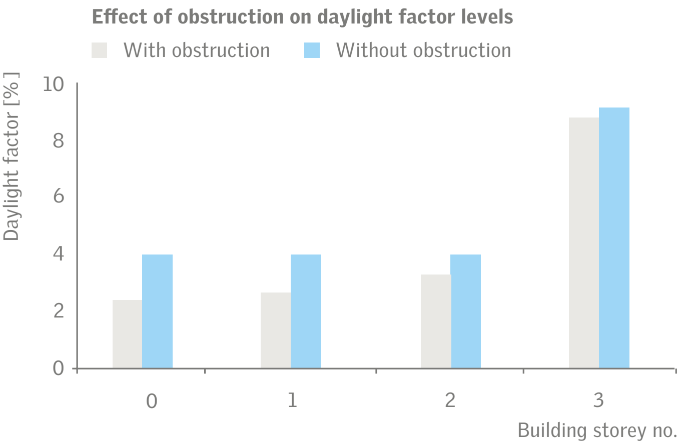


Figure 1.16. Comparison of the average daylight factor obtained for each storey of the building with and without external obstruction.

1.4.3 Orientation

The orientation of a building influences the availability and qualities of daylight in the interior. In the northern hemisphere, light coming from the north will in many cases be diffuse skylight and provide the interior with a functional and comfortable light, which will remain stable throughout the day. Light coming from the south, east and west orientations will in many cases provide the interior with direct sunlight and light levels that vary significantly throughout the day as the sun pursues its course inside the building.

Note that roof windows and skylights installed in low pitched roofs are likely to receive direct solar radiation even when facing north.

1.4.4 Building geometry

The geometry of a building influences its capacity to deliver adequate levels of daylight in the interior. When the building is deep, daylighting solely by façade windows has its limitations. No matter how much glass there is included in the façade, it will only be possible to achieve an adequate daylight distribution (DF > 2%) a few meters from the façade, as shown in Figure 1.17.

Measures like light shelves and reflective ceilings can improve the light dis tribution from the façade slightly, but these solutions are often associated with visual discomfort. The most effective way to bring daylight deeper into buildings is to use light from the roof with products like VELUX roof windows and sun tunnels.

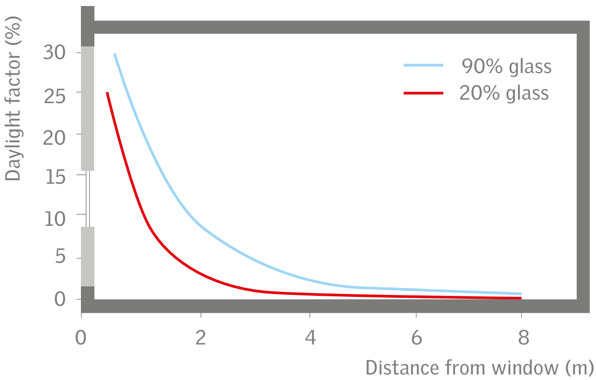


Figure 1.17. Daylight factor levels for two facade window configurations.

Example: Daylight in deep buildings

The simulations below demonstrate the daylight performance of a deep room with 3 different window configurations installed.

Room dimensions: 8m (d) x 4m (w) x 3m (h)
Pane visual transmittance (τ_v): 0.78
Surface reflectance: 0.35 (floor), 0.66 (wall), 0.90 (ceiling)

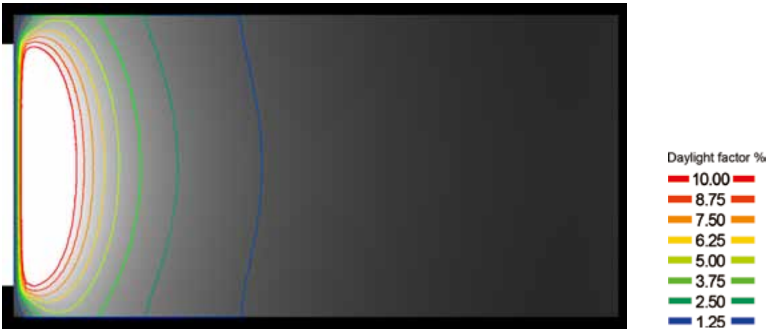


Figure 1.18. Luminance and daylight factor simulations of scenario 1.

1) Situation with 10% glazing to floor area ratio (façade window only).

The results from scenario 1 show that a 10% glazing to floor area ratio will only achieve a DF of 2% a few meters from the façade and leave the back of the room with very low light levels. Even though the average DF of the room is equal to 1.9%, only a small work plane area achieves values above 2%, and only 1 of the 3 workplaces represented can be considered daylit.

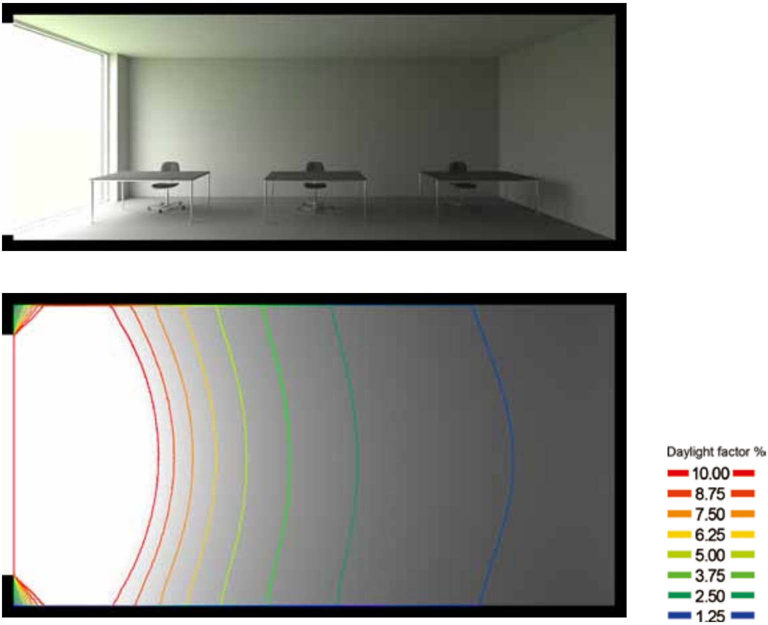


Figure 1.19. Luminance and daylight factor simulations of scenario 2.

2) Situation with 30% glazing to floor area ratio (façade window only).

The results from scenario 2 show that a 30% glazing to floor area ratio will achieve a DF façade 2% approximately 4.5 meters from the facade. The DF average is equal to 5.1%, but it is highly non-uniform and not well distributed over the work plane area with very high values near the window and low values at the back, a luminous environment likely to cause visual discomfort and glare. In this scenario, 2 of the 3 workplaces represented can be considered daylit.

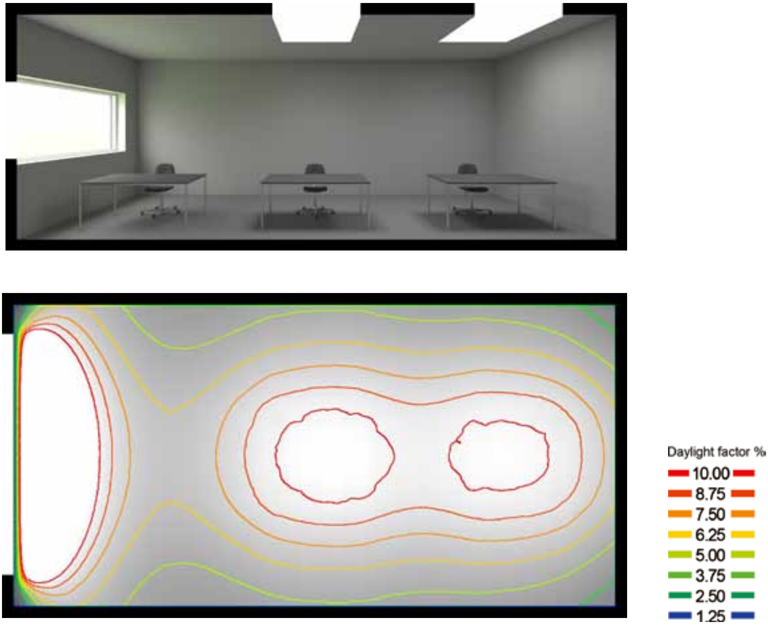


Figure 1.20. Luminance and daylight factor simulations of scenario 3.

3) Situation with 20% glazing to floor area ratio (11% façade window + 9% roof window).

The results from scenario 3 show that a combination of façade and roof windows with a 20% glazing to floor area ratio permits to achieve generous and useful DF levels over the entire work plane with an average DF of 6.4%. The results demonstrate that the use of roof windows provides better daylighting performance and a luminous environment not as likely to cause glare and visual discomfort. In this scenario, 3 of the 3 workplaces represented can be considered well daylit.

Simulations performed with the VELUX Daylight Visualizer. CVP VELUX roof windows are used in scenario 3.

1.4.5 Material properties

The colour and reflectance of room surfaces are part of the lighting system. Dark surfaces reflect less light than bright surfaces and the result is likely to be an unsatisfactory luminous environment in which there is little indirect or reflected light. Bright vertical room surfaces are generally preferred over dark ones, provided that glare is controlled.

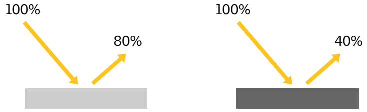


Figure 1.21. Diagram showing the influence of surface reflectance on light distribution.

Example: Impact of surface reflectance on luminance levels
The simulations below show the impact of using light or dark colours on the appearance and luminance levels of a room. The false colour images show that the room with light colours obtained higher luminance levels on all surfaces and permits a better use of the light input coming from the windows.

Model properties
Pane visual transmittance τ_v: 0.78
Surface reflectance light room: wall 0.80, floor 0.75, ceiling 0.90.
Surface reflectance dark room: wall 0.40, floor 0.35, ceiling 0.80.

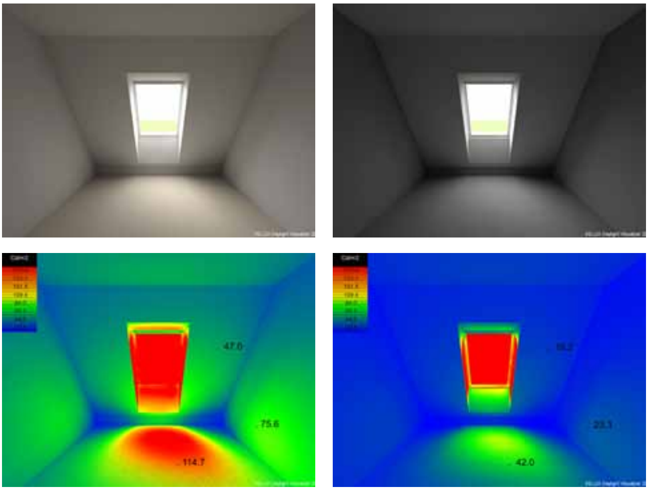


Figure 1.22. Simulations showing the impact of surface reflectance on luminance levels. Simulations performed with VELUX Daylight Visualizer.

1.4.6 Windows

Glazing area

The amount of daylight entering a room is linked to the total glazing area of windows in that room.

Pane

The amount of daylight transmitted through a window pane is reduced by the number of glass layers it has to penetrate. As a rule-of-thumb, double glazing (without any coating) lets in approx. 80% of the light, while triple glazing (without any coating) lets in approx. 70% of the light (compared to an open window). Coloured or coated glass can reduce the visible transmittance of a window pane to values as low as 20% and significantly modify the spectral quality of the transmitted light, as well as the perception of surface colours in the interior.

Position

The positioning of windows will influence the distribution of daylight in the room and determine the amount of "useful" daylight. Window position also needs to consider the relation between the view to the outside and the eye level of the occupants.

Linings

The geometry of window linings will influence the amount of daylight entering the room and can be used to soften the luminance transition between the high luminance values of the window and the surfaces of the room.

Remember

As a rule-of-thumb, a double layer glazing transmits approx. 80% of the light and a triple layer glazing transmits approx. 70% of the light.

Coloured or coated glass can reduce the visible transmittance of a window pane to values as low as 20%.

» It is impossible to "optimize" buildings for good daylighting performance with static glazing alone since daylight intensity varies dramatically «

Shading

Shading and sun screening are just as important as the window itself for good daylighting performance. Pleated blinds and Venetian blinds can be used for adjusting the amount of daylight entering spaces and reducing window luminance to control glare. The Venetian blind can also be used to redirect the light into the room.

The most efficient shading solution to prevent direct solar radiation into the building is by utilizing external shading. Examples of external shadings are roller shutters and awning blinds. A dark grey screen (VELUX awning blind 5060) will reduce the illuminance and luminance levels significantly to a level where the risk of glare can be avoided.

Interior shading, Venetian Blind

Exterior shading, Roller Shutter

Interior shading, Pleated Blind

Exterior shading, Awning Blind

Figure 1.23. Different shading solutions.

1.5 Daylight with roof windows

1.5.1 Impact of three window configurations on daylight conditions

More light

Under similar conditions, roof windows are shown to give at least two times more light than vertical windows of the same size, and three times more light than dormers of the same size, illustrated in Figure 1.24. The roof window also provides a larger variation of light levels which increases the visual interest of the room [26].

Better light distribution

Under similar conditions, roof windows are shown to give higher wall luminance than dormer and facade windows which results in a softer transition between the high luminance of the window pane and the adjacent wall, and reduces the risk of glare.

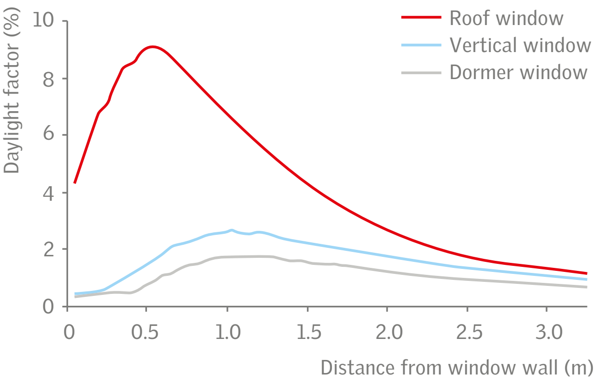


Figure 1.24. Comparison of daylight factor levels along the depth of the room.

» Skylights invariably improve daylighting performance and offer energy savings potential «

1.5.2 Effects of skylights in residential buildings

The effects of adding skylights in residential buildings have been investigated in a climate-based daylight analysis carried out by the Institute of Energy and Sustainable Development at De Monfort University (UK).

The main goal of the study was to assess and quantify the impact of VELUX roof windows/skylights, installed high up, on daylight conditions for various scenarios. In total, ten building designs were evaluated for all combinations of eight orientations and six climate zones. Therefore, there were 480 sets of unique climate-based daylight simulations daylight simulations. Figure 1.25 below shows one of the house models used in the analysis.

Among the main findings, it was shown that [13]:

- The addition of skylights invariably improves the overall daylighting performance of the space. For some designs, the addition of skylights led to a typical increase in daylight availability from 12% to 45% of the occupied year.
- The addition of skylights results in a significant reduction of periods with too low light levels in the rooms (less than 100 lux) for which electric lighting is likely to be used.
- The addition of skylights results in an increase of periods with light levels higher than 2500 lux. Recent research indicates that moderate exposure to high light is likely to have significant health benefits.

Figure 1.25. Renderings showing one of the house models used in the analysis.

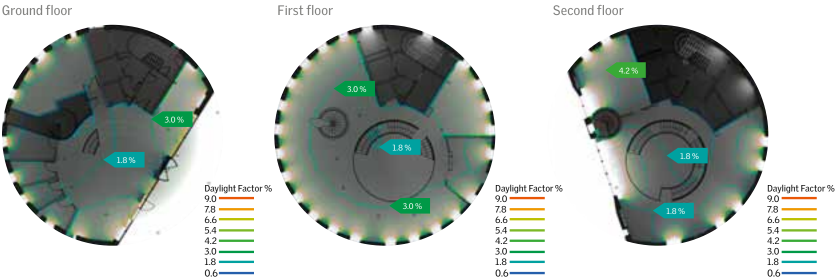
1.5.3 Effects of roof windows in Green Lighthouse

The daylight performance of Green Lighthouse, a VELUX 2020 Model Home, has been evaluated with daylight factor simulations. In order to show the effects of VELUX roof windows, a comparison of the daylight conditions with and without the use of roof windows was performed.

The results, presented in Figure 1.26, show that the roof windows deliver high levels of daylight to the second floor's lounge area, providing the occupants with a healthy indoor environment, strongly daylit, and with a contact to the sky.

The results also show that the use of roof windows contributes to raise the daylight levels on the lower floors substantially via the bright atrium space and results in a better distribution of daylight on all floors by balancing the light coming from the façade windows.

Daylight performance, without roof windows



Daylight performance, with roof windows

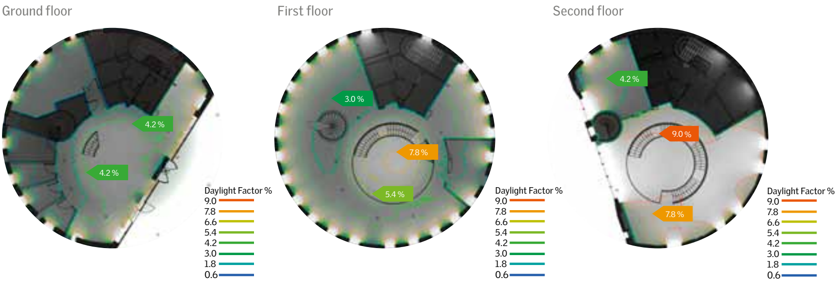


Figure 1.26. Daylight factor renderings of Green Lighthouse comparing the daylight performance with and without roof windows.

1.6 Evaluation of daylighting performance

1.6.1 Illuminance

Illuminance is the measure of the amount of light received on a surface. It is typically expressed in lux (lm/m²). Illuminance levels can be measured with a luxmeter, shown in Figure 1.28 or predicted through the use of computer simulations with recognized and validated software (e.g. VELUX Daylight Visualizer). Figure 1.29 shows an example of an illuminance rendering. Illuminance is the measure of light currently used by most performance indicators to determine daylight availability in the interior.

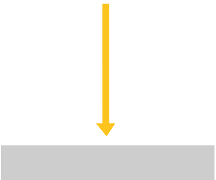


Figure 1.27. Illuminance diagram.

Figure 1.28. Luxmeter.

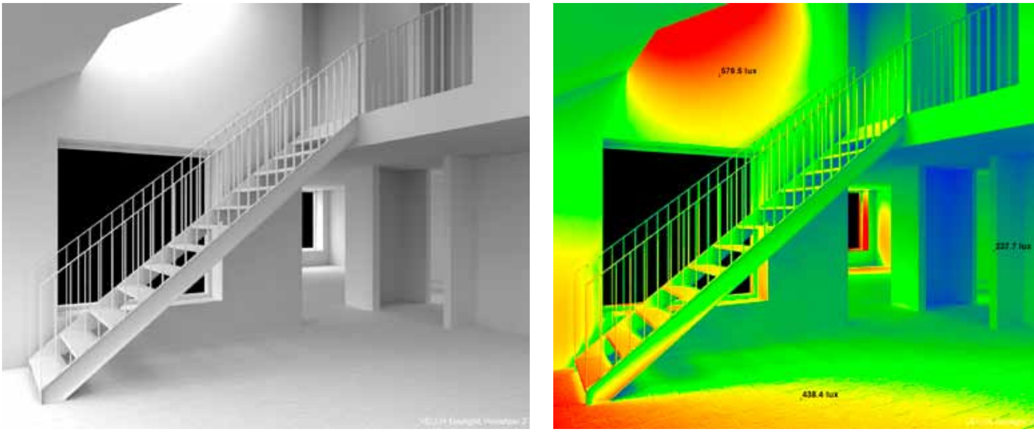


Figure 1.29. Illuminance renderings of VELUX MH2020 Home for Life.

Typical illuminance values:	
Direct sunlight	100 000 lux
Diffuse skylight	3 000-18 000 lux

Minimum levels for tasks and activities:	
Residential rooms	200-500 lux
Classrooms (general)	300-500 lux
Workspace lighting	200-500 lux

Remember

Illuminance (lux) is the measure of the amount of light received on a surface.

Illuminance is the measure of light currently used by most performance indicators to determine daylight availability in the interior.

1.6.2 Luminance

Luminance is the measure of the amount of light reflected or emitted from a surface. It is typically expressed in cd/m².

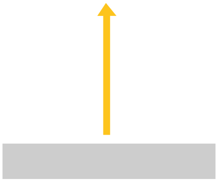


Figure 1.30. Luminance diagram.

Luminance levels can be measured with a luminance meter, shown in Figure 1.32 or through the use of high dynamic range (HDR) imaging techniques together with a digital camera and a luminance mapping software (e.g. Photolux), example shown in Figure 1.33. Luminance levels can be predicted through the use of computer simulations with recognized and validated software (e.g. VELUX Daylight Visualizer). Figure 1.34 shows an example of a luminance rendering. Luminance is the measure of light used to evaluate visual comfort and glare in the interior.

Figure 1.31. Cool pix camera and fish eye lens used to create luminance maps.

Figure 1.32. Luminance meter.

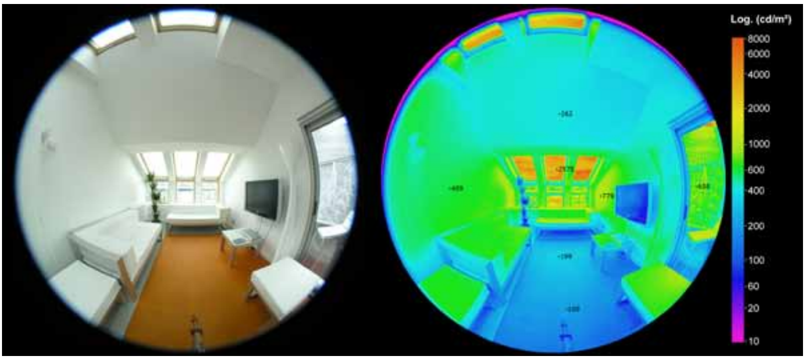


Figure 1.33. Luminance map showing the distribution of luminance values in Atika, a concept house by VELUX, under overcast sky conditions.

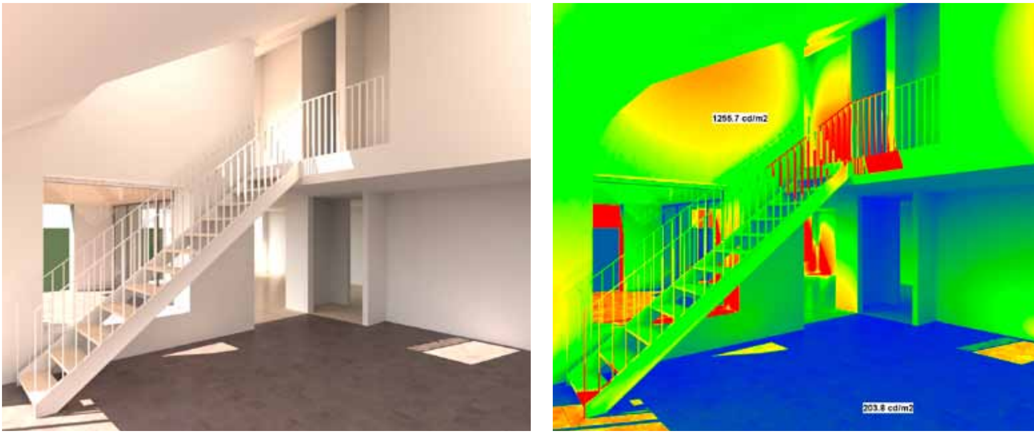


Figure 1.34. Luminance renderings of VELUX MH2020 Home for Life.

Typical luminance values:	
Solar disk at noon	1 600 000 000 cd/m^2
Solar disk at horizon	600 000 cd/m^2
Frosted bulb (60 W)	120 000 cd/m^2
T8 cool white fluorescent	11 000 cd/m^2
Average clear sky	8 000 cd/m^2
Average cloudy sky	2 000 cd/m^2

Remember

Luminance (cd/m^2) is the measure of the amount of light reflected or emitted from a surface.

Luminance is the measure of light used to evaluate visual comfort and glare in the interior.

1.6.3 Performance indicators

Daylight factor (DF)

The daylight factor (DF) is a common – easy to use – measure, which permits determination of the availability of daylight in a room.

The DF expresses – as a percentage – the amount of daylight available in the interior (on a work plane) compared to the amount of unobstructed daylight available outside under standard CIE overcast sky conditions [27].

Figure 1.35. Drawing showing the values measured by the daylight factor method (simultaneous reading of the internal and external (unobstructed) illuminance levels on a horizontal plane).

The higher the DF, the more daylight is available in the room. Rooms with an average DF of 2% or more can be considered daylit, but electrical lighting may still be needed to perform visual tasks. A room will appear strongly daylit when the average DF is above 5%, in which case electrical lighting will most likely not be used during daytime [28].

With regard to guidelines for daylighting, the VELUX Group recommends to achieve an average DF of 5% in the main living areas and activity zones of a building.

Figure 1.36. Daylight factor rendering of VELUX MH2020 Home for Life.

Remember

DF is based on illuminance readings (lux).

DF is calculated under CIE overcast sky conditions and does not account for the effects of direct sunlight on the daylight levels.

DF does not allow for evaluation of the effect of orientation.

An average DF below 2% generally makes a room look dull and electrical lighting is likely to be frequently used, whereas an interior will look substantially daylit when the average DF is above 5%.

Daylight autonomy (DA)

Daylight autonomy (DA) is a new performance indicator calculated on basis of recorded climatic data.

The DA is defined as the percentage of time – over a year – for which daylight can provide a specific intensity of light (e.g. 500 lux) in the interior (on a work plane).

The DA permits taking into account the effects of direct solar radiation on the indoor illumination levels and is sensitive to the orientation and climatic conditions of the building site.

The example below shows the daylight autonomy levels obtained for 4 different rooms of a kindergarten project. In this case, the daylighting performance of the rooms was evaluated with the occurrence of 4 specific illuminance levels: 200 lux, 500 lux, 1000 lux and >2500 lux to predict the risk of glare and overheating.

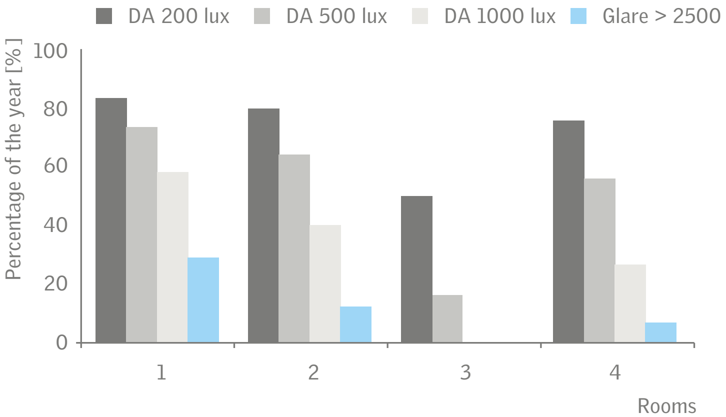


Figure 1.37. Occurrence of daylight autonomy levels (DA) and the risk of glare and overheating in 4 different rooms.

1.7 Daylight requirements in building codes

Daylighting is met with very limited (or no) requirements or recommendations in existing standards and building regulations that are enforceable by law in any country.

Legislation related to daylighting tends to be of three types [29]:

- The access that buildings have to sunlight. This type of legislation, usually referred to as "solar zoning legislation", attempts to guarantee building occupants access to sunlight for a predetermined period of time. "Solar zoning" (e.g. in Japan and China) relates to public health, safety and welfare.

- Requirements for windows and their glazing area in relation to the room area or façade area. It is important to emphasize that legislation, which mandates a minimum ratio of glazing area, cannot be considered as daylight legislation, since it does not translate the actual daylight presence inside the room or building; it is not considering outside boundary conditions, building overhangs, permanent shading, glass configuration or transmittance etc.

- The quantity of indoor illumination inside a room. Levels for daylighting are generally described as preferred or recommended; either by specific illuminance (lux) levels on a workplane or by the daylight factor (DF) method.

The VELUX Group works to have windows recognized as sources of illumination and sun provision in buildings; we are promoting healthy indoor environments and contributing to a reduction of the electricity used for lighting. Our goal is that daylighting should be specifically mentioned and considered in building standards and regulations, together with specific performance criteria for all main living areas and activity zones of a building.

1.8 Daylight summary

Daylight has a wide range of effects on buildings and their occupants. It influences the demand for electrical lighting, cooling and heating in buildings, and offers an array of comfort and health benefits essential to the occupants.

A good daylighting design will deliver high amounts of light, without glare or thermal discomfort. Whereas a poor daylighting design will deliver either inadequate amounts of light so that electric lighting has to be used frequently, or high amounts of light together with discomfort and glare.

Interiors with an average daylight factor (DF) of 2% or more can be considered daylit, but electrical lighting may still be needed to perform visual tasks. A room will appear strongly daylit when the average DF is above 5%, in which case electrical lighting is not likely to be used during daytime.

It is impossible to "optimize" buildings for good daylighting performance with static window solutions alone since daylight intensity varies dramatically. It is always important to consider and include proper external and internal solar shading in order to optimize visual comfort.

The size and placement of windows must always be considered together with the total energy use of the building and specific requirements for daylighting.

The VELUX Daylight Visualizer can be used to predict the daylighting performance of a building design and to visualize the character of daylight in the interior.

Ventilation

Ventilation

The purpose of ventilation is to freshen up the air inside buildings in order to achieve and maintain good air quality and thermal comfort. Ventilation also has important psychological aspects, which can be summarized as "creating a link to nature" (the outdoor environment).

2.1 Indoor Air Quality

The quality of the indoor air influences humans in several ways [30]:

- Comfort: The pleasantness of the air is immediately felt when a person enters a building.
- Health: Breathing indoor air can have negative health effects if the quality of the air is poor.
- Performance: Indoor air can improve mental performance and general satisfaction if the quality of the air is high.
- Other: Fresh air creates a link to the outdoor environment and fresh air through windows is a valued aspect of ventilation.

Indoor air contains many different – and also unwanted – compounds, which include [31]:

- Gases; e.g. formaldehyde, organic chemicals (VOC) and inorganic chemicals (NO_x, SO_x, etc.).
- Particles; e.g. dust, combustion products, skin flakes and textile particles.
- Radioactive gases; radon.
- Biological; e.g. mould, fungi, pollen and dust mites.
- Water vapour (humidity).

Most of the pollutants come from sources indoors. They include [31]:

- Human beings and their activities; e.g. tobacco smoke, products for cleaning and personal care, consumer electronics and electrical office equipment like laser printers.
- Building materials; e.g. thermal insulation, plywood, paint, furniture and floor/wall coverings.
- Outdoor sources; e.g. pollen, traffic and industry. Radon exists naturally in the ground and enters the house through the floor construction.

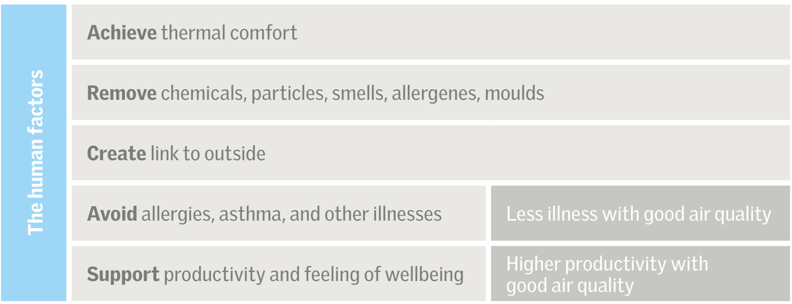


Figure 2.1. The main reasons for ventilation.

» Children are particularly vulnerable to poor air quality «

2.1.1 Health

To better understand the impact of indoor air on our health, we need to consider the amount of air we breathe per day. An average person consumes 2 kg of food and water per day, whereas the intake of air is 15 kg per day (12 000 litres). The health impact is clearly important [32].

90% of our time is spent indoors, so most of the air we breathe comes from indoor environments. And we spend a lot of time in our homes; 55% of the intake of food, water and air during a lifetime is indoor air from our home, as seen in Figure 2.2 [33].

The individual or combined effects of the many compounds in the indoor air on human health are not fully understood, but large research studies have shown that indoor air quality has an important impact on the health of humans in buildings.

Professor Jan Sundell, International Centre for Indoor Environment and Energy at DTU, says that "we do not know much about causative agents in indoor air, but there is mounting evidence that the indoor environment, especially dampness and inadequate ventilation play a major role in a public health perspective, and that the economic gains to society for improving indoor environments by far exceed the cost."

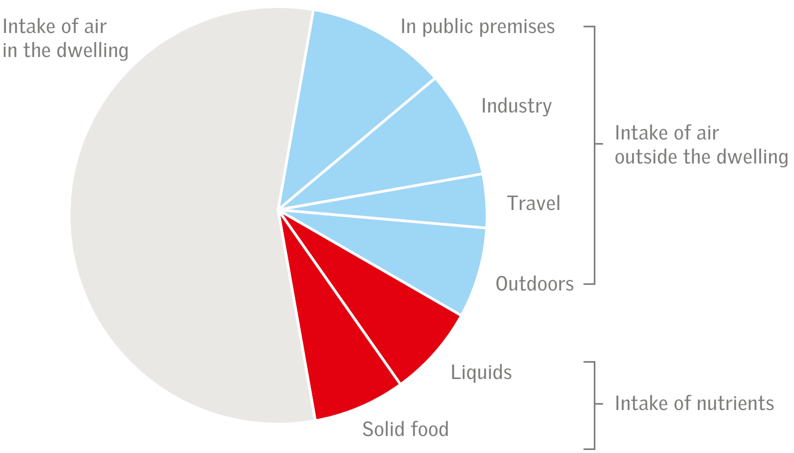


Figure 2.2. 55% of the total intake of air, water and food for a person is indoor air from our dwellings.

Especially in Northern Europe, asthma and allergy are becoming more and more common among children and this phenomenon has been studied by doctors and indoor environment scientists. One study investigated the prevalence of these illnesses among Swedish conscripts.

From the 1950's to the 1980's a large increase in the number of persons (prevalence) with illnesses like asthma and allergy was recorded. The trend is too rapid to be explained by genetic changes and must be explained by environmental changes instead. No direct link to indoor air quality has been found, but most researchers recognize that a link exists [34].

To emphasize the importance of healthy indoor air, WHO has adopted a set of statements on "The right to healthy indoor air" [35].

Sick Building Syndrome (SBS)

The term "Sick Building Syndrome" (SBS) is used to describe situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building, but no specific illness or cause can be identified. The complaints may be localized in a particular room or zone, or may be widespread throughout the building [36].

The symptoms of these problems include headaches; eye, nose or throat irritation; dry cough; itchy skin; fatigue; concentration difficulties. These symptoms are defined as SBS symptoms. The World Health Organization (WHO) concludes that 15-50% of buildings have these problems [37].

The symptoms are believed to be caused by poor indoor environments and can be helped by improving the air quality.

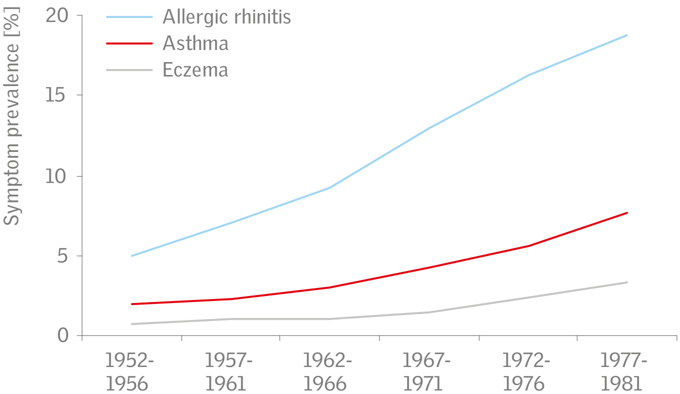


Figure 2.3. The prevalence of allergy, asthma and eczema among Swedish conscripts (young men that join the armed forces).

Moisture in buildings can cause illnesses

Living or working in "damp" buildings are among the factors that relate to indoor air which are most likely to cause illnesses. Investigations of 100 000's of houses have shown that damp buildings can cause illnesses such as cough, wheeze, allergies and asthma. A "damp" building is a building with an increased moisture level (the exact "risk" level of moisture is not known). Figure 2.4. is an example of the effects of damp buildings and it shows how dampness increases the risk of allergy [38,39].

Human activities such as cleaning, cooking, bathing, etc. add moisture to the indoor air. Therefore the indoor air contains more moisture than the outdoor air. The activities of a family of four typically add 10 litres of water to the indoor air – per day [40].

There is no clear scientific explanation of exactly how the dampness has an impact on health. It is well-known, however, that house dust mites thrive in humid indoor environments. House dust mites are a well-known cause of allergy. To reduce the risk of allergy caused by house dust mites, the relative humidity should be kept below 45% for several months a year [41].

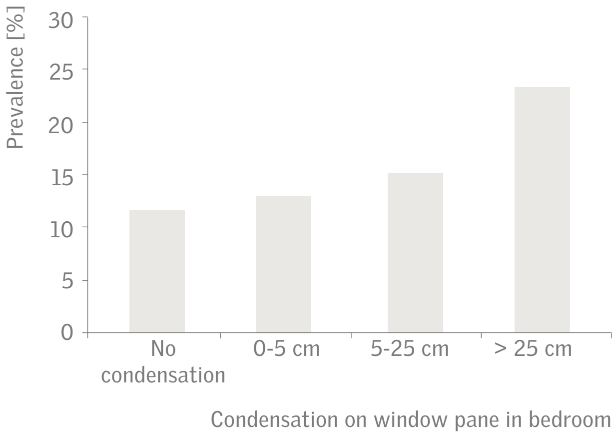


Figure 2.4. Shows the amount of condensation seen on the inside of bedroom windows and how this affects the prevalence of allergic rhinitis among children living in the houses [42].

Remember
The moisture production from a typical family is 10 litres per day – this corresponds to emptying a large bucket of water on the floor every day.
It should be removed with adequate ventilation to reduce the risk of illnesses.

Low ventilation rates can cause illnesses

The ventilation rate is an indicator of how frequently the indoor air is changed in a house. If the ventilation rate is below 0.5 ACH, as typically required in the North European building legislations [43], there is an increased risk of becoming ill with the dampness-related illnesses like asthmas and allergies, as seen in Figure 2.5.

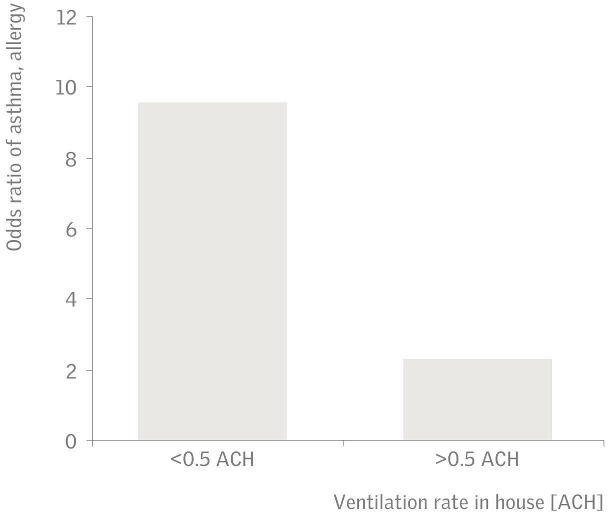


Figure 2.5. The odds ratio is an expression of probability. The figure shows the risk of becoming ill with asthma and allergy increases in houses with a ventilation rate below 0.5 ACH [44].

Remember

Good indoor air quality is a precondition for preventing important illnesses like asthma and allergy, especially among children.

2.1.2 Mental performance and indoor air quality

Investigations on the mental performance of occupants in office buildings and schools have shown that poor air quality reduces mental performance, while good air quality improves mental performance, see Figure 2.6. [45,46].

It can be assumed that if the indoor environment was productive to work in, it would also support our ability to concentrate and stay focused at home. At home, we engage in activities, which require concentration like reading, playing games, listening to music, etc. and which can be expected to benefit from an indoor environment which supports productivity.

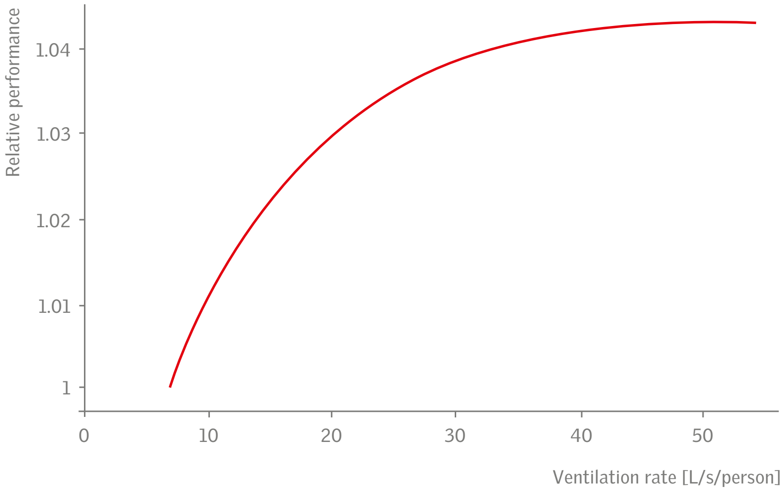


Figure 2.6. The performance of students in schools is improved when the air quality is improved by increasing the ventilation rate [46].

» Opening windows is more than just ventilation – opening a window creates the link to the outside and is a symbol of affection for your family «

2.1.3 The direct link to the outside

Windows do not only provide fresh air for our physical needs and to support our health. Opening a window is also of psychological importance for us. An anthropological study carried out in several residential buildings in Denmark [47] concludes that people want to be able to open windows for several reasons:

- To create a link to the nature outside the house
- To remove unpleasant smells from the house and make it smell fresh
- To mark the passage from one situation to another: from sleep to wake; returning home from work, etc.

Furthermore, the daily airings performed by a parent are subconscious symbols of love and affection for the family.

Opening the windows to let in some fresh air is like enjoying a glass of wine, one of the home-owners said.

The investigation made it clear that it is very important for the occupants that they can open windows in their house.

2.2 Ventilation systems

There are several ways to bring fresh air into our homes. Ventilation systems can be natural, mechanical or hybrid – hybrid is a combination of the two.

2.2.1 Natural ventilation

Natural ventilation uses natural forces to exchange the air in a building. The driving forces are wind and temperature differences, which are explained further in section 2.4.1.

In residential buildings, air is often supplied through the façade and extract air is removed from selected rooms (often kitchen and bathrooms) through ducts, as illustrated in Figure 2.7.

The air supply can be through fresh air grilles in the façade or through the ventilation flaps of VELUX roof windows. It can also be through leakages in the façade.

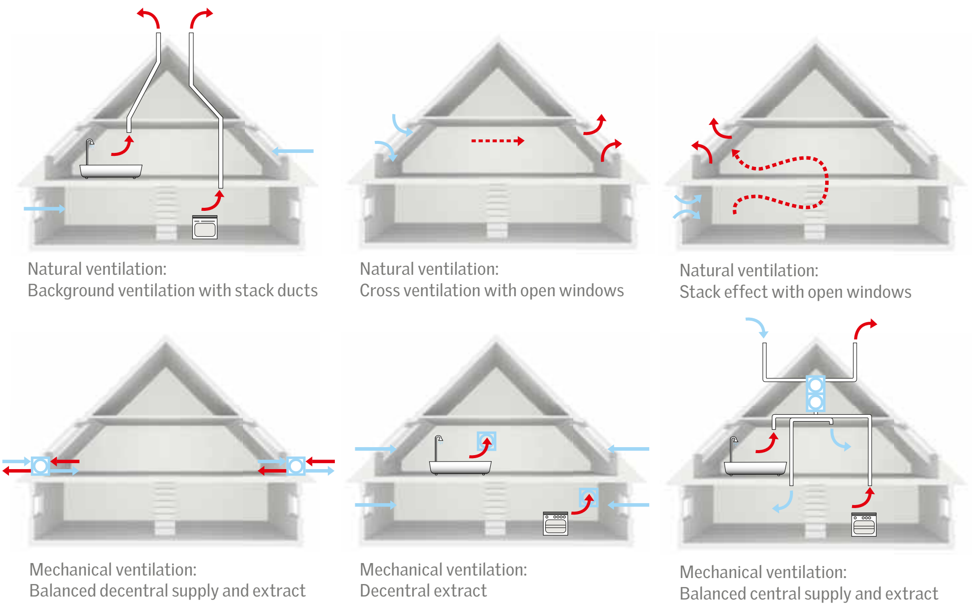


Figure 2.7. Common natural and mechanical ventilation systems

2.2.2 Mechanical ventilation

Mechanical ventilation systems use electrically powered fans to direct the airflow in the building. Mechanical ventilation can provide a constant air change rate independently of the external weather conditions, but uses electricity and usually cannot change the ventilation rate as the need changes over the day and year.

Several variations exist, as illustrated in Figure 2.7. Systems with both supply and extract can be combined with a heat recovery unit, which recovers (reuses) the heat of the extract air, which is otherwise lost. Up to 90% of the energy can be 'reused'.

It is becoming a standard solution in many North European countries that new-built houses are provided with mechanical heat recovery ventilation to be able to meet the present energy requirements. This is a very energy efficient solution for the heating (winter) season. However, in the summer season, electricity for running of fans can be saved by using natural ventilation. Systems shifting between natural ventilation and mechanical ventilation are called hybrid ventilation systems.

Mechanical ventilation requires that filters are changed regularly. Dirty filters are a source of pollution of the indoor air and reduce the indoor air quality which reduces the performance of the occupants of the building and increases the prevalence of SBS symptoms [48,49].

It has been found that SBS symptoms occur more frequently in buildings with air conditioning than in naturally ventilated buildings [48].

It is necessary that the building is quite airtight for a mechanical ventilation system with heat recovery to perform energy efficiently. If not, a substantial part of the ventilation will come from infiltration, which bypasses the heat exchanger. Therefore, mechanical ventilation is often not a solution, which can be applied in existing buildings to reduce the energy demand.

» Hybrid ventilation combines the best of natural and mechanical ventilation in new-built houses «

2.2.3 Hybrid ventilation

Hybrid ventilation is when a combination of natural and mechanical ventilation is used. Several variations of hybrid ventilation systems exist and hybrid ventilation is a relevant solution in new residential buildings, especially if roof windows are available for stack effect

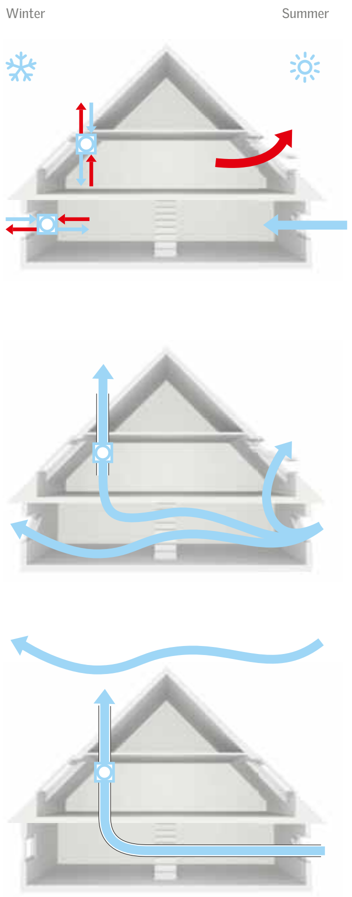


Figure 2.8. Three principles of hybrid ventilation systems [50].

Combined natural and mechanical ventilation

Mechanical ventilation is used in the heating period and natural ventilation is used during the rest of the year. This principle provides a good energy performance for new-built houses and works well with VELUX roof windows.

Fan-assisted natural ventilation

This principle is mainly used in larger commercial buildings where the natural driving forces are inadequate in some periods and, therefore, a fan is used for assistance.

Stack- and wind-assisted mechanical ventilation

This principle is also mainly used in larger commercial buildings, where the ventilation system is designed with ducts to transport the air and where natural driving forces provide most of the airflow – whereas fans are used for assistance.

Hybrid ventilation is used to optimize the indoor environment while reducing energy costs. As mentioned, mechanical ventilation with heat recovery is used in new houses to reduce the heating demand and to make the house meet the energy requirements for heating. But during the warm part of the year, it is more energy efficient to use natural ventilation to reduce the electricity demand for the electric fans. Furthermore, open windows are appreciated by most users in the warm part of the year.

Hybrid ventilation combines the best of both worlds: good winter energy performance with mechanical heat recovery ventilation and good summer performance with natural ventilation.

Example: Using hybrid ventilation to save energy

An exemplification of how much energy that can be saved with hybrid ventilation compared to mechanical heat recovery ventilation.

Typical houses in Istanbul, Paris and Copenhagen are investigated. Natural ventilation is used whenever it is warm enough to make the heat recovery ventilation unnecessary [51].

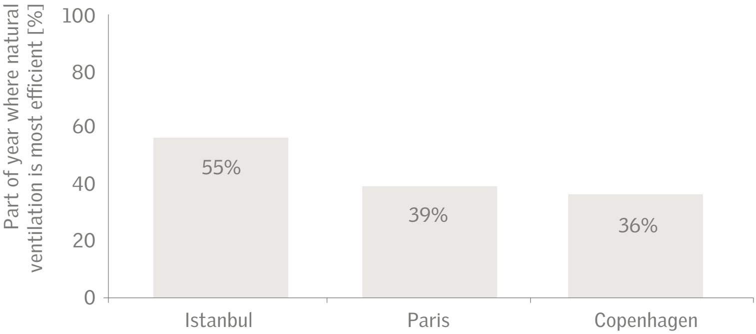


Figure 2.9. In Paris and Copenhagen natural ventilation is more energy efficient than heat recovery ventilation for 36% - 39% of the year, in Istanbul it is the case for 55% of the year.

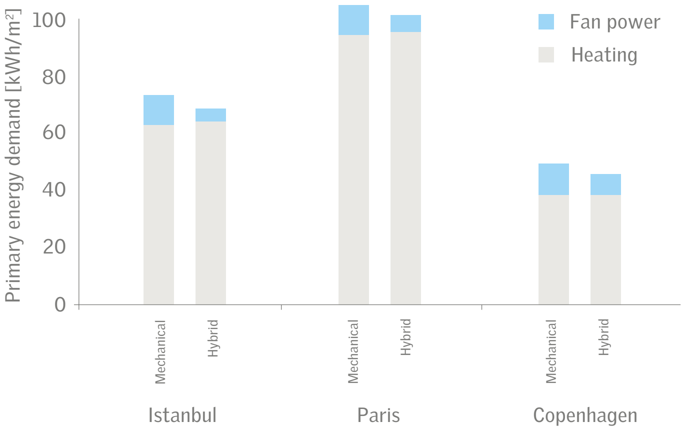


Figure 2.10. Hybrid ventilation is more energy efficient than mechanical heat recovery ventilation in Istanbul, Paris and Copenhagen.

The annual primary energy savings range from 3 kWh/m² in Paris to 5 kWh/m² in Istanbul. This is compared to the maximum primary energy demand in the table below. Three periods of construction are investigated, and it is seen that the relative reduction increases from 5% for a recent building to 9% for a future building.

	Total maximum primary energy demand for a 150 m² house	Relative reduction from a saving of 4 kWh/m² with hybrid ventilation
2005	85 kWh/m²	5%
2010	61 kWh/m²	7%
2015	42 kWh/m²	9%

Figure 2.11. Potential primary energy savings by using hybrid ventilation instead of mechanical ventilation with heat recovery. Based on requirements from the Danish building code [52].

For new-built houses, hybrid ventilation can be a very cost-efficient solution to reduce the energy demand and make the house meet the energy requirements. A reduction of the primary energy demand of 3-5 kWh/m² can lead to reductions of 5-9% in the future.

To achieve a low energy demand, the alternative to hybrid ventilation could be additional insulation, photovoltaics etc., which are more costly solutions.

Remember

Hybrid ventilation is more energy efficient than mechanical ventilation with heat recovery because of the saved electricity in the summer time.

2.3 Ventilation rates: impact on energy and health

The ventilation rate is a compromise between energy demand and a healthy indoor environment. In section 2.1.1 we saw that high ventilation rates could improve human health. But high ventilation rates also increase the heating demand in climates with cold winters, as shown below.

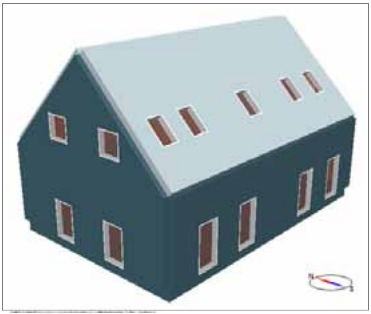
2.3.1 Building codes and standards

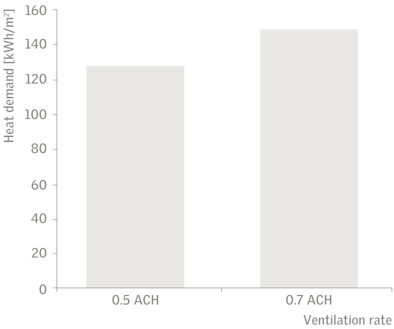
In most countries the building codes have requirements for the minimum amount of required ventilation in a building, and international standards, e.g. EN 15251, provide guidelines.

Most North European countries have building code requirements for ventilation around 0.5 ACH.

Example: Effect of ventilation rate on heating demand.

A house in Stockholm, Sweden, is investigated with VELUX Energy and Indoor Climate Visualizer.
The heating demand is determined for a ventilation rate of 0.5 and 0.7 ACH.
The heating demand is increased by 21% when the air change rate is increased from 0.5 to 0.7 ACH.





2.3.2 Demand-controlled ventilation

In reality the need for ventilation changes constantly and the ventilation rate should be increased when cooking, cleaning or many persons are present in the house. When the house is left during the day, the need for ventilation is reduced.

CO_2 as indicator for air quality

CO_2 is a good indicator of the indoor air quality in houses, where the occupants and their activities are the main reason for ventilation. Outdoor air contains approximately 400 ppm. Breathing generates CO_2, so the indoor CO_2 concentration will always be at least 400 ppm and usually higher. A set point for CO_2 of 750 provides very good air quality, while 900 ppm will ensure a good indoor air quality in most situations, and a CO_2 concentration above 1200 ppm indicates a poor air quality [53].

Relative humidity as indicator for air quality

The relative humidity indoors will vary on a yearly basis in correspondence to the humidity level outdoors.

A high level of humidity in the indoor air can increase the presence of house dust mites. In climates with cold winters the relative humidity inside should, therefore, be kept below 45% during winter [54].

Example: Effect of air change rate on air quality

A house in London, England is investigated with VELUX Energy and Indoor Climate Visualizer. The house is occupied by five persons, and has an internal floor area of 175 m^2. The CO_2-level is determined for two constant air change rates: 0.3 ACH and 0.5 ACH.

	Average CO_2-level	Average relative humidity in December, January and February
0.5 ACH	728 ppm (very good)	42% (good)
0.3 ACH	943 ppm (just acceptable)	59% (too high)

The results show that at 0.5 ACH the CO_2-level will be below 750 ppm, which indicates that the air quality will be very good. At 0.3 ACH the CO_2-level will be above 900 ppm, which indicates that the air quality is just acceptable for existing buildings and could be improved.

At 0.5 ACH the relative humidity is 42% on average during the winter months, while it is 59% for 0.3 ACH. It is recommended that the relative humidity should be below 45% in this part of year; this is achieved at 0.5 ACH, but at 0.3 ACH the relative humidity is too high, which means that there will be a risk of mould growth and an increased risk of moisture-related illnesses.

For the investigated house, the air quality will be very good at a ventilation rate of 0.5 ACH and poor at 0.3 ACH.

Remember

For residential buildings, the ventilation rate can be controlled based on the humidity level and CO_2 concentration. The actual need for ventilation changes constantly and demand-controlled ventilation will provide the best compromise between air quality and energy consumption.

2.4 Natural ventilation with roof windows

2.4.1 Driving forces of natural ventilation

Natural ventilation is driven by temperature differences and wind pressure.

Stack effect (temperature difference)

Warm air is lighter than cold air and that causes the stack effect, which means that warm air inside a building will rise upwards.

The warm air will leave the building at the top through leakages, stack ducts or open windows and the air will be replaced by cold air entering the building at ground level. The higher the building, the more powerful the stack effect. For the stack effect to work efficiently there must be air passages through the building. These can be stairways in combination with windows, where windows at both ground level and roof level can be easily opened at the same time. Due to the position in the roof, VELUX roof windows maximize the ventilation potential of the stack effect.

See section 2.4.3 for an example of stack effect.

Wind (wind pressure)

When a building is exposed to wind, air will enter the building at the windward side and leave the building through openings at the leeward side. The wind pressure is higher on the windward side than on the leeward side. This will drive air from the windward side of the building through the building to the leeward side.

The shape of the building and the surrounding landscape or buildings have an impact on the air flow.

The magnitude of the pressure difference generated by wind pressure is determined automatically as part of a simulation in tools like the VELUX Energy and Indoor Climate Visualizer or typical values can be found in standards (e.g. BS5925:1991, DIN1946-6:2009).

See section 2.4.3 for an example of wind driven natural ventilation.

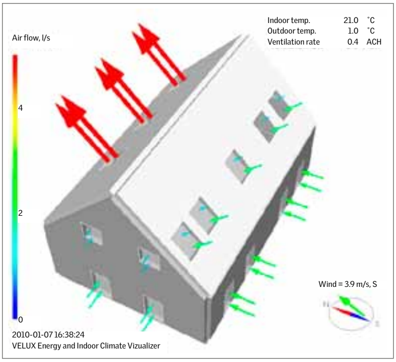
Remember

The higher the windows are placed and the larger the temperature difference, the more powerful the stack effect. Therefore, in a building where VELUX roof windows are used for natural ventilation, the stack effect is greater than in a building with only façade windows.

» Natural ventilation with roof windows uses the stack effect to prevent summertime overheating «

2.4.2 Background ventilation with the VELUX ventilation flap

The ventilation flap of VELUX roof windows can be used to provide a continuous flow of fresh air into the building.



Example: Background ventilation with ventilation flap

The example investigates which background ventilation rate that can be achieved with different numbers of roof windows per floor area. Two ratios of windows to floor area are used, i.e. 10% and 20%. The house is in Berlin, Germany.

Figure 2.12 shows the ventilation flows on 7 January 7 where the flows are in the range of 2-6 l/s per window.

Figure 2.12 Animation of ventilation flows by VELUX Energy and Indoor Climate Visualizer.

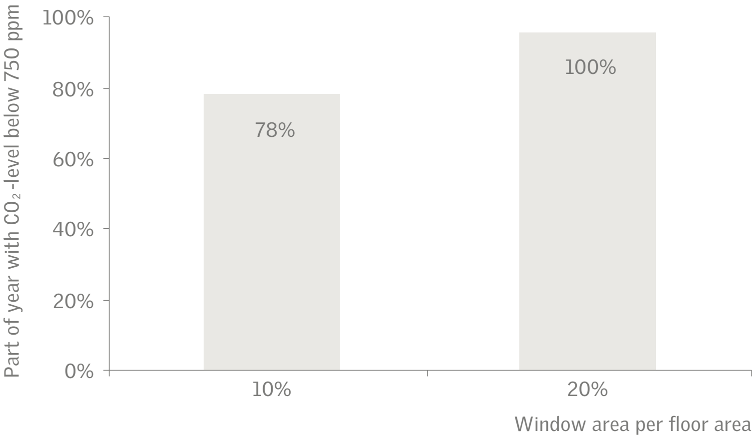


Figure 2.13. The part of the year with a CO_2-level below 750 ppm is used as an indicator of good air quality. This is achieved in 78% of the year with 10% windows to floor area, while it is increased to almost 100% with 20% windows to floor area.

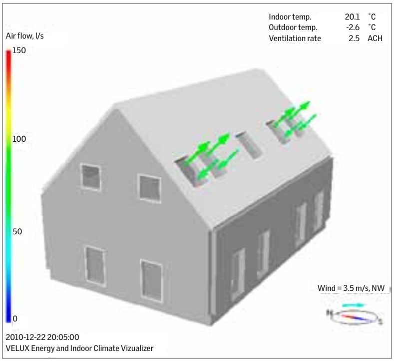
2.4.3 Airing

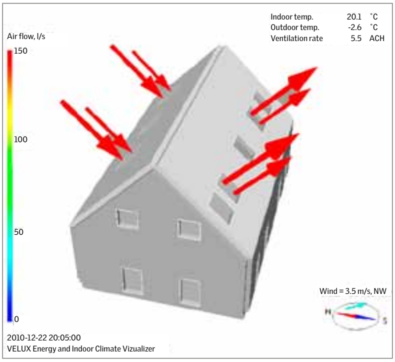
An airing is a short period with a high ventilation rate due to one or more open windows.

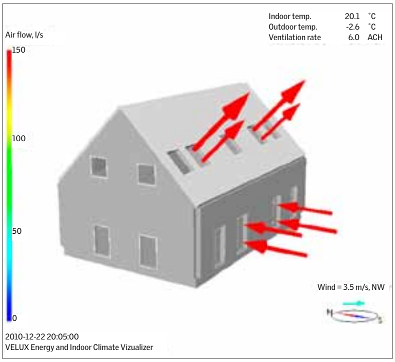
Using airing, odours and humidity can be removed efficiently at the place and time of generation. The effect of airing depends on how many windows are opened and how they are located in relation to each other. The most efficient airing is when stack effect and wind pressure are used by opening windows at opposite façades and different heights.

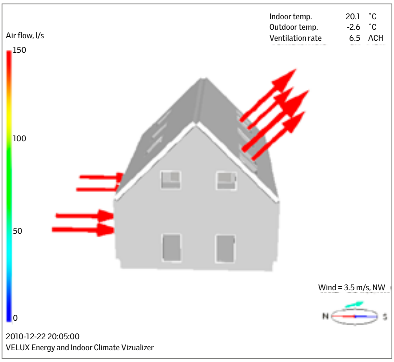
Example: Airing

Ventilation rates achieved with airing are calculated with the VELUX Energy and Indoor Climate Visualizer. Four windows used for airing, and the ventilation rates achieved with single sided airings, cross ventilation and stack ventilation are found for a summer and a winter situation. The house is located in Berlin, Germany.









The images from the animation of ventilation on 22 December during the morning airing show single sided, cross, stack effect and combined stack effect and cross ventilation.
The ventilation rates that occur during the airing are shown in the table below.

	Typical summer day: August 3	Typical winter day: December 22
Single sided	1.5	2.5
Cross ventilation	2.5	5.5
Stack effect	4.5	6.0
Combined stack and cross ventilation	5.0	6.5

The ventilation rates that are achieved with airings are in the range of 1.5 ACH to 5.0 ACH, which is up to 10 times higher than the background ventilation rate of 0.5 ACH. The highest ventilation rates in the example were achieved with combined stack effect and cross ventilation (5.0 - 6.5 ACH), then stack effect (4.5 – 6.0 ACH), followed by cross ventilation (2.5 – 5.5 ACH) and single sided ventilation (1.5 – 2.5 ACH).

The effect on the air quality in the case of combined stack and cross ventilation is investigated. The part of the year with a CO_2-level below 900 ppm is determined and the additional energy demand (and associated cost) is determined. A gas price of 0.085€/kWh is used [55].

	Part of year with CO_2-level below 900 ppm [%]	Heating demand [kWh/m²]	Energy costs [€/m² per year]
Without airings	62	45.9	3.9
With airings	77	50.3	4.3

The results show that the use of airings increases the part of the year with a CO_2-level below 900 ppm from 62% to 77% of the year, i.e. a substantial increase of 24%. The energy costs increase from 3.9 to 4.3 €/m² per year which is a 10% increase.

Remember

Airing through windows is efficient and relevant in many situations:

- In the morning when you get out of bed
- When cooking
- During and after showers
- During and after cleaning
- When drying laundry indoors
- In the afternoon when you return to your home

2.4.4 Optimal winter ventilation strategy for existing buildings

The ventilation flap can be used to provide background ventilation, which will achieve good indoor air quality when the house is not used to its full capacity.

During activities like cooking, cleaning and showering (as mentioned in section 2.4.3), airings should be used. VELUX roof windows in combination with façade windows provide efficient airings with stack effect and cross ventilation.

The combination of background ventilation and airings is the optimal strategy to achieve good air quality at a reasonable energy demand, as short airings are more efficient than continuous ventilation [26,27].

Airings can cause draught, but by making short and efficient airings, the problem can be minimized. See section 3.1.1.

Remember
Use a combination of background ventilation through the ventilation flap and 2-4 airings per day to achieve the optimal indoor air quality.

2.4.5 Summer ventilation

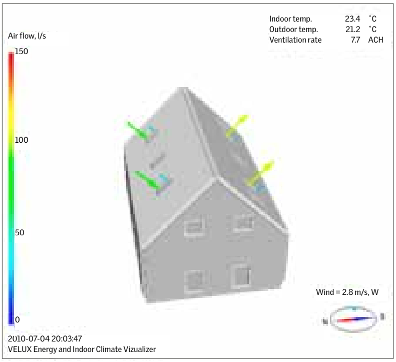
In warm summers, natural ventilation can be used to maintain a comfortable indoor temperature. In this situation there is no heat loss to consider – on the contrary, there is a potential for saving energy for cooling, if air conditioning is installed in the building.

Increased ventilation rates in summer prevent overheating and the increased air motion is pleasant when it is warm. See section 3.5.3 in the Thermal Comfort chapter for an example of use of both solar shading and natural ventilation to maintain thermal comfort.

The use of natural ventilation to improve thermal comfort in warm periods is explained in more detail in the Thermal Comfort chapter.

Example: Summer ventilation in Northern Europe.

The VELUX Energy and Indoor Climate Visualizer is used to find the effect of summer ventilation in a house in Stockholm. The ventilation flows achieved per window are in the range of 40-70 l/s when the windows are used to maintain a pleasant temperature and the ventilation rate of the house is in the range of 5-8 ACH where 15 windows are opened.



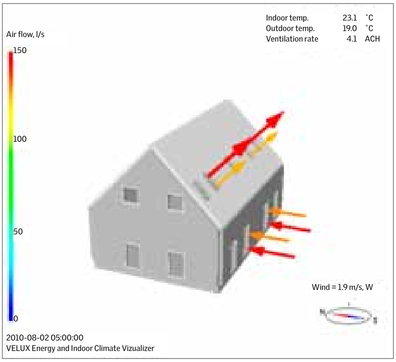
	Occupied part of year with temperatures out of comfort range
No summer ventilation	3% (304 hours)
With summer ventilation	0% (0 hours)

The results in the table show that without summer ventilation 3% of the occupied hours of a year will experience overheating. With summer ventilation the problem is eliminated. Using natural ventilation thus improves the thermal environment during the summer.

2.4.6 Night cooling

Night cooling uses natural ventilation to improve the thermal environment in summertime and is relevant in the same situations as summer ventilation, see previous section.

Night cooling uses the fact that the outdoor temperature is lower during the night than during daytime. When windows are opened during the night, the temperature in the house is reduced to e.g. 21°C in the morning. During the day, the indoor temperature will increase, but the temperature in the afternoon will be lower than if night cooling had not been used.



Example: Night cooling in Southern Europe.

The VELUX Energy and Indoor Climate Visualizer is used to find the effect of night ventilation in a house in Rome. The ventilation flows achieved per window are in the range of 50-100 l/s when 8 roof windows are used for night cooling, and the ventilation rate of the house is in the range of 4-6 ACH.

	Occupied part of year with temperatures out of comfort range
No night cooling	12% (1043 hours)
With night cooling	9% (757 hours)

The results in the table show that without night cooling, 12% of the occupied hours of a year experience overheating. With night cooling the problem is reduced to 9%, which could be further reduced with solar shading. Using natural ventilation for night cooling thus improves the thermal environment in the house.

2.4.7 Increased air tightness requires occupant action

50-100 years ago, the houses in most of Europe were often leaky, which meant that the ventilation rate of these houses were often in the range of 1 ACH without open windows. This led to high heating demands and the building codes have been focusing on reducing leakages since the 1960's. Measurements show that infiltration has been reduced, as illustrated by Figure 2.14.

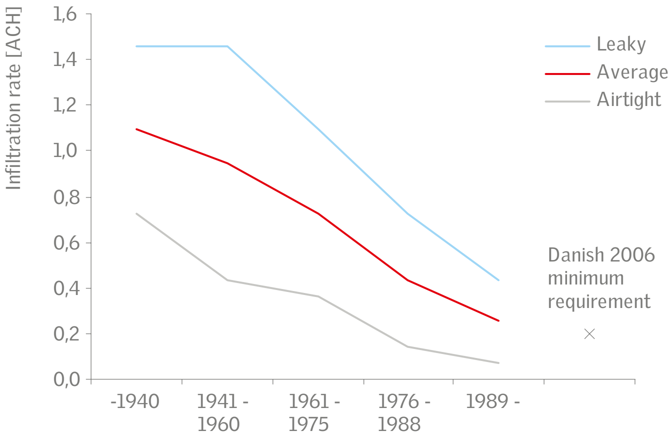


Figure 2.14. Measured infiltration rate in Swedish houses, from EN 13465.

Infiltration is a measure of the air tightness of the building; infiltration is the uncontrolled ventilation through leakages in a building.

The increased air tightness provides better energy performance, but today buildings in Northern Europe are generally so airtight that infiltration alone is far from sufficient in order to provide reasonable ventilation and good air quality.

Consequently, building occupants need to actively ventilate their homes to achieve good air quality and a healthy indoor environment. It is important that the VELUX ventilation flap is used to ensure a reasonable background ventilation rate, and especially important that airings are performed several times a day. Children are particularly vulnerable to poor air quality, as was seen in section 2.1.1.

» Use VELUX Integra roof windows for automatic ventilation to ensure a healthy indoor environment «

2.4.8 Automatic window opening with VELUX roof windows

The VELUX Integra windows can be programmed to open automatically. This can be very helpful in a busy daily routine, where there might not always be time to do the required airings.

Windows in selected rooms of the house can be programmed to open for e.g. 10 minutes in the morning and the afternoon, and at midday on weekends.

The ventilation flap can be programmed to open when the occupants are at home, or during the entire day or night.

Remember
A consequence of the increased air tightness of buildings is the increased need for additional ventilation in order to obtain a good and healthy indoor environment.

2.5 Ventilation summary

The indoor air quality has an important impact on our health, well-being and productivity. Fresh and healthy indoor air supports human needs, while poor indoor air quality can have serious negative effects.

Of particular importance is humidity and ventilation rate. These factors are linked to illnesses like asthma and allergy, and it is important to keep the relative humidity low – below 45% - during the winter months and to provide adequate ventilation.

The driving forces behind natural ventilation are wind, temperature and stack effect. VELUX roof windows are well suited for natural ventilation as they are located in the roof which increases the ventilation potential due to the stack effect in combination with façade windows.

The most efficient natural ventilation is achieved by a combination of background ventilation (through the VELUX roof window ventilation flap) and short and frequent airings, which match the rhythm of the building.

Hybrid ventilation is the combination of natural ventilation in the summertime and mechanical ventilation with heat recovery in the wintertime. This combination is very energy efficient and is relevant in new, airtight buildings.

During warm summer periods, daytime natural ventilation by airings will provide high ventilation rates, which improve the thermal comfort by reducing temperature and increasing air motion. Night time natural ventilation (night cooling) can also be applied to further increase the cooling capacity of natural ventilation.

The VELUX Energy and Indoor Climate Visualizer can be used to evaluate the natural ventilation performance of residential buildings and to visualize ventilation flows through windows.

Thermal comfort

Thermal comfort

We try to achieve thermal comfort subconsciously every day. One of the main purposes of buildings is to protect us from extreme outdoor conditions. Thermal comfort is taken for granted by most people, but energy is used to obtain thermal comfort, e.g. through heating or cooling. When designing buildings it is important to consider thermal comfort; designs that provide good thermal conditions based on energy efficient technologies like natural ventilation, solar shading and intelligent building design.

3.1 What is thermal comfort?

Thermal comfort can be defined as "that condition of mind which expresses satisfaction with the thermal environment" [58].

Thermal comfort is more than just pleasant conditions; it is part of a vital survival behaviour. Whenever people feel too warm or too cold a warning system is alerted by our body controlled basic instincts. The human body is a very efficient "piece of machinery" and is able to keep the core temperature within a very narrow range of 37 °C. Some actions are subconscious like removing blood from decentralized areas like hands and feet to keep the vital organs warm in cold environments or to start sweating in warm environments. More conscious actions include removing or adding clothes and adapting our activity level. All in all, the right thermal conditions are needed to survive [3]. And if the thermal environment does not meet the expectations, the building occupants will try to influence the thermal environment to make it meet their expectations, i.e. by installing local electrical heating or cooling units. Equipment using additional energy that could have been avoided if the building had been designed with thermal comfort in mind from the beginning.

Many people associate thermal comfort directly with the air temperature, but this is not the whole truth since the temperature subjectively experienced in a room is a combination of several parameters. The most important parameter is perhaps people's different expectations to thermal comfort. Therefore, thermal comfort can only be calculated for the average human-being and the individual experience is important.

Remember
Thermal comfort depends on other parameters than the air temperature alone, such as activity, clothing and individual preferences of the occupants.

3.1.1 Thermal discomfort

Thermal discomfort occurs when the thermal environment does not meet the requirements of the human mind or body. In cold environments we feel cold and our hands and feet drop in temperature; we get goose bumps and even start to shiver, in extreme cases resulting in hypothermia. Opposite, in warm environments perspiration will start, possibly leading to hyperthermia in extreme cases. All of these measures are a response to non-comfortable environments. Below some examples of specific discomfort cases are described.

Draught

The sensation of draught depends on the air temperature, the air movement and on how turbulent the movements are. The human body is not able to sense the actual air movements, but it can feel the increased cooling of the skin, which is caused by the air movements.

VELUX roof windows can be a source of draught. Older roof windows with a damaged gasket can be leaky and let cold air into a room in winter. Therefore, frequent maintenance is needed in order to keep the window in a good condition. Old and large panes may cause downdraught from the windows where a cold inside pane temperature cools the air and causes a downward air movement. New low energy panes minimize the risk of draught.

Figure 3.1. Person exposed to uncomfortable air motion.

Radiant temperature asymmetry

The phenomenon can be described with a person facing a fireplace on a cold night. One side of the person feels warm while the other feels cold. The air temperature is the same – the difference in thermal sensation is caused by the difference in radiant temperature between the fireplace and the cold surface.

This phenomenon can be seen in two situations with VELUX products. In wintertime when the inside pane temperature is very cold due to the higher heat loss compared to the walls. But, as for draught, new windows will rarely cause problems. An internal blind or external shutter or awning blind can reduce or eliminate the risk. In summertime when the occupants are exposed to direct sun, solar shading can be used to eliminate the thermal discomfort by blocking the direct solar radiation.

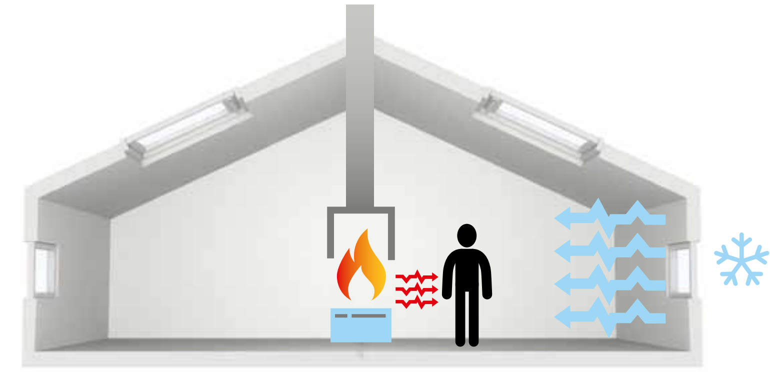


Figure 3.2. Person exposed to one cold and one warm surface.

Remember
Thermal discomfort can in most cases be reduced by user behaviour, such as closing a window, moving to a different position in the room or putting on more clothes.

3.2 Parameters influencing thermal comfort

Many experiments have been made to find out what has an influence on our sensation of the thermal environment [59]. The results of these experiments are the basis for the standard ISO 7730. Ergonomics of the thermal environment [58].

Six parameters have a major influence on the sensation of thermal comfort:

- The activity of a person, commonly referred to as metabolic rate [met].
- How much clothes a person is wearing, commonly referred to as the clothing index [clo].
- The movement of air (air velocity) [m/s].
- The mean radiant temperature [°C], which is a weighted average of the temperature of the different surfaces (walls, ceiling, floor and windows) in a room seen from the position of the occupant.
- The air temperature [°C] in the room.
- The relative humidity in the room.

Of the six parameters, four of them are influenced by windows and their accessories – and by that, VELUX products. The air velocity and relative humidity are influenced by the use of the windows for ventilation; both the ventilation flap and normal opening have an influence. The air temperature and radiant temperature are influenced by the heat transfer and sunlight through the window and by the use of accessories such as blinds and shutters.

A sevenths parameter is also important, namely the human mind. Individual expectations have shown to have an influence on the acceptance of thermal comfort. Especially in warm climates the expectations from the occupants have shown to influence the comfort ranges.

Remember

People are all different and want different thermal environments.

3.3 Adaptation to a warm climate

EN ISO 7730 is based on climate chamber studies, which show that people basically have the same thermal preferences, regardless of where they live on earth [60]. At the same time, field studies show that people working in naturally ventilated office buildings in warm climates accept higher temperatures [61]. The standard EN 15251 provides limits for acceptable indoor temperatures for naturally ventilated buildings. These temperature levels assume that people can freely adapt their clothing and operate windows. Based on the outdoor "running mean" temperature during the last week, acceptable indoor temperatures are found in Figure 3.3. A running mean is a weighted average of a time period where the latest time periods has the largest weight.

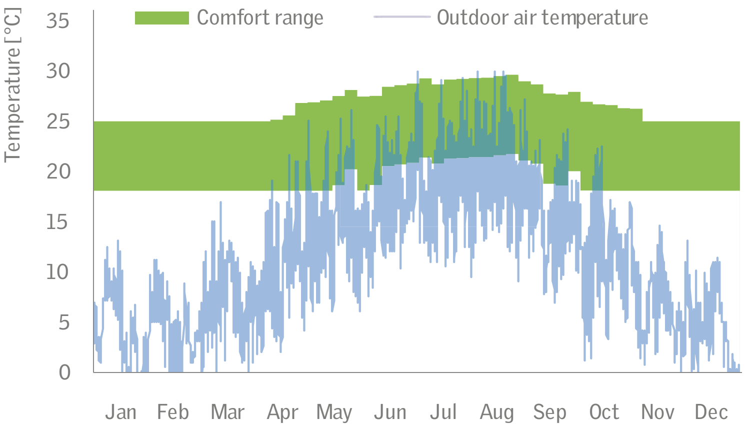


Figure 3.3. The figure shows the comfort range for Denmark. Calculation based on the principles of adaptation [53].

In residential buildings it can be assumed that the occupants will adapt their clothing to obtain comfort and in buildings with VELUX roof windows they will operate the windows, which were the assumptions for using the adaptation method.

The consequence of adaptation is that thermal comfort can be achieved in warm climates without air conditioning by using natural ventilation, solar shading and intelligent building design. This allows large reductions in energy use – see section 5.4.4.

3.4 Influencing thermal comfort with window systems

Windows combined with a heat source (e.g. a fire place) are one of the oldest methods of achieving thermal comfort in buildings. Today the simplest way to achieve thermal comfort is to install a system that can adjust the parameters. Most houses have a heating system installed and in warm climates possibly a cooling system. However, windows can cool down a building on a warm summer day.

Draught and temperature asymmetry can be caused by windows, as mentioned earlier. It can be difficult to determine whether the sensation of coldness is caused by draught from the windows or by cold radiation. A leaky window can have the gasket and/or the pane replaced. Alternatively the whole window should be replaced. Cold radiation can to some extent be avoided with the use of an internal blind that will reduce the inside surface temperature.

Remember
Expectations to the thermal environment in naturally ventilated buildings are dependent on the outdoor temperature.

3.4.1 Blinds and shutters

Blinds and shutters will block the solar radiation and thus reduce the amount of heat entering a room. Overheating during summer can be efficiently reduced and even eliminated by the use of proper solar shading. Solar shading can also improve the thermal performance (heat insulation) of windows in winter by increasing the inner surface temperature of the window. This can reduce thermal discomfort from cold radiation and temperature asymmetry. Even better, when applied at night this extra insulation can decrease the demand for heating. Energy wise, shading should only be used at night during winter because the solar gains are often of greater importance than the heat loss, see section 5.4.3.

Example: The operative temperature for different glazing and accessories.

The measured values are the results of a small experiment. The operative temperature was measured behind the glass unit with different shading accessories to illustrate the effect of different types of shading.

Glazing	Accessories	Operative temperature [°C]
59 Low energy		34.0
76G Low energy, solar protected		29.3
59 Low energy	RFL Roller blind	29.0
59 Low energy	MHL Awning blind	28.7
59 Low energy	MHL + RFL Awning blind + roller blind	26.6
	Shutter	26.2

Example: Solar shading as cooling

A study from CSTB in France made for an attic room investigated how solar shading could be used to assist or replace a mechanical cooling system. Simulations were made for Hamburg, Munich and Stuttgart in Germany and Paris, Lyon and Marseille in France [62,63].
The conclusion was that the experienced temperature could be lowered by up to 7°C when using a solar shading device for locations in both Germany and France. Regarding energy for cooling this was eliminated in all locations except Marseille where it was lowered by 90%. The figure shows the experienced temperature on a typical hot and sunny summer day in Paris with and without solar shading.

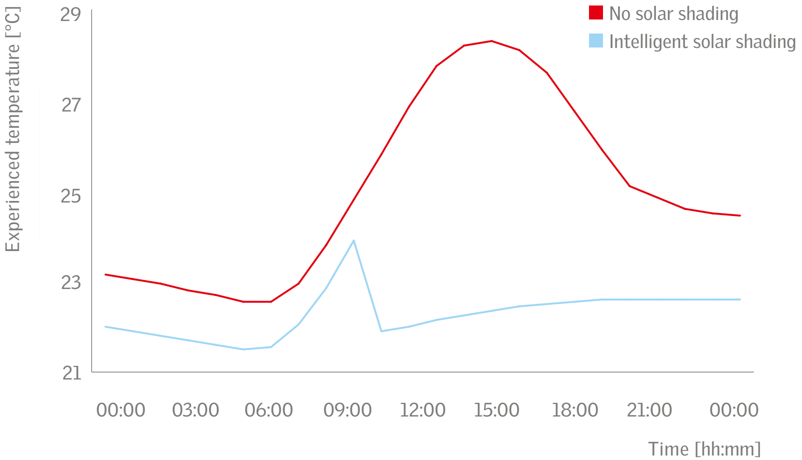


Figure 3.4. Experienced temperature on a hot and sunny day summerday in Paris, France [63].

Remember
Opening of windows reduces overheating efficiently.

3.4.2 Opening of windows (airing)

Airing is a very direct and fast method of influencing the thermal environment. An open window will cause increased air motion and if the outdoor temperature is lower than indoors the temperature will decrease. See the example in section 2.4.5.

Airing strategies

Most people will simply open the windows when it is too warm, but other strategies can be applied. One example is the so called night cooling where the thermal mass of a building is used to keep a low temperature during summer days, see sections 2.4.5 and 2.4.6.

3.4.3 Dynamic window systems

A dynamic window system is not only a window, but consists of different accessories such as an electric window opener, external shading and/or internal blinds, and most important a control system. The control can be carried out by the user but the best solution is a sensor based control. Alternatively, time control can achieve good performance.

The advantage of a dynamic system is the ability to adjust the window and its accessories to fit the actual need of the occupants. If the solar gain causes overheating the external shading is used and when it makes sense energy and comfort wise the shading is rolled off.

The VELUX ACTIVE Climate Control and Energy Balance are good examples of dynamic window systems. Energy Balance is a time-controlled feature available in all VELUX Integra and Solar products controlled by io-homecontrol. The VELUX ACTIVE Climate Control is a sensor based control that can also be used with all electrical VELUX products compatible with io-homecontrol.

The VELUX ACTIVE Climate Control algorithm has been validated by the French building research institute, CSTB, for both German and French locations [62,63]. Their findings are that a dynamic shading control can reduce the experienced temperature by up to 7°C in summer and in most cases eliminate overheating (or reduce the cooling demand by up to 90%).

Remember
Dynamic window systems can reduce overheating and the need for mechanical cooling.

3.5 Evaluation methods

Different methods attempt to express the thermal sensation experienced in a room in a single, easy to understand number.

3.5.1 Operative temperature

The operative temperature is an attempt to provide a number corresponding to the temperature actually experienced by the body. The operative temperature includes air temperature, radiant temperature asymmetry and air velocity in one number, which corresponds to the temperature a person would experience in a space with uniform air and surface temperatures and no air movement [58]. The operative temperature is an intuitive representation of the temperature experienced in a room. However, it does not provide an indication of how the thermal environment is experienced since activity, clothing and expectations are not taken into account in the value.

3.5.2 Predicted Mean Vote (PMV)

PMV is commonly used in scientific literature and is described in [58]. PMV takes into consideration the six parameters mentioned in section 3.2 (metabolic rate, cloth index, air velocity, radiant temperature, air temperature and RH). PMV is a seven point scale ranging from cold (-3) to hot (+3) with 0 as neutral. The PMV value can be a better indication of how the thermal environment is experienced than the operative temperature alone, but it is a more abstract term to many people.

From the PMV-index it is possible to calculate the percentage of people who would be dissatisfied with a specific thermal environment. Different individuals do not have the same comfort levels which is why at least 5% will always be dissatisfied with the thermal environment.

Experienced temperature

PMV is a very technical term and can be difficult to communicate. Instead, a fictive temperature, the experienced temperature, can be calculated from the PMV value. This can be done to explain effects of changes in PMV, for instance higher or lower air velocity, humidity or radiant temperature. Experienced temperature can also include the effect of direct solar radiation and is often relevant when the effect of windows in combination with shading is evaluated.

The PMV index is based on a 7-point scale of thermal sensation:

+3 Hot
+2 Warm
+1 Slightly warm
0 Neutral
-1 Silghtly cool
-2 Cool
-3 Cold

When the six parameters are known it is possible to predict how most people will experience the thermal environment.

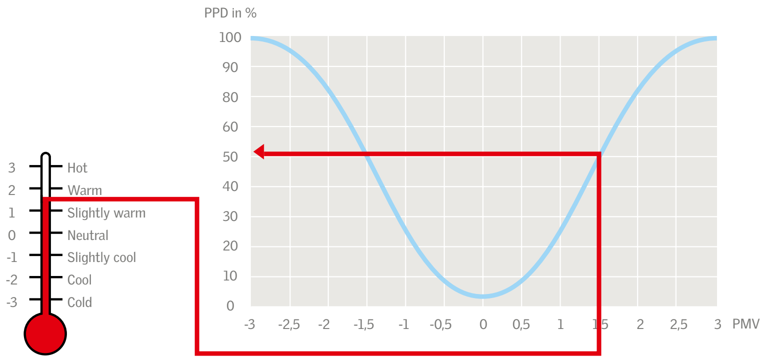


Figure 3.5. The figure shows how the percentage of dissatisfied (PPD) is determined, based on the thermal sensation. The example shows that in a situation where the thermal sensation is slightly warm, just over 50% will be dissatisfied [58].

3.5.3 How to evaluate results

Measured results

The thermal environment can be evaluated by measurements of four of the six parameters: air temperature, humidity, radiant temperature and air velocity. The last two parameters need to be estimated from tables, for instance in [58].

Measured data can be used to illustrate the effects of changes in the parameters. It cannot always be used to evaluate the thermal environment as it only applies to the situation when measured. Also, other factors influence the thermal sensation of the occupants. For instance, moods can have a positive or negative effect on the expectations.

Occupant surveys

Surveys made by the occupants can help identify possible problems with the thermal environment. Questions like: "Do you feel hot/cool?" or "Would you prefer it to be warmer or colder?" can together with measurements help to find the user's preferences.

A disadvantage is that the thermal sensation is subjective and is based on expectations. Again, the psychological state of the occupants will play a large role. If a survey is made in a house occupied by one family and adjusted to their preferences based on surveys, other families might not agree on that.

Dynamic simulations

A dynamic simulation can be used to predict the risk of overheating in a building. The simulation calculates the heat balance of the building, time step by time step. The results show the energy use of the building, but also the temperature. When evaluating dynamic results the number of hours out of the thermal comfort range is the typical method. The hours to be counted are the occupied hours and of those 5% are allowed to be out of range [53]. When making dynamic simulations, the criteria are taken from various standards or legislation and will apply to the average population. The VELUX Energy and Indoor Climate Visualizer can be used for such evaluations.

Example: Passive cooling in warm climates

A study made on passive cooling methods in warm climates is an example of the use of the VELUX Energy and Indoor Climate Visualizer for thermal comfort evaluations. Simulations made for Malaga, Spain show that passive measures such as airings and the use of solar shading can almost eliminate the use of a cooling system [64]. The figure illustrates how the operative temperature is kept in the comfort band (shown in grey) with the use of passive cooling methods whereas no actions result in significant overheating. The results are also quantified as the part of year with good and poor thermal comfort, again showing large improvements of thermal comfort.

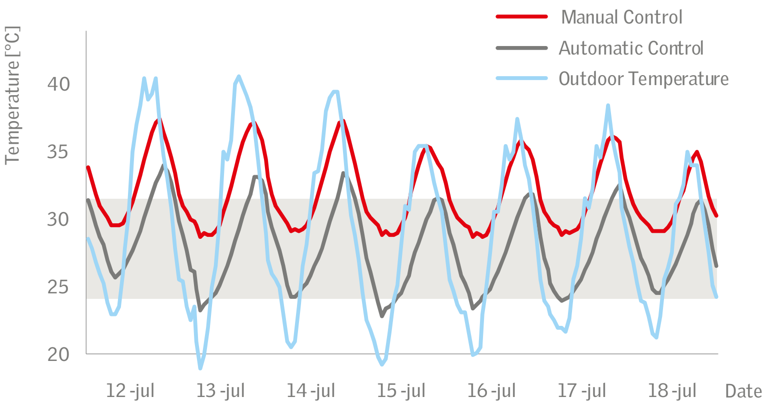


Figure 3.6. The indoor and outdoor temperature by different control methods in June in Malaga, Spain [64].

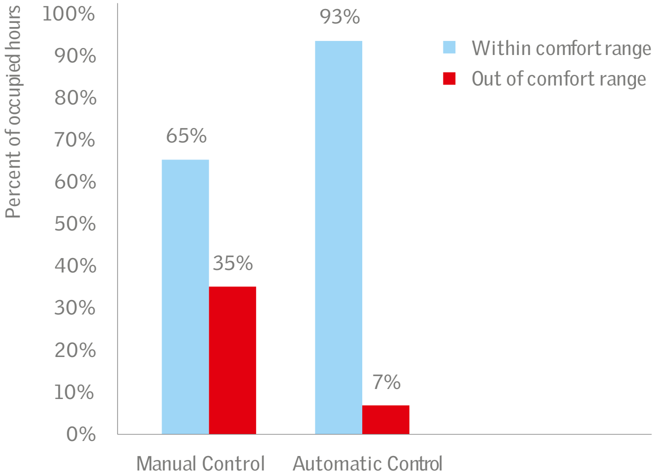


Figure 3.7. The part of year within and out of comfort range by different control methods in Malaga, Spain [64].

3.6 Thermal comfort summary

Thermal comfort can be defined as "that condition of mind which expresses satisfaction with the thermal environment" and is influenced by six parameters:

- Air temperature
- Radiant temperature
- Relative humidity
- Air velocity
- Clothing level
- Activity level

Personal preference and expectations also have an impact on the thermal comfort. Thermal comfort is achieved when the six parameters are in balance. Knowing the parameters makes it possible to estimate the number of satisfied occupants. At least 5% will always be dissatisfied. Adaptation has a significant influence on how we experience the thermal environment and allows for the acceptance of wider temperature ranges in naturally ventilated buildings.

VELUX roof windows have an impact on the four first parameters. The air temperature is influenced by solar shading and venting, the radiant temperature is influenced by solar shading, and humidity and air velocity are influenced by venting.

The VELUX Energy and Indoor Climate Visualizer can be used to make evaluations of thermal comfort in residential buildings. Especially, evaluating cases with different cooling settings is easy with the built-in comparison report feature.

Acoustics

Acoustics

One important function of the building envelope is to protect the interior from unwanted outdoor noise. Sound insulation is an important parameter of building components, as outdoor noise can have negative effects on health, mood and learning capabilities.

4.1 Noise or sound

Human perception plays an important role in identifying if it is noise or sound that we hear. Our subconscious mind will constantly evaluate if a sound is known or unknown, if it's pleasant or annoying. Noise is defined as unwanted sound, even at normal intensity levels.

4.2 Effects of noise on health and learning

Noise can have a significant impact on the health and performance of the building occupants. Stress, headache and learning difficulties can all be caused by the presence of noise. Sleeping problems and lack of rest can also be caused by noise. Especially at night noise is perceived as annoying and special consideration must be taken with sound insulation of bedrooms [65].

Road noise increases the stress level and the risk of cardiovascular diseases. A conservative estimate is that every year in Denmark between 200 and 500 are dying prematurely from cardiovascular diseases and hypertension because of road noise [65].

Remember
Noise can cause stress, headache and learning problems

4.3 Evaluation of sound levels

The physical description of sound is vibrations (longitudinal waves) of the air in a frequency, Hz that people can hear.

Decibel, dB is the unit used to measure sound level and decibels is a logarithmic unit used to describe a ratio. Sometimes you see decibel in dB(A) instead of decibel in dB. The (A) means that you have a total sound level (consisting of many individual frequencies), which is "A-weighted" and thereby equals human subjective perception of sound. In the table below are typical sound levels.

Painful:	120 - 140 dB(A) =	jackhammer, jet plane take-off, amplified music at 0.8 - 1.2 m distance from the loudspeaker
Extremely loud	90 - 110 dB(A) =	rock music, snowmobile, chain saw, pneumatic drill, lawnmower, truck traffic, subway
Very loud	60 - 80 dB(A) =	alarm clock, busy street, busy traffic, vacuum cleaner
Moderate	30 - 50 dB(A) =	conversation, moderate rainfall, quiet room

Figure 4.1. Typical sound levels [66]

Remember
A change of 3 dB is barely noticeable to the human ear, a change of 5 dB is a small difference, a change of 10 dB sounds like double the quietness or loudness [67].

4.4 Outdoor noise levels

4.4.1 Location

The surroundings of a building have a big influence on the expected outdoor noise level. For example, in Austria the outdoor noise level is 60 dB(A) in a city centre and 50 dB(A) in a residential area in suburbs [68].

4.4.2 Parameters affecting outdoor noise level

Many parameters will affect the outdoor noise level at the specific location, some of the parameters are described below [68].

The distance to the noise source has a large influence on the perceived sound level. Each time the distance from the source doubles, the sound level is reduced by approximately 6 dB.

The spread of noise will be affected by the wind direction. Noise in headwind will be bent upwards which gives lower noise levels and in following wind, the noise will be bent downwards resulting in higher sound levels.

The presence of noise barriers or baffles, reflections from and absorption in the surfaces will change and influence the sound level at a specific location. For example, an opposite building, trees (summer or winter appearance), the geometry of the noise barrier and the surface absorption properties will influence the sound level and how it is redirected [3], see figure 4.2.

See the following four different examples of reflections, absorption and baffles:

Remember
Roof windows in a house situated in farmland will normally require less sound insulation compared to a roof window in a city house.

1) A baffle absorbs some noise and reflects noise to the opposite side.
Noise will be reflected from one house to the other.

2) The baffle redirects the noise in the air with less reflection to the house above.

3) A small bush will redirect noise and less will be reflected to the opposite side.

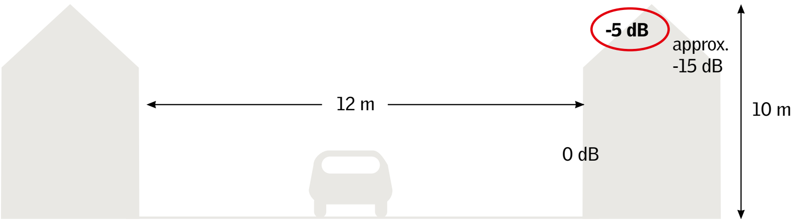
4) The bush has grown large into a tree and now the noise is redirected to the house.

Figure 4.2. Examples of absorption, reflection and redirection.

4.4.3 Determination of adjustment of the road noise level

In the first example shown below, a roof window will experience 8 dB lower noise levels than a façade window in the same building. A roof window facing the backyard even experiences approximately 15 dB lower noise level. The second example shows that an opposing building will reflect some of the noise and reduce the diminution in noise level experienced by the roof window to 5 dB.

1) Shows the reduction of the outdoor noise level on the building envelope where there are no houses opposite.



2) Shows the reduction of the outdoor noise level on the building envelope where there are houses opposite.

Figure 4.3. Example on the effect of neighbouring buildings on the noise level on the roof.

Remember
A roof window will experience an outdoor noise level, which is typically 5 dB lower than a façade window.

4.5 Sound insulation

The individual building components and joints between components of a building contribute to the overall sound insulation of the building envelope. The consequence is that a building envelope that fulfils a certain sound insulation level can consist of various building components with lower and higher sound insulation, but together they will reach the required level.

4.5.1 Measurement of sound insulation

EN ISO 140-3 and EN ISO 717-1 [69,70] are used for test and classification of the sound insulation of a window. The sound insulation found from the measurement is expressed with R_w(C, Ctr) in dB. The R_w value expresses the ability to reduce noise from outside to inside the building. Two correction factors (C and Ctr) are also found from the measurements. The C factor should be used if the source of sound is talking and Ctr should be used when the source of sound is rhythmic music or traffic noise.

A typical roof window with a standard 2 layers glass construction of 4 mm glass, 16 mm spacer and 4 mm glass will reach an R_w of 32 dB.

If further sound insulation is needed, then windows with a pane construction of 3 layers and/or different glass thickness in the different layers will perform better. The VELUX Group has several products that provide improved sound insulation. The 3-layer pane 65 and the 2-layer pane 60G with different glass thickness both achieve a better sound insulation. To go even further, the GGL 62&63 with a 4-layer construction can be used.

4.6 Rain noise

The sound/noise of rain on the roof is perceived differently. For some it is a pleasant sound and for others it is noise. At night most will perceive it as noise if they are awakened by it.

To enable comparison of different products, the international test standard ISO 140-18 has been developed to measure rainfall sound pressure levels.

Furthermore, the French authorities have made investigations limiting the rainfall indoor sound pressure level to SPL_{max}<50 dB so children will not be awakened by the sound of rain [71].

The VELUX Group has developed the first roof window taking directly into account the ability to reduce the noise of rain and with a sound pressure level of 48 dB it fulfils the French authorities' recommendation of a rainfall sound pressure level of max. 50 dB indoor.

VELUX products with a 60G pane and and RNR (Rain Noise Reduction) reduce the rain noise by 7 dB compared to a classic roof window and achieve a SPL_{max} of 48 dB. This meets the French authorities' recommendation of a rainfall sound pressure level of max. 50 dB indoor.

Remember
The VELUX Group has developed the first roof window taking into account the ability to reduce the noise of rain so children will not be awakened by it at night.

4.7 Building acoustic summary

Road noise can cause stress, headache and learning problems.

Acceptable outdoor sound levels depend on location; there will be more noise in a city centre than in rural areas. Therefore, a roof window in a house situated in a rural area will require less sound insulation compared to a roof window in a city house to reach an acceptable indoor sound level.

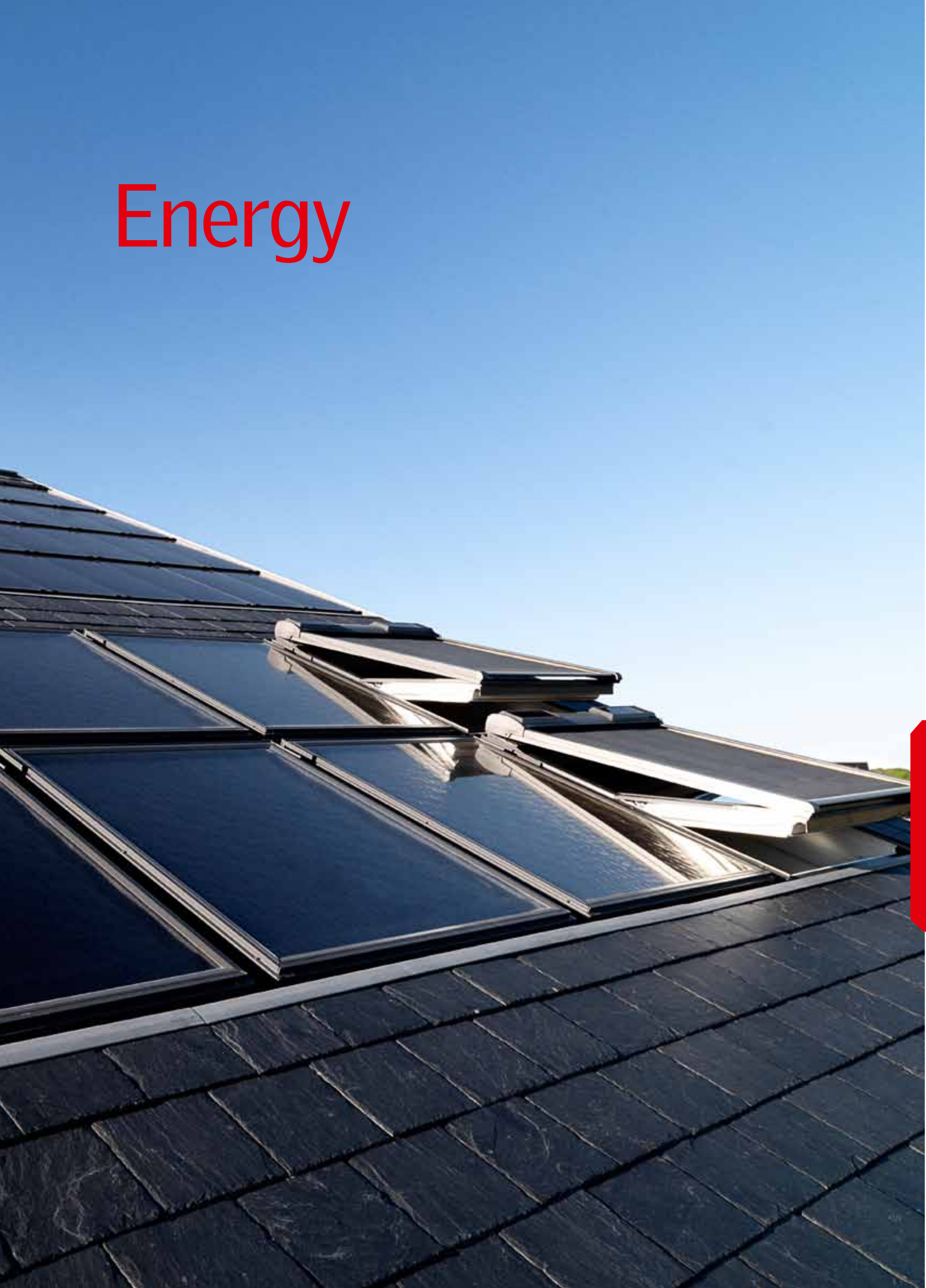
A roof window located in a roof construction facing the street will experience an outdoor road noise level that is typically 5 dB lower compared to the façade window in the same building also facing the street.

The sound insulation for a roof window is the ability to reduce the outdoor sound level. The sound insulation for a roof window is expressed as R_w(C, Ctr) in dB.

If the roof window needs further sound insulation, a solution can be to use an insulation pane with 3 layers or different glass thickness in the pane construction.

The VELUX Group has developed the first roof window directly taking into account the ability to reduce the noise of rain and with a sound pressure level of 48 dB that meets the French authorities' recommendation of a rain noise level of max. 50 dB indoor.

Energy



Energy

During the last decades there has been an increasing focus on energy consumption, not least on the energy consumption of buildings where efficient use of energy is an important part of the solution. A reduced dependence on fossil fuels and increased use of renewable energy are also of importance.

The world's energy demand has doubled during the last 40 years [72] and the increasing amount of fossil fuel used to cover this demand has had, and still has, a severe impact on the climate [73]. Furthermore, estimates suggest that we, with our present dependence on fossil fuels, will only have supplies for the next 200 years [55]. All over the world there is an increasing concern about these issues and most countries take actions both regarding the amount of energy we consume and the dependence on fossil fuels.

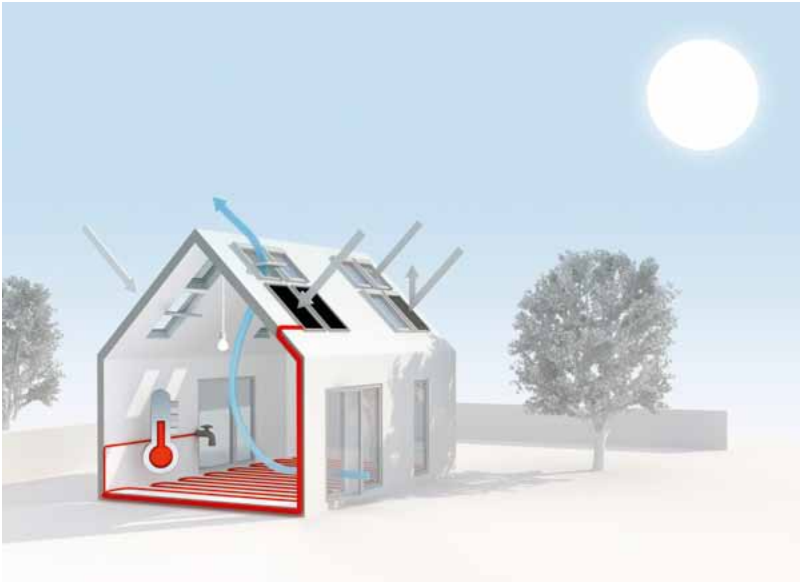
In Europe buildings take up 40% of the total energy consumption [74]. In the European Union there is a saving potential of 20-50% by refurbishment of the existing buildings and with more strict regulations of new buildings [75]. And products, such as solar thermal systems and more costly options like small windmills or PV-panels, make it possible for homeowners to produce their own renewable energy and by that change the source of energy.

5.1 Energy terminology

The VELUX Group's current terminology on energy use and windows includes two concepts: "Energy Performance" and "Energy Balance" [76].

Energy performance refers to the total yearly energy demand of a building including heating, cooling, hot water and electric lighting (household appliances or other electrical equipment are not included). Energy performance is often expressed in kWh per year per m^2 of heated floor area (kWh/m^2). The lower the value, the better. Energy performance can be used to find the difference between two scenarios, e.g. impact of more or less VELUX roof windows on the energy performance of a building. It can be calculated with dynamic simulation tools, among others the VELUX Energy and Indoor Climate Visualizer. See section 7.2 for more information.

Energy balance refers to a single window and is expressed in kWh/m² per year for the window. The value expresses the energy efficiency of the window alone and can be used to compare different windows with regard to type, size, pane and other parameters. See section 5.3.2 for more information on this subject.



Remember

Buildings represent 40% of the energy consumption in the EU. Windows have a substantial impact on the energy consumption in buildings and on the indoor environment. However, the effect can be both positive and negative and care has to be taken to use the advantages of windows and avoid the disadvantages.

5.2 Energy use in buildings

Most of the energy used in buildings is used to maintain a comfortable indoor environment in terms of thermal comfort (heating or cooling) and air quality (ventilation). Other energy uses are electrical light, domestic hot water and household appliances or other electrical equipment (refrigerators, computers, TVs etc.).

Figure 5.1. Illustration of the flow of energy through a building on an annual basis. The amount of energy, which is supplied from an external source, is less than the total heat loss of the building, because occupants, electrical devices and especially windows add "free" energy.

While the energy consumption for heating in Denmark has been reduced during the last four decades due to efforts in legislation, the electricity consumption has risen [77]. Similar trends on the electricity consumption are expected to be seen in the rest of the western world. The reason is an increased number of consumer electronics such as TVs, computers, stereos, portable music players, etc., which are not covered by legislative requirements for energy efficiency.

When designing a building or planning for refurbishing, it is important to use energy efficient solutions, and perhaps even more important to do so without compromising the quality of the indoor environment. In the end, buildings are built to protect us from the weather and keep us comfortable. However, considerate design can reduce the energy demand significantly.

» The sun supplies thousands of times more energy than used per year on earth «

5.2.1 Energy sources

Energy for use in buildings can be produced locally at the building or at a remote location. Local production is often a furnace burning oil, natural gas, wood etc., or it can be a geothermal resource e.g. a heat pump. Furnaces are mainly used for heating and hot water. Other local sources are renewable sources such as solar collectors or photovoltaic (PV).

Remote production of electricity is mainly based on combustion of fossil fuels, biomass or waste, or by nuclear power. Heat can also be produced in a remote location in form of district heating. District heating can be produced in combination with electricity plants (combined heat and power, CHP) making it a very energy efficient method. In later years central solar heating plants have been built in connection with district heating systems. Generally there is a great interest in renewable energy sources, but today most of the world's energy demand is still covered by fossil fuels.

Fossil fuels emit CO_2 when converted to heat or electricity. The CO_2 causes climate changes [73] and the reserves are on their way to depletion. Renewable sources (wind energy, hydro power, solar power, etc.) are all powered by the sun, an almost unlimited source of energy.

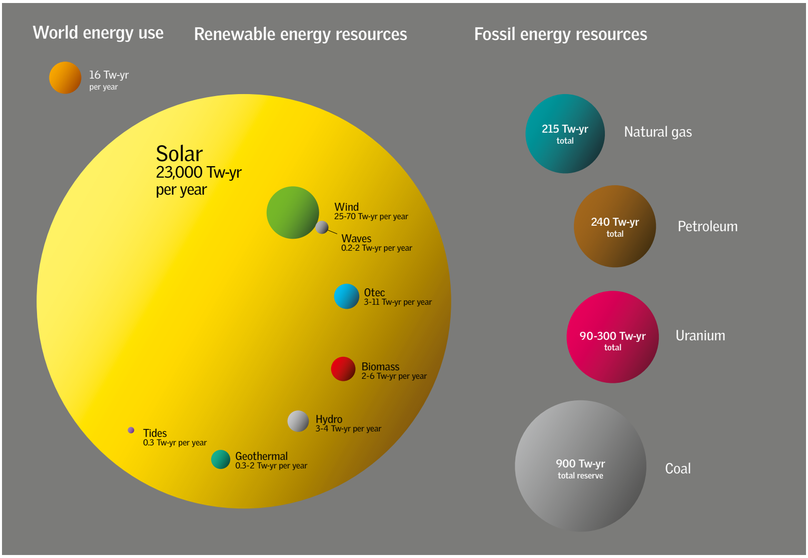


Figure 5.2. The available energy sources compared to the world total energy use [5].

In Figure 5.2. the total energy resources are compared to the total energy demand. Estimates suggest that we will run out of oil and gas in the 21st century and coal and uranium in the 22nd century [55] whereas the sun will not burn out for billions of years.

5.2.2 Primary energy vs. net energy

Net energy (or final energy) is often the result of energy performance calculations. Different energy sources have different utilization factors and different impact on the environment and should, therefore, be weighted differently. The concept of "primary energy" is that a factor for each energy source is used to weigh each source with regard to environmental impact. The factor is multiplied by the energy demand and can be different for different types of energy.

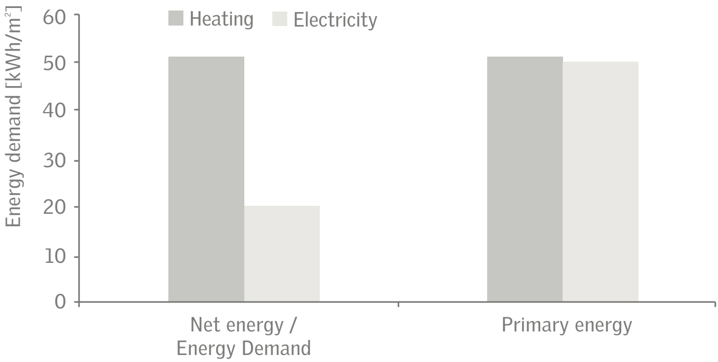


Figure 5.3. Energy demand for an existing Danish house for heating and electricity (cooling, ventilation fans and lighting) compared with the primary energy (factor = 2.5).

In Norway and Sweden a lot of the electricity production is hydro powered and thus does not have a great impact on the environment; the primary energy factor for electricity in Sweden is 2.35 [78]. In Germany the main energy source for electricity production is still coal, which has a much greater impact; the primary energy factor for electricity in Germany is 2.7 [79].

In the UK the primary energy factor for natural gas is 1.02 and 2.92 for electricity, [80]. Figure 5.3 illustrates the difference between net energy and primary energy; the net heating demand is substantially higher than the net electricity demand, whereas the primary energy demand for heating and electricity is approximately the same.

Remember
Primary energy is different from net energy. Primary energy includes the effect of "converting" e.g. coal to electricity. Electricity production requires more fuel (e.g. coal or gas) than heat production, and this is the background for the primary energy conversion factor, which is between 2.5 and 3.0 for most European countries.

5.3 Window systems

5.3.1 Glazing

U-value

The U-value of a building component expresses the amount of energy that is transmitted from the warm side to the cold side. The lower the U-value, the less energy is transmitted. It is often the aim to reduce the U-value of building components to reduce the heat loss, and thereby the heating demand, of the building.

The U-value is expressed in W/m^{2}K. In glazing constructions, heat is transferred from the inside through the insulating glass unit to the outside by radiation, convection (warm air rises, cold air falls), and conduction. The U-value for windows is denominated U_w and is a combination of the frame U_f-value and the glazing U_g-value.

To reduce the convection loss inside the glazing cavity, the cavity can be filled with gas, e.g. Argon or Krypton. To reduce the radiation heat transfer, low emissivity coatings can be applied to one of the glass panes facing the cavity. By adding internal or external shading devices to the window, the U-value can also be reduced by reducing the radiation to the sky and by improving the heat resistance. See section 5.4.3.

The optimum cavity thickness is about 15 mm for Argon and about 10 mm for Krypton. In general VELUX roof windows are mainly made with Argon.

It is common practice to declare U_w for sloped windows at 90°, i.e. as façade windows.

U-value for sloped windows (roof windows)

As roof windows are installed in sloped constructions, the U_w-value will be higher than for windows installed vertically.

This has an effect on the energy performance of a building, since the heat loss through the roof window is increased due to the larger U_w-value. On the other hand, the amount of solar gain and daylight are also increased. The reason that the U_w-value is increased for roof windows is that the convective heat loss in the air gap is increased.

Roof windows are also exposed to a larger part of the sky than façade windows and are normally installed without any constructive shadows, thus increasing the amount of daylight and solar gain as seen in section 1.4.2.

g-value

The g-value (total solar gain transmittance) is quantified by the amount of solar gain entering through the window. The g-value of glazing is a measure of the solar gain transmitted through the glazing. The g-value is defined as the ratio between the solar gain transmitted through the glazing and the incident solar gain on the glazing. The g-value will be in the range of 0–1 (or 0 – 100%).

» Dynamic window systems with VELUX ACTIVE Climate Control improve both the winter and summer energy balance of window systems «

Dynamic window systems

The g-value of a combination of window and accessories, as for example solar shading, is dynamic and can be changed according to indoor and outdoor conditions. The shading can be controlled by the user or automatically with e.g. VELUX ACTIVE Climate Control.

Coatings

By using coated glass, parts of the solar gain can be blocked by reducing the g-value. Depending on the type of coating, different parts of the spectrum can be blocked. For solar protective coatings the goal is usually to block as much as possible of the near infrared radiation and allow as much of the visible radiation to penetrate the coating. For clear coatings the goal is usually to allow as much of the total solar radiation as possible to penetrate the coating. Even clear uncoated glass will reduce some wavelengths more than others. Coated glass will always affect the colour perception indoors.

5.3.2 Energy balance

The term energy balance is used to describe the energy characteristics of a window. The intention is to communicate the balance between solar gain and heat loss. Energy balance is calculated as the sum of usable solar gain through the window during the heating season minus any heat loss. Energy balance is a more accurate way of describing the energy characteristics of a window than just the U_w-value, as energy balance includes both U_w-value and g-value to provide a more complete picture.

Methods

In general, the energy balance of a window is determined by determining the amount of useful solar gain during a year and withdrawing the total heat loss through the window from that. However, since the solar gain during the heating season contributes positively to the heating demand, it may have a negative effect during a possible cooling season.

The higher the energy balance, the better. Energy balance is quantified in kWh per m^2 of window.

The amount of solar gain has to be found for both the heating and the cooling season respectively. For the heating season the useful solar gain is determined by a utilization factor multiplied by the amount of incident solar gain on

the window. It is very dependent on the building type and location. If the building is well insulated the utilization factor is low (e.g. about 70%), while it is high (e.g. about 90%) for a poorly insulated building.

The amount of solar gain reaching the window is dependent on the slope of the window and the orientation.
The total heat loss from a window is dependent on U_w-value and the air permeability.

The heat loss through a window is found for both the heating and the cooling season respectively and determined by the amount of heat degree hours for a year where there is a heat loss during the heating and the cooling season respectively. It is dependent on the building type (insulation level) and the climatic conditions.

The energy balance for windows for the heating season can be expressed as:

Energy Balance = $I_{solar} \times g_w - D \times (U_{w,slope}$ + air permeability)) [kWh/m^2]

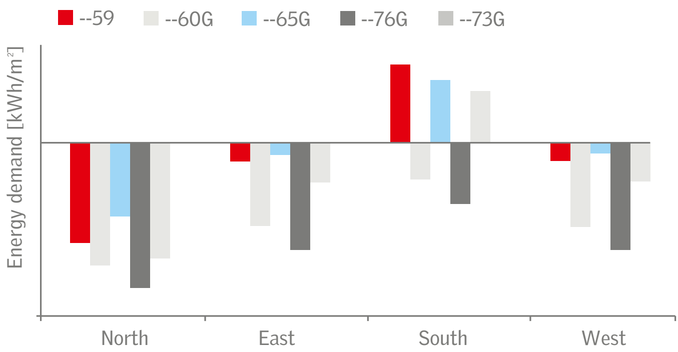


Figure 5.4 Energy balance for roof windows for each orientation during the heating season based on the method proposed for the Danish 2010 Building Regulations [81].

» Roof windows have in general a better energy balance than facade windows during the heating season «

In some European countries (UK, DK) a simplified definition of energy balance for façade windows during the heating season has existed for some years. It is important to note that the energy balance for roof windows during the heating season is in general better than the energy balance for façade windows, which is why it is important that they are distinguished from each other.

The simplified method for energy balance considers only existing buildings with a specific distribution of windows per orientation. This method is shown in [82]. In the 2010 Danish Building Regulations [81], energy balance for windows will be recognized as a legislative requirement for window replacements.

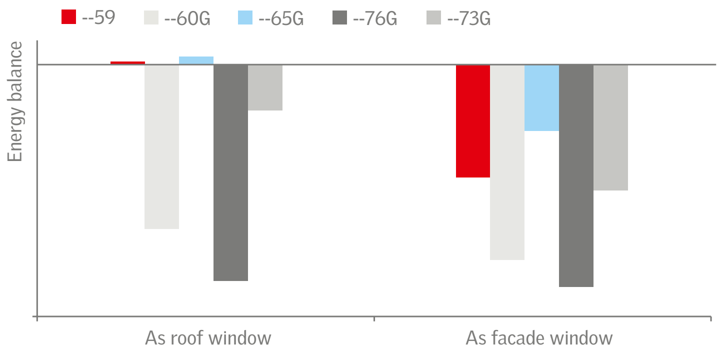


Figure 5.5 Energy balance for roof and facade windows with different pane types for the heating season, based on the current draft for the Danish 2010 Building Regulations [81].

Remember
Energy balance is expressed in kWh/m² window. If the figure is positive, the window adds energy to the building.

Remember
The Energy balance for south-orientated windows is better than other orientations.

» The use of energy balance ensures that the best available window product can be chosen. The higher the energy balance, the better the window performs «

The VELUX Group is convinced that energy balance is a more correct and robust metric for the performance of windows than U_w-value and the VELUX Group is working for a standardized method for determining the Energy Balance [83].

» For existing buildings the tendency is that the g-value is at least as important as the U-value for the energy performance «

Remember

The energy balance of a window depends on the type of building where the window is installed, the orientation and slope of the window and the geographical location.

5.4 Energy performance

5.4.1 Energy aspects of daylight

By using daylight to its full potential, the electricity demand for lighting during daytime can be significantly reduced or even eliminated.

The Architectural Energy Corporation has stated [84] that "Daylighting can drastically improve the energy efficiency of a space with adequate control of electrical lighting and solar heat gain".

In offices, the electricity demand for lighting can account for as much as 40-50% of the total energy demand [85], which can results in significant savings if replaced by daylighting. In order to quantify the energy savings on electric lighting, it is necessary to know the number of hours for which daylight is an autonomous light source in the interior. The relevant light levels for residential buildings were discussed in section 1.6.1.

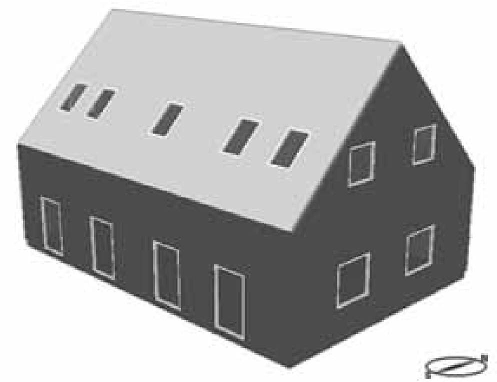
The optimal use of windows in buildings to provide good daylight conditions with good energy performance requires a careful selection of the window characteristics τ_v, g (and U_w). Due to laws of physics, the g-value will always be at least 50% of τ_v.

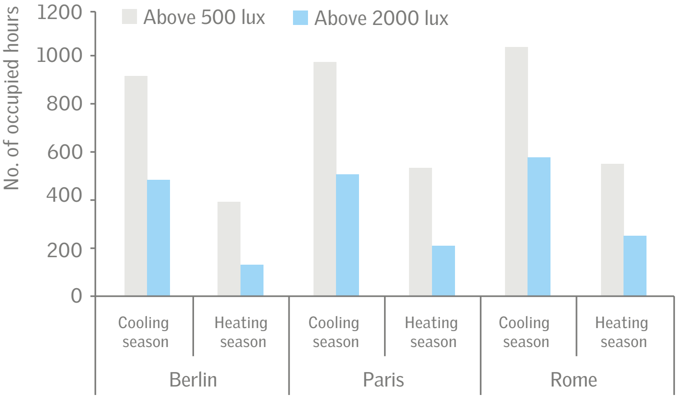
The best solution is often a combination of window and solar shading. A window with high g-value and high τ_v-value will generally provide a good result. High values of g and τ_v will perform well in the part of year with least light, and during parts of the year with excessive light, solar shading should be used.
It is important that the design of the building and the placement of windows in the building are planned as part of a holistic process where the requirements for daylight and energy performance are continuously evaluated and used as design parameters [86].

The following example illustrates that high light levels are achieved with daylight and that windows are very energy efficient light sources.

Example: Energy performance of a house without windows

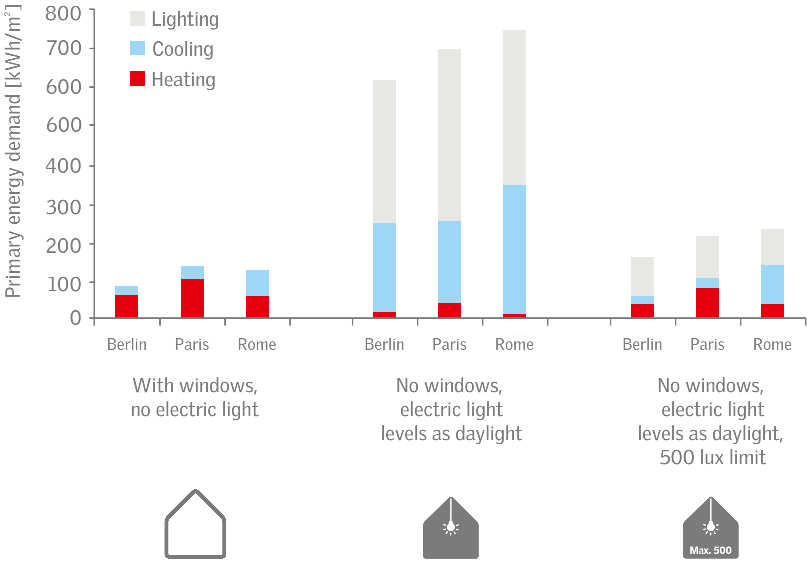
In a typical house, the light level achieved with daylight is determined for every hour of the year. Four locations are investigated: Berlin, Paris, Rome and Istanbul. High light levels (above 2 000 lux) are achieved achieved all year round as illustrated in the figure below.





What impact does daylight have on the energy use in a building? To answer this it has been investigated what would happen if there were no windows in the house and the light levels should be achieved with electric lighting. As the amount of electric light influences the heating and cooling need, the resulting energy use for lighting, cooling and heating in the building must be evaluated together. The results from VELUX Energy and Indoor Climate Visualizer are shown in the following figure.

» Windows are low energy light sources «

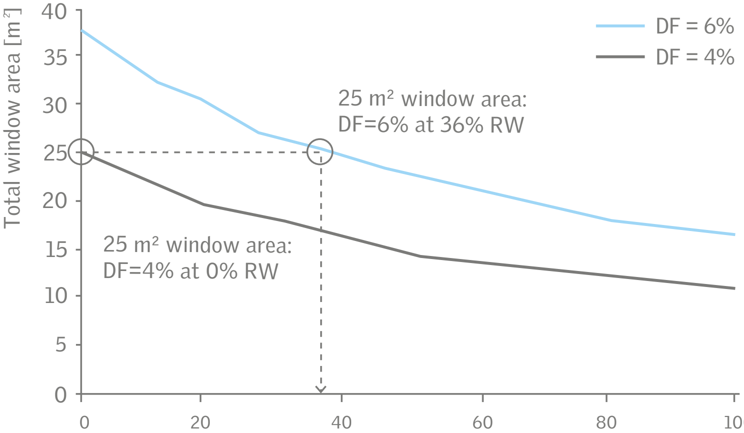


For each location the lowest total primary energy demand is achieved by the building with light provided by windows. The energy demand of the building without windows is approximately 5 times higher than the building with windows if we use electric light to obtain the same light levels. This underlines that windows are low energy light sources [87].

Example: Impact of roof window area on daylight and energy performance
It was shown in the daylight chapter that roof windows deliver more daylight than façade windows. For an actual building that means that a specific daylight factor can be achieved with less window area if roof windows are used.

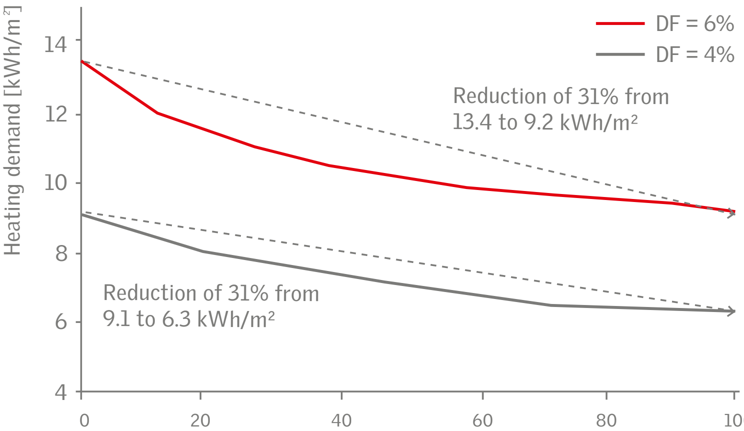
A low energy 1-storey house with an 8 x 18 m footprint located in Berlin has been investigated. The VELUX Daylight Visualizer was used to find combinations of roof and façade windows areas that reach a daylight factor of 4% and 6%, respectively.

» The use of roof windows will result in higher daylight factors «



By increasing the percentage of roof windows, a higher daylight factor can be achieved. A total window area of 25 m² of façade windows only will provide a DF of 4%, while 25 m² with a mix of 64% façade windows and 36% roof windows will provides a DF of 6%, as indicated by the dotted lines on the figure.

Next the VELUX Energy and Indoor Climate Visualizer was used to determine the heating demand for each combination of RW and FW. The results are shown in the figure below



The energy performance is improved by increased roof window area. For DF = 4% the heating demand is reduced from 9.1 to 6.3 kWh/m², and for DF = 6%, the heating demand is reduced from 13.4 to 9.2 kWh/m². Both reductions correspond to 31%.

» Natural ventilation in combination with mechanical ventilation is more energy efficient than mechanical ventilation alone «

5.4.2 Energy aspects of ventilation

Ventilation – and particularly natural ventilation – has an influence on the energy demand for heating, cooling and electricity for fan operation.

Ventilation and heating

When the outdoor temperature is below the indoor temperature, energy for heating is required to increase the temperature of the fresh air to the desired indoor temperature. The magnitude of the energy demand depends on the ventilation rate and the temperature difference.

Heat recovery units can be used to recover (reuse) most of the heat of the extract air to heat up the fresh outdoor air before it is supplied to the building. Heat recovery systems are generally only available with mechanical ventilation, as it requires a physical unit through which both the supply and extract air can be circulated. Up to 90% of the heat can be recovered.

Electricity is used to operate the mechanical ventilation system, but this amount of energy is small compared to the amount of energy that can be recovered when the outdoor temperature is low. Therefore, mechanical ventilation with heat recovery is an energy efficient solution for new airtight buildings during winter. However, leaky buildings will have less benefit from heat recovery as mentioned in section 2.2.2. Mechanical ventilation also requires maintenance (filter changes and cleaning, etc.), which should be considered.

When the outdoor temperature is in the range of 14-18°C (depending on the building), there is no need for energy to heat the supply air. In this situation natural ventilation is more energy efficient than mechanical ventilation, since no electricity is used for fan operation. The combination of natural and mechanical ventilation is called hybrid ventilation.

See section 2.2.3 for an example of the energy savings that can be achieved with hybrid ventilation, and section 2.3.1 for an example of the impact on energy demand of the ventilation rate.

Remember
Hybrid ventilation uses no electricity for fan operation during the summertime.

Natural ventilation and cooling

When the outdoor temperature in combination with solar gains causes the indoor temperature to rise, there is a risk of overheating. In some buildings this is handled with air conditioning, but natural ventilation is an efficient alternative. As a substitute for air conditioning, natural ventilation saves energy. Natural ventilation can be used during daytime (summer ventilation) to control the temperature, as mentioned in section 2.4.5.

Natural ventilation can also be used during night time (night cooling), to cool the building and thus prevent the use of air conditioning the following day, as mentioned in section 2.4.6.

Night cooling works by cooling the constructions in the house. The effect is larger if the building is "heavy". Concrete and bricks are "heavy" materials, so a building with concrete or bricks as wall, ceiling or floor materials is "heavy".

5.4.3 Energy aspects of solar shading

Solar shading has an important influence on the energy performance of buildings. The use of solar shading affects both the g-value and the U-value, and solar shading can, therefore, be used both in warm and cold climates to improve the energy performance of buildings. And as solar shading is dynamic – it can be activated when useful – it is an important part of the window system.

External shading prevents solar heat gains more efficiently than internal shadings. External shading is, therefore, the best choice when the purpose of shading is to prevent overheating and reduce the electricity demand for cooling.

Internal shading does provide some reduction of overheating. Internal shading is generally more efficient at increasing the insulation of the window system, which means that the heating demand of the building can be reduced if used correctly. Internal shading also serves the purpose of controlling daylight.

VELUX ACTIVE Climate Control is an example of a dynamic window system, where the use of the solar shading is optimized automatically without any interaction from the user, thus reducing the need for heating and cooling, while the indoor comfort is improved significantly [88].

5.4.4 Building energy performance in warm climates

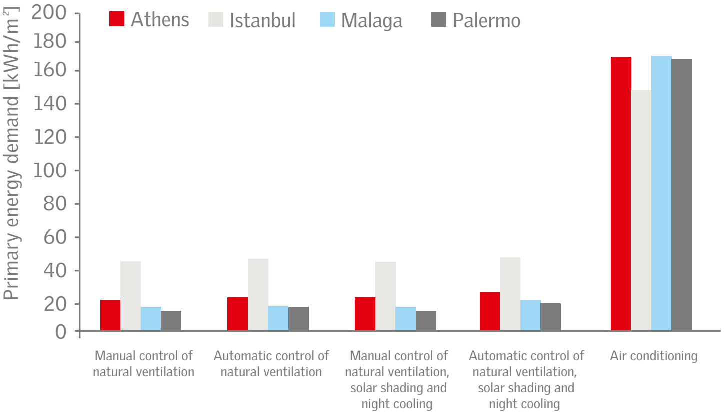
In warm climates the main design objective is to achieve thermal comfort during the warm part of the year, rather than to minimize the heating demand during the cold part of the year.
As seen in the previous sections, the electricity demand for cooling can be minimized and often eliminated by using natural ventilation, night cooling and automatic solar shading in combination with intelligent building design, where the shape and orientation of the building provide shading and thus reduce the peak loads of solar gains.

It has been shown in section 3.3 that thermal comfort in naturally ventilated buildings can be achieved at indoor temperatures above 26°C due to adaptation.

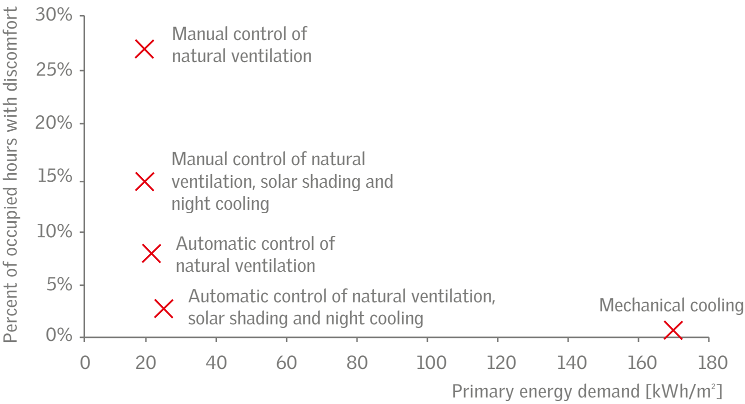
The main target should, therefore, be to design the building without a cooling system and instead use solar shading and natural ventilation to avoid unneeded energy use.

Example: Solar shading and natural ventilation provide good energy performance and thermal comfort in warm climates.

The performance of a typical building in 4 cities in warm climates was investigated with the VELUX Energy and Indoor Climate Visualizer. Different combinations of solar shading and natural ventilation were investigated and compared to an air conditioned house. The investigated cities were Athens, Istanbul, Malaga and Palermo [64].
The energy performance of the building with air conditioning was in the range of 150 – 160 kWh/m^2, which is 3 to 10 times worse than the buildings without air conditioning.



The houses without air conditioning also achieve acceptable thermal comfort. The graph below represents results from Athens and shows that acceptable thermal comfort can be achieved in 98-99% of the time with automatic control of natural ventilation, solar shading and night cooling.



The figure shows both energy performance and thermal comfort for Athens and shows that the thermal comfort achieved with an automatic control is as good as with mechanical cooling.

5.4.5 Building energy performance in cold climates

In cold climates, the main design objective is to minimize the heating demand and the electricity demand for lighting. Secondarily, the electricity demand for fan operation should be minimized and the building should be designed without need for cooling.

Windows provide useful solar gains every month of the year, also during the summer months. The energy evaluation should, therefore, be based on annual calculations such as e.g. the VELUX Energy and Indoor Climate Visualizer can be used for. The example in Figure 5.6 shows that the useful solar gains in May to August in Denmark are substantial, which means that even though there are cold days and nights also in the summertime, heating is usually not needed during the warm months.

The importance of solar gains during the summer is illustrated in the following example.

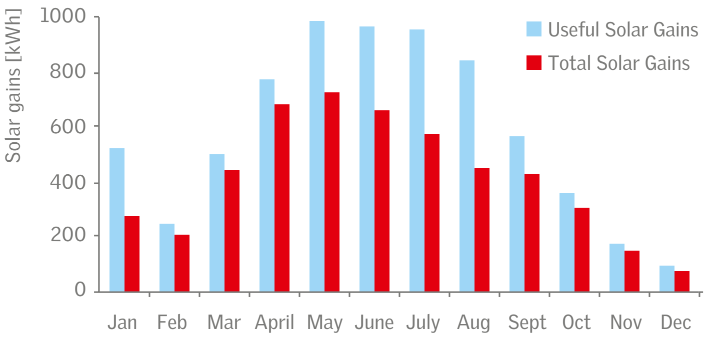


Figure 5.6. Example of useful solar gains in an existing building in Denmark.

Remember

Windows provide solar gain all year round – not just in the wintertime. The solar heat gain through windows is the main reason why we can in many cases can turn off the heating during summer even in cold climates.

» The energy performance of an existing house could be worsened if the windows were removed «

Example: Energy performance of a house without windows

The heating energy performance of a building with windows is compared to a building without windows. The building is located in Berlin. The table below shows the results for four different construction periods. The calculations were performed in BSim.

	GGL 59	GGL 65G	No windows
Low energy building (2020)	25 kWh/m²	20 kWh/m²	20 kWh/m²
New building (2005)	61 kWh/m²	56 kWh/m²	61 kWh/m²
Existing building (1980)	87 kWh/m²	82 kWh/m²	93 kWh/m²
Existing building (1940)	146 kWh/m²	143 kWh/m²	162 kWh/m²

For a new or future building, the energy performance of the house without windows is of the same magnitude as the house with windows, which means that the solar gains of the windows are of the same magnitude as the additional heat loss.

For existing buildings, the house with windows performs better than the house without windows.

5.4.6 Consequences of future requirements for better energy performance

Current trends in European and national legislation point towards a continued focus on energy in the building legislation, which means that the minimum requirements for the energy performance of new buildings as well as refurbishments will be tightened.

Cold climates

As seen in section 5.3.2, the energy balance of windows depends on the building where they are installed. In section 5.4.5 there was an example of how much of the annual solar gains that can be utilized in an existing building in northern Europe. In a high-performing building the heat loss is low and, therefore, less solar gains can be used.

In high-performing buildings, the focus of windows will be on low U_w-value rather than high g-value.

The example shows that the relative saving by using 3-layered glazing is largest for low energy buildings, while only small savings are seen for existing buildings.

Example: Relevance of 3-layered glazing in high-performing buildings

The previous example showed the impact of using 2-layered vs. 3-layered glazing in Berlin in a typical house of four different construction periods. In the table below, the relative reductions by using a 3-layered pane compared to a 2-layered pane are shown.

	Low energy building (2020)	New building (2005)	Existing building (1980)	Existing building (1940)
Relative reduction of heating demand	17%	7%	6%	2%

Remember
For high-performing buildings, the window U-value is becoming increasingly important compared to the g-value, because less solar gains can be used in low energy buildings.

5.4.7 Renewable energy supply with solar thermal systems

In the previous sections on energy, we discussed how the space heating and cooling demand of buildings can be reduced by using the optimal combination of windows and accessories. The focus of this section is the possibilities of using free, renewable energy from the sun to supply part of the remaining energy demand of a building.

Solar thermal systems can be used to provide solar energy for room heating and for domestic hot water production. By using solar energy, a building's demand for conventional energy is reduced, which means that the solar thermal system contributes to reduced emissions of greenhouse gases. The only running cost associated with solar thermal systems is electricity for the pump and control system, which is approximately 80 kWh annually.

The VELUX solar collectors are designed to be integrated into the roof to match VELUX roof windows in size and quality, or they can be individually installed using the VELUX range of flashings. Most solar thermal systems are designed to produce domestic hot water.

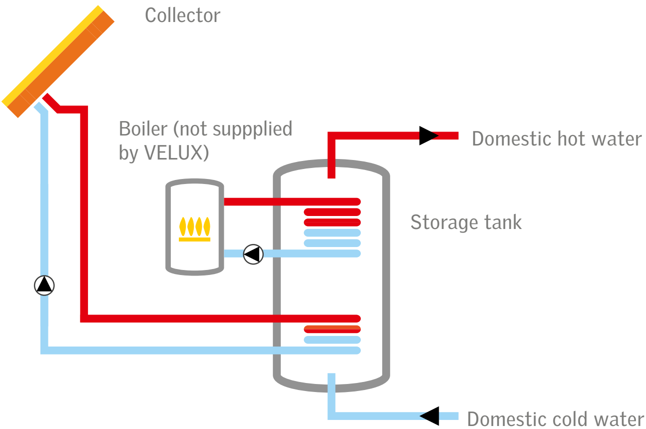


Figure 5.7. Diagram of a solar thermal system for domestic hot water production. A VELUX system includes all required components, i.e. collector, tank, pipes, control system and pump.

A solar thermal system produces energy when the sun is shining. The energy is stored in a water tank, which is sized to hold the domestic hot water consumption of a building for 1-2 days. Such a tank holds 200-300 litres for a typical family. The optimal area of solar collectors for a building will meet the daily domestic hot water demand of a building during the summer months. In the less sunny parts of the year, the solar thermal system will also produce energy. The energy produced in a year is divided by the domestic hot water demand of the building; this number is called the solar fraction and expresses how large a part of the domestic hot water demand is supplied by the solar thermal system. Systems are designed to provide a solar fraction between 60% and 75%.

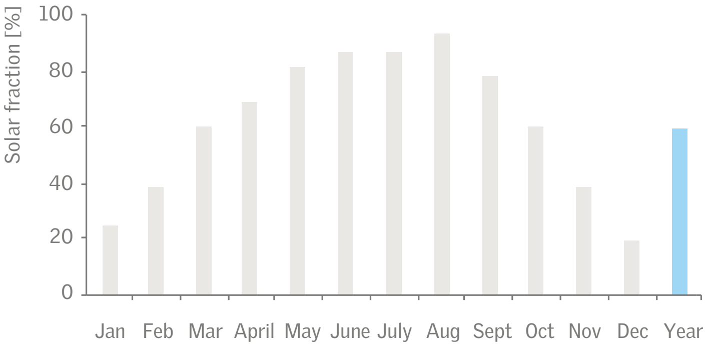
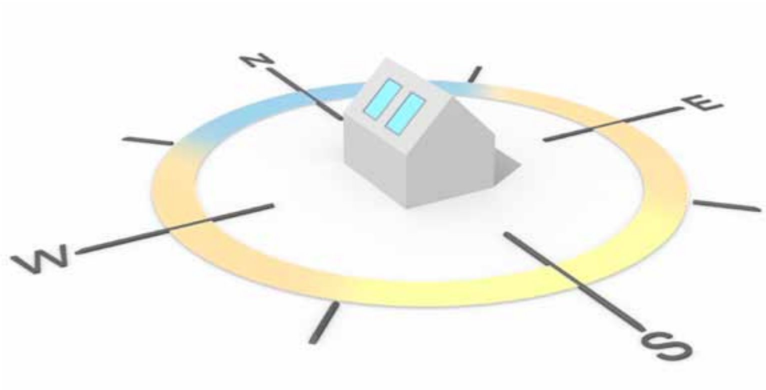


Figure 5.8. Example of the monthly solar fraction in London, UK. The solar fraction is almost 90% in the summer and 60% on an annual basis.

Remember
Solar collectors can provide up to 75% of the energy demand for domestic hot water.



The area of solar collectors required for a specific house depends on the solar intensity at the location of the house. The annual energy gain from the sun in southern Europe is approximately 50% higher than the gain in northern Europe. Solar collectors have the highest performance when they are installed on a south-facing roof with a 45° slope. But collectors installed at a different slope or orientation will still have a performance close to optimal. South-facing collectors perform at 91% if installed close to vertical or horizontal position, as illustrated by the table below.

	South	SE or SW	East or west
Slope 15°	91%	89%	82%
Slope 30°	96%	92%	82%
Slope 45°	100%	95%	81%
Slope 60°	101%	96%	79%
Slope 75°	98%	98%	75%
Slope 90°	91%	91%	69%

The table shows the relative performance of solar collectors depending on slope and orientation. Collectors facing south with a 45° slope has a relative performance of 100%. Collectors installed towards the SE at a 60° slope will have a relative performance of 96%.

5.5 Energy summary

The energy systems we have today are dependent on fossil fuels. Renewable alternatives are available and the sun alone supplies 1500 times more energy to the earth than used per year.

Buildings represent 40% of the energy use in the EU. National and EU legislation aims to reduce this while increasing the renewable share of the energy system.

Windows have a substantial impact on the total energy demand of buildings as windows provide daylight and useful solar gains all year, but energy is also lost through the windows.

The energy balance for a window characterizes the window with respect to energy and enables a better choice of window product and a better ranking of different types of windows than U-value and g-value alone. Solar shading improves both the U-value and g-value of window systems and with the VELUX ACTIVE Climate Control they can be controlled dynamically for optimal performance.

Windows are energy efficient providers of daylight, and daylight should be included when windows are evaluated with respect to energy.

Energy efficient ventilation of new buildings can be achieved with a combination of natural ventilation and mechanical ventilation, as natural ventilation is the most energy efficient solution for a substantial part of the year. During summertime, natural ventilation efficiently reduces overheating.

Environment

Environment tools

Environment, in this book´s context, refers to the built, constructed surroundings that provide the setting for human activity, ranging from the large-scale civic surroundings to the personal places. Environment includes a large number of subjects, each with a specific purpose, and is typically very complex in content and use. This section attempts to provide an overview of the most common environmental themes with a brief introduction to the topic.

6.1 Life Cycle Assessments

The essence of an environmental assessment is to identify environmental impacts throughout a product's life, from the first raw material to disposal of the product. This is called a Life Cycle Assessment (LCA).

Raw material production is the first step in the cycle, followed by production itself. The next part is the use of the product and finally disposing of it. Disposal can include recycling or reuse of all of the product or parts of it. Amidst all the steps in the cycle is the transport factor that must also be included in the life cycle assessment.

An LCA results in an inventory of the product's global, regional and local environmental effects, consumption of renewable and non-renewable energy and the consumption of resources.

The assessed effects are [89]:

Global

- **Global warming potential (kg CO_2-equivalent)**
  is the measure of how much a given mass of any of the greenhouse gasses (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O)) and a number of fluorinated gaseous compounds (HFCs, PFCs, SF_6) are contributing to global warming. The unit for the global warming potential is kg CO_2 equivalents which means that the potential of any greenhouse gas is converted to CO_2-equivalents.

- **Ozone depletion potential (kg R11-equivalent)**
  Ozone depletion caused by anthropogenic (halocarbons) emissions of halocarbons, eg. CFCs.

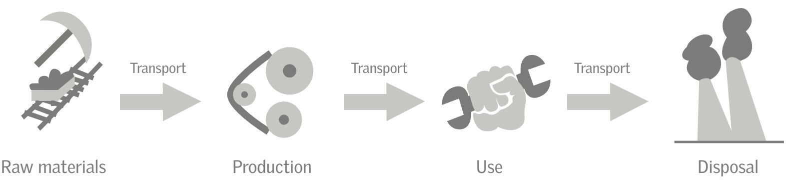


Figure 6.1. The different phases in an LCA.

Regional

- **Acidification potential (kg SO_4-equivalent)**
  is a process in soil and water caused by the burning of sulphur-containing products.

- **Nutrient enrichment potential (kg NO_3-equivalent)**
  Discharge of nitrogen from agriculture and combustion processes can among other things lead to large blooms of algae.

- **Photochemical oxidant potential (kg ethene-equivalent)**
  is emissions of "volatile organic compounds" (VOCs), which react with NO_x which comes mainly from cars. This reaction is better known as smog.

Local

- **Ecotoxicity of soil and water (m^3 soil and water)**
  is the toxic effects of a released chemical and causes damage or even dead to the environment.

- **Human toxicity of air, soil and water (m^3 air, soil and water)**
  is toxic effects accumulated through the ecosystems, e.g. fish exposed to heavy metals. In the following text are Carbon footprint and Cradle to cradle assessments are briefly described.

Carbon footprint

A "Carbon footprint" is a subset of a full LCA, where greenhouse gas (e.g. CO_2) emissions are evaluated. It is a measure of how much greenhouse gas is emitted through our activities, e.g. transport. "Carbon footprint" is measured in tons or kg of CO_2 equivalents and is divided into primary and secondary footprints. The primary footprint comes from energy and transport, and the secondary footprint comes from the use of the product [90].

Cradle to Cradle

LCA describes a typical product from cradle to grave, but in recent years a different philosophy of environmental thinking has gained ground which is called "Cradle to Cradle". The main idea is that we cannot continue to live on earth if we do not reduce the amount of waste and stop using fossil fuels and emitting problematic chemicals. The design philosophy is based on three principles of sustainability:

1. Waste must be considered as food / raw material for the next product.
2. Renewable energy must be exploited.
3. Diversity must be valued. Products designed based on Cradle to Cradle will have a neutral or positive impact on the environment. Although the Cradle to Cradle is formulated several years ago, the use in product development and production is still immature [91].

6.2 Environmental assessment of buildings

The assessment schemes mentioned in this section all operate with several levels of sustainability and, consequently, also several levels of certification.

6.2.1 LEED (USA)

LEED (Leadership in Energy & Environmental Design) is an American system that verifies that the building is designed based on strategies to achieve a minimum energy and water consumption, material selection with a low impact on the surroundings, reduction of CO_2 emissions and good indoor climate as well as stewardship of resources and sensitivity to their impacts. LEED can handle both commercial and residential buildings and assesses the entire life of the building from design, construction, operation and maintenance. LEED is also used outside America [92].

6.2.2 BREEAM (UK)

BREEAM (Building Resource Establishments Environmental Assessment Method) is a British system, which is very similar to the LEED system. BREEAM uses trained assessors to evaluate the project and "Best practice" is an established basis for an evaluation. BREEAM is well established in the UK where all new public buildings must be certified by BREEAM, but BREEAM is also used outside the UK [93].

6.2.3 DGNB (DE)

DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) is a relatively new German system that goes a step further to look at several more aspects in the assessment and and considers its approach more thoroughly than LEED and BREEAM. In CEN, the standardization organ of EU, the technical committee TC350 is working on new standards for building assessment and DGNB is using this newest work as a starting point. In the example DGNB also takes into account the energy that has been used to produce the materials for the building component [94].

6.2.4 Passivhaus (D)

The Passivhaus concept has existed in Germany since the 1990's, providing target values for heating requirements, building air tightness and total primary energy demand. Additionally, the building does not make use of a conventional heating system. The Passivhaus concept is a certification scheme and calculations for annual energy consumption for heating, hot water and household electricity are evaluated against the requirements [95].

6.2.5 Active House

Active Houses is a new vision that can be applied to both new-built or renovation projects and they can be homes, offices or public buildings. Active House proposes a target framework for how to design and renovate such buildings that contribute positively to human health and well-being by focusing on the indoor and outdoor environment and the use of renewable energy.

An Active House is evaluated on the basis of the interaction between energy consumption, indoor climate conditions and impact on the environment.

The VELUX group is among the initiators of the Active House vision [96].

6.2.6 Green building rating systems around the world

There are many building rating systems and below are some of those not mentioned above:

- Japan: CASBEE
- Australia: Nabers / Green Star
- China: GB Evaluation standard for green building
- Finland: PromisE
- France: Care & Bio, Chantier Carbone and HQE
- Italy: Protocollo Itaca
- Netherlands: BREEAM Netherlands
- New Zealand: Green Star NZ
- Portugal: LiderA
- Spain: VERDE
- Switzerland: Minergie
- United States: Green Globes

6.3 Life Cycle Assessment of Building Products

6.3.1 VELUX LCA model

The VELUX Group has developed an LCA model for VELUX products which can be used to establish a secure LCA evaluation. Input parameters to the model are the materials used for the product and the quantities used for each product. A scenario for the phase of use is also part of the evaluation, including the location where the window system is installed and the user pattern of the building.

An example of a question, which an LCA assessment can answer, is whether it is best to use internal or external blinds from an environmental impact point of view. Or what is the CO_2 impact of a given VELUX product in a specific installation and use? Figure 6.2 shows an example of the CO_2 impact of a GGL with a BDX in a building in Berlin.

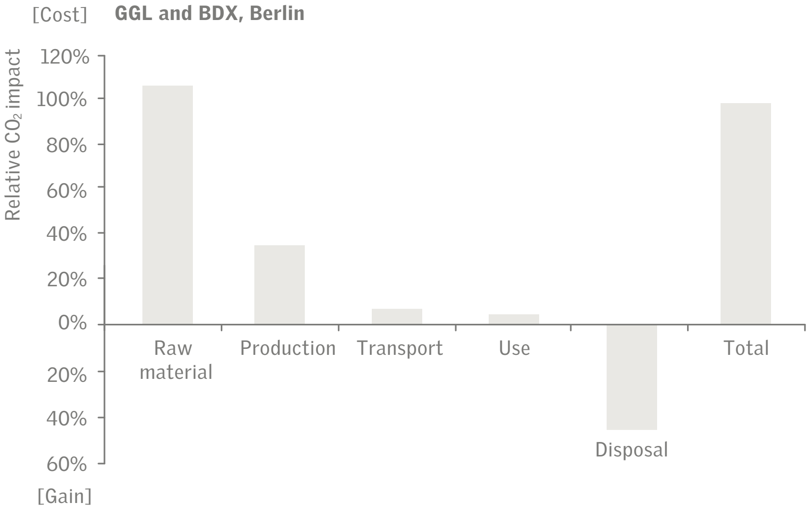


Figure 6.2. The CO_2 impact of a GGL with BDX installed in Berlin.

6.3.2 Forest certification schemes

The two most important forest certification schemes are PEFC and FSC. The Programme for the Endorsement of Forest Certification (PEFC) is committed to promote sustainable forest management through independent third party forest certification. The Forest Stewardship Council (FSC) is an international network to promote responsible management of the world's forests.

The VELUX factories were some of the first to start working with the new standards that were adopted by FSC and PEFC in autumn 2004 and some of our factories succeeded in obtaining FSC and/or PEFC certification as early as in 2004.

This means that we can now document that the majority of our windows come from certified factories. All the factories that produce VELUX windows are owned by the VELUX Group, so we are in control of the whole process from the wood leaves the suppliers' sawmills till the windows have been manufactured in the factories.

Our FSC or PEFC certified factories are controlled by an independent third party who verifies on an ongoing basis that we live up to the requirements in the FSC and PEFC standards [97,98].

PEFC
PEFC/09-31-020

PEFC certified
VELUX wooden roof windows are from sustainably managed forest and controlled sources
www.pefc.org

6.4 Environment summary

Life cycle analyses (LCA) is used to evaluate the environmental impact of e.g. a product from raw material, production, use, disposal and transport. A full LCA results in an inventory of the global, regional and environmental impacts of the product, e.g. green house gasses including CO_2. The CO_2 impact is sometimes called a Carbon footprint and is typically assessed in tons or kg of CO_2 equivalents.

While LCA looks at the life of a product from cradle to grave another assessment model called Cradle to Cradle goes a step further. The philosophy of Cradle to Cradle is different from the LCA philosophy, with a main difference being that waste materials are considered as resources for the next product.

Building assessment schemes have been developed on national level and work on a European standard has started. Today there are several schemes, i.e. LEED (USA), BREEAM (UK), Passivhaus (D) and others. The most extensive model is DGNB (DE) which is included in the work in the coming European standard. There are also more holistic concepts and visions for the assessment of a building, such as "Active house" where energy consumption, indoor climate and the surroundings are included.

The VELUX Group has developed an LCA model for VELUX products and this model can for a specific case be used to determine the environmental impact of products including the CO_2 impact of a given product.

Since 2004, the VELUX Group has worked with the forest certification schemes, FSC and PEFC to commit to promoting sustainable forest management.

Simulation tools

Simulation tools

The VELUX Group has developed simulation tools for the evaluation of building performance which permit to demonstrate the effects of VELUX products on the daylighting, energy and indoor climate performance of buildings.

The tools have been used to create most of the examples in this book. Selected examples used in this book are also found on the websites.

7.1 VELUX Daylight Visualizer

The VELUX Daylight Visualizer is a simple tool for daylighting design and analysis. It is intended to show the effect of VELUX products and to promote the use of daylight in buildings by predicting daylight levels and the appearance of a space prior to realization of the building design.

The VELUX Daylight Visualizer is based on the validated lighting engine DALI by LUXION Aps [99,100].

Intuitive user interface

The intuitive design of the user interface makes it easy to use and accessible. The simulation process has been divided into distinctive steps, which are displayed on a progress bar at the top of the screen to provide user guidance. Each of these steps consists of a series of inputs defined by the user using simple mouse interactions, menu selections and numerical inputs.

The user interface remains simple and easy to use whether you are creating your own 3D model for daylight analysis within the VELUX Daylight Visualizer or are importing it from another application such as AutoCAD.

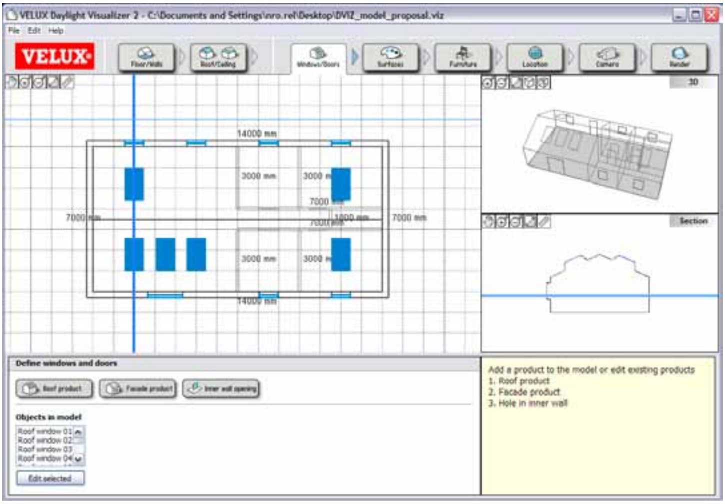


Figure 7.1. Screenshot of the 3D modeller user interface.

3D modeler

The 3D modeler permits quick generation of 3D models in which roof and façade windows are freely inserted. Modeling operations, such as the insertion of windows, have been automated and simplified in order to make the creation of 3D models accessible to a wide range of users.

3D importer

The 3D importer permits to import 3D models generated by other CAD programs in order to facilitate a good workflow and provide flexibility to the models geometry. It is possible to import model in the following formats: OBJ, DWG, DXF, SKP.

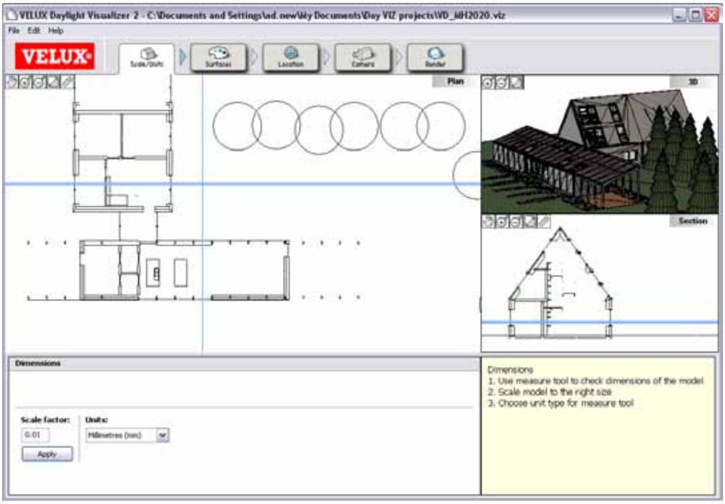


Figure 7.2. Screenshot of the 3D importer user interface showing VELUX MH2020.

Predefined settings

The VELUX Daylight Visualizer uses predefined settings to simplify the assignment of the model and simulation properties, and to ensure that valid inputs are used. The figures below show the assignment of predefined surface properties as well as the rendering specifications.

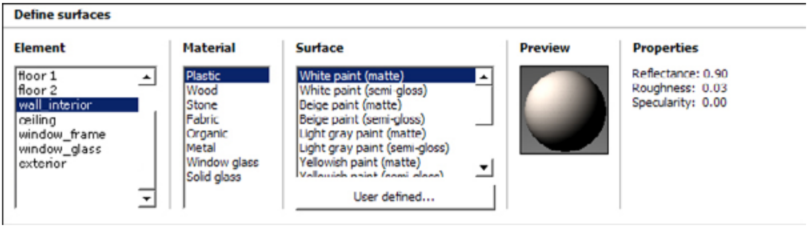


Figure 7.3. Screenshot showing the assignment of predefined surfaces.

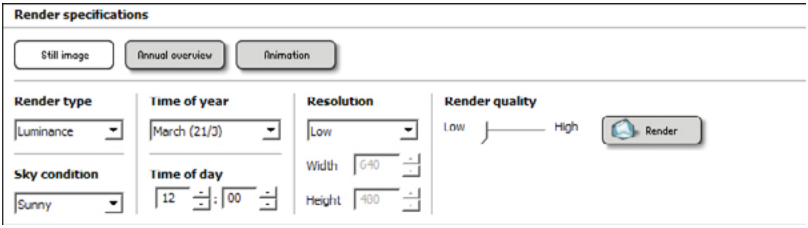


Figure 7.4. Screenshot showing the rendering specifications.

Results

The Daylight Visualizer 2 uses recognized metrics and performance indicators to assess the availability and quality of daylight in buildings, including illuminance (lux), luminance (cd/m^2) and daylight factor (%), described in section 1.6. Simulation can be performed in the form of still images or time-lapse animations.

The simulation results can be visualized, analysed and saved through an output viewer in which you can assign false-colour or iso-contour mapping to the rendered images and read pixel values.

Luminance

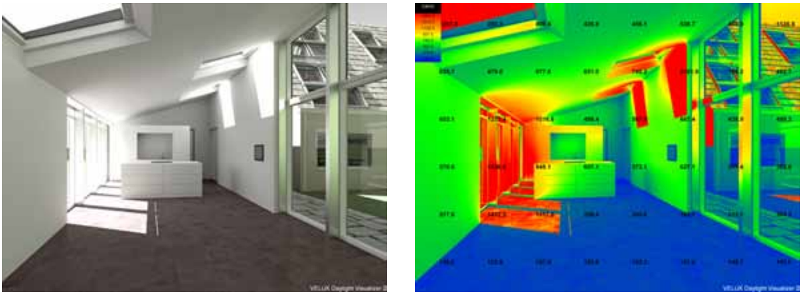


Figure 7.5. Luminance rendering of VELUX MH2020 under sunny sky conditions.

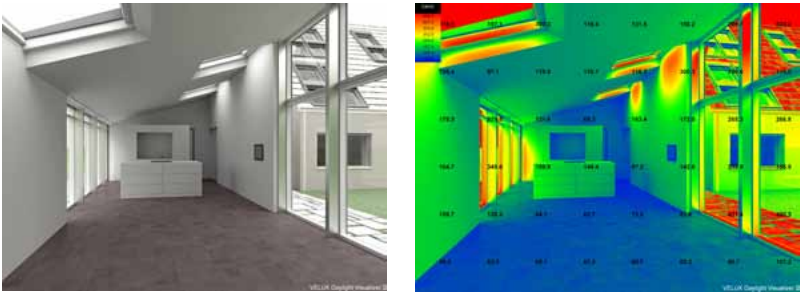


Figure 7.6. Luminance rendering of VELUX MH2020 under overcast sky conditions.

Illuminance

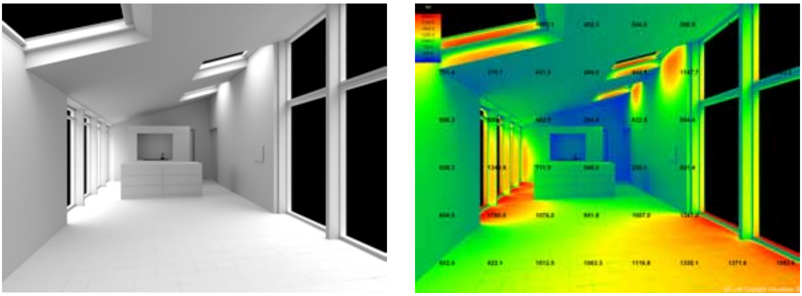


Figure 7.7. Illuminance rendering of VELUX MH2020 under overcast sky conditions.

Daylight factor

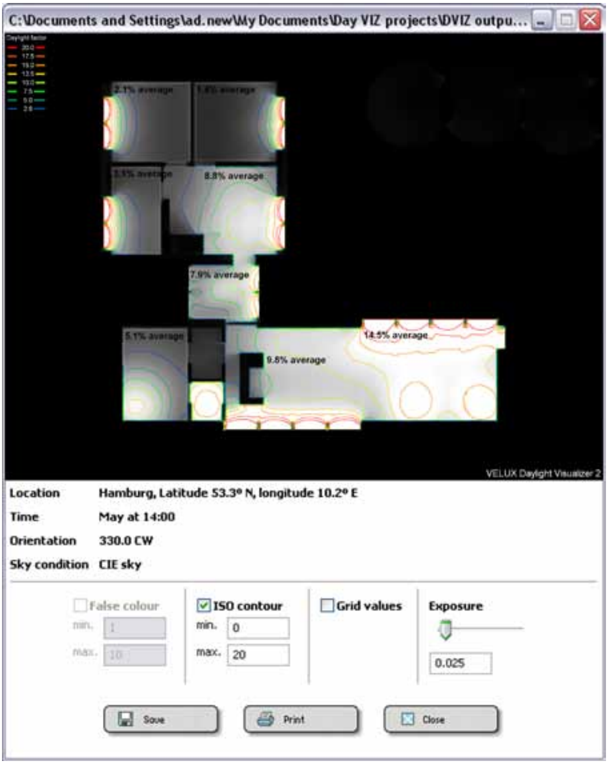


Figure 7.8. Screenshot of a daylight factor rendering in the VELUX Daylight Visualizer output viewer.

7.2 VELUX Energy and Indoor Climate Visualizer

The VELUX Energy and Indoor Climate Visualizer is used to design and evaluate residential buildings with a holistic approach to daylight, indoor climate and energy [101]. It focuses on the effects of VELUX products, while including all the information needed for detailed building performance simulations.

The EIC Visualizer is based on the validated IDA ICE engine by EQUA Simulation AB [102,103,104,105].

Intuitive user interface

It has an intuitive user interface where the navigation is based on seven tabs, which provide an overview of the steps to be taken to perform a simulation. The building model is visualized as a rotatable 3D representation.

For all input values, a default value is provided which is reasonable for residential buildings. This means that it is only necessary to change specific input values related to the project, and not necessarily all input values.

The user interface supports an integrated workflow. Figure 7.9 illustrates the start of the process, where the geometry of the house is defined. Predefined house geometries are available for easy and quick model generation, and it will be possible to import any house 3D models in version 2.0, which will be released by autumn 2010.

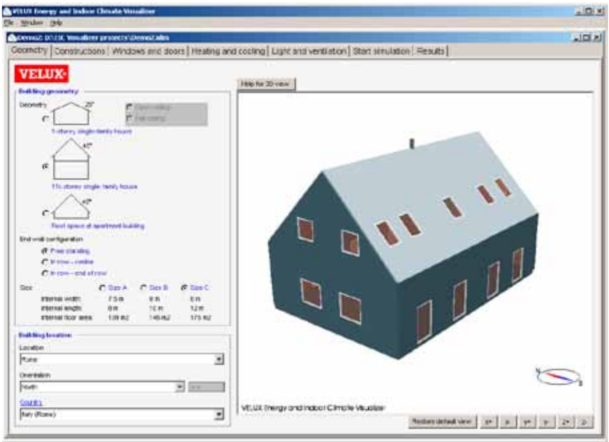


Figure 7.9. The building geometry is easily selected from 3 pre-defined geometries

Windows and doors are inserted after the geometry and construction have been defined, and a wide range of VELUX products including roof windows and accessories are available, as shown in Figure 7.10.

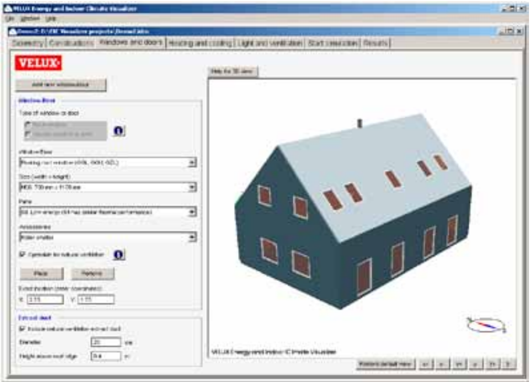


Figure 7.10. Windows can be inserted at any location and with any combination of pane, window type, window size and accessories.

After the house geometry and windows have been defined, controls for heating, lighting, cooling and ventilation need to be selected. Figure 7.11 shows the controls for ventilation, where you can select from a range of typical natural ventilation controls.

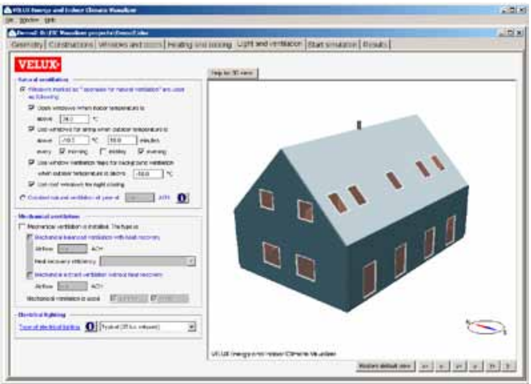


Figure 7.11. The control options for natural ventilation represent the typical use of windows for ventilation. The focus is on maintaining a good IAQ as well as preventing overheating.

Results

The results report provides an overview of key results. The report can compare results for several models, which are relevant for design optimisation. Additional advice and guidance can be included in the report which assist in the interpretation of the results. The results report is divided into sections on Energy, Thermal comfort, Ventilation, and Air Quality.

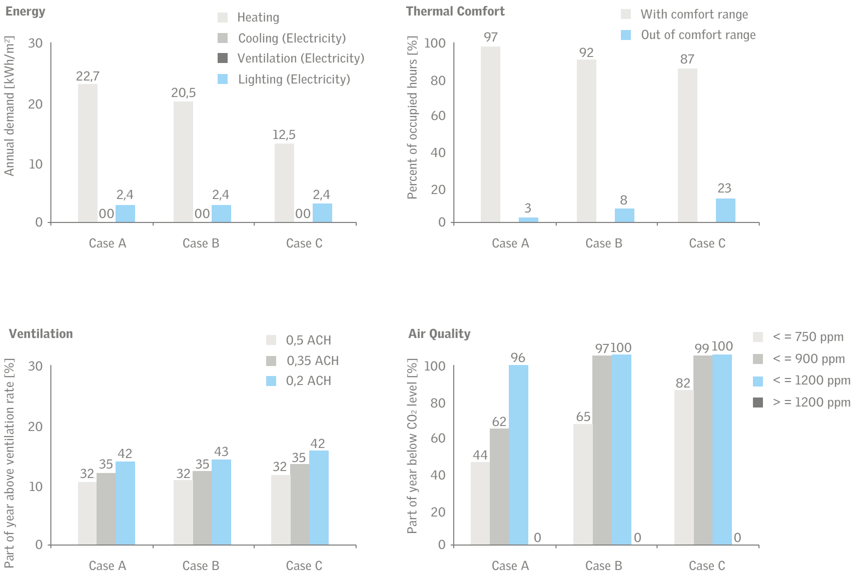


Figure 7.12 Example of results from 3 cases which are compared using the VELUX Energy and Indoor Climate Visualizer Comparison report

Animation of ventilation flows

Natural ventilation flows through windows can be visualized by an annual animation. The airflows are visualized as coloured arrows with size and colour representing the flow magnitude and direction.

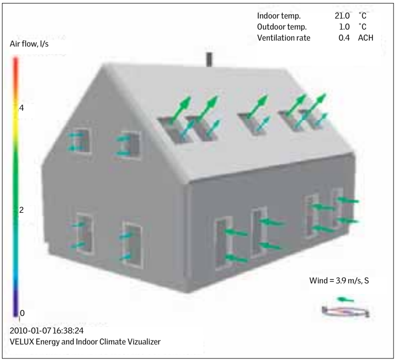


Figure 7.13. An example of the animation of natural ventilation flows

Visualization of thermal comfort

The evaluation of thermal comfort reflects the fact that humans adapt to high outdoor temperatures, as is shown in section 3.3. The indoor temperatures from several models can be displayed in a graph with the comfort range shown as a solid stripe in the background. The comfort range will change over the year depending on outdoor temperature, and the graph will easily show when overheating occurs. The graph can be used to identify which remedies should be used to reduce overheating.

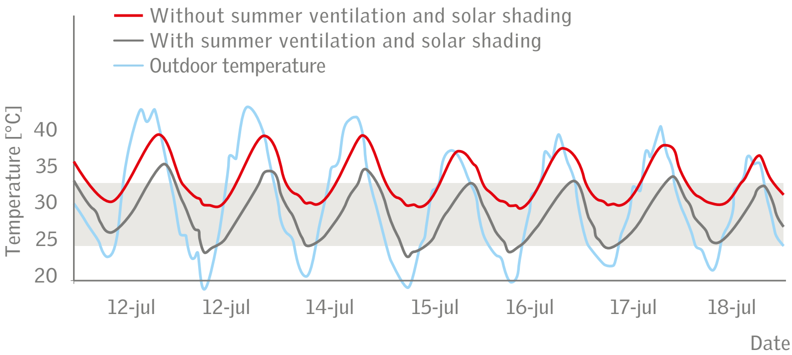


Figure 7.14. Evaluation of indoor temperatures according to EN 15251.

7.3 Using simulation tools for performance evaluations

The VELUX Visualizer simulation tools are used together to evaluate and optimise building performance holistically with regard to daylight, energy and indoor climate altogether rather than to optimise individual elements.

It is essential that the first design evaluation is performed at a very early state of the design process, and that the architects and engineers work together in the design process and that the Visualizer output is continuously used to steer the process. This process will maintain focus on Key Performance Indicators and help ensure a building design with good and balanced performance on daylight, energy, thermal comfort and air quality.

The first step in the process is the initial evaluation of daylight, energy and indoor climate performance. If weak points are identified in the design, improvements can be suggested and the effect of these can be evaluated with the VELUX Visualizers.

Thus, the process of using the VELUX Visualizers is often that an initial building design is evaluated, and several possible design alterations are considered and evaluated, ending in a final design proposal.

The process involves several runs of the VELUX Visualizers which should lead to a well-performing final design, see Figure 7.15.

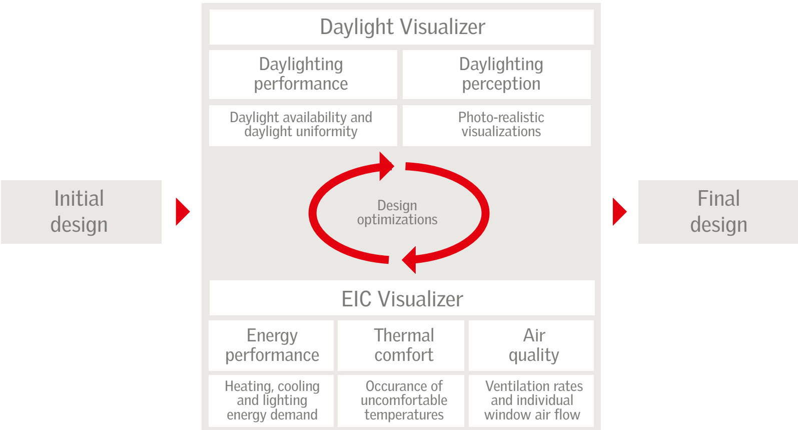


Figure 7.15. The integrated design process, where the VELUX Visualizers are used to evaluate and optimize a building design.

7.4 Case story

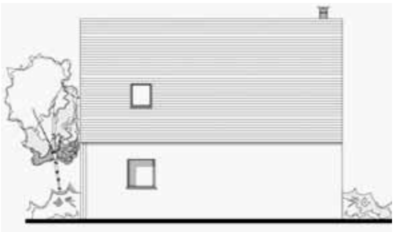
The following example shows how the Daylight Visualizer and Energy and Indoor Climate Visualizer can be used to evaluate and optimize the daylighting, natural ventilation, thermal comfort and energy performance of a residential building.

7.4.1 Project description

The investigation was performed for a single-family with 2 storeys located in Paris, France. Technical drawings of the building provided by the customer were used to prepare the simulation models. The following pane properties were used:

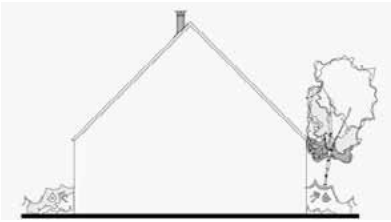
Window glass
(τ_v: 0.77, g: 0.60, U: 1.4 W/m²K)

Elevation South



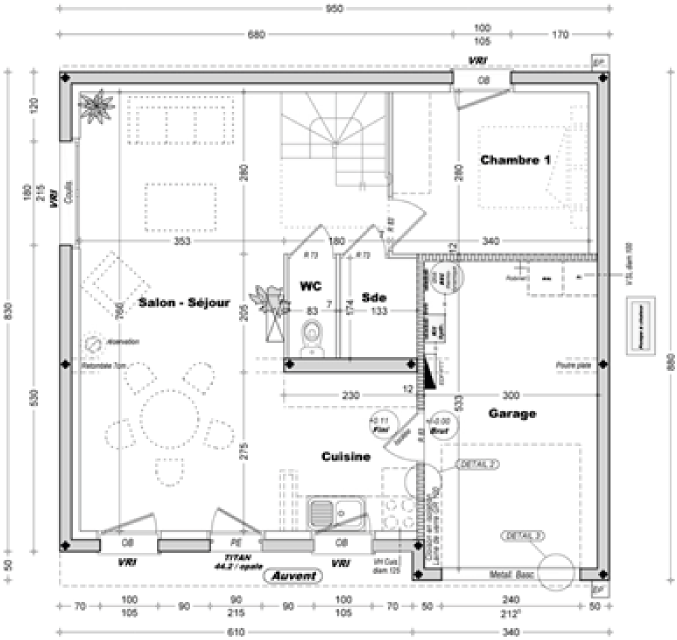
Elevation North

Elevation West

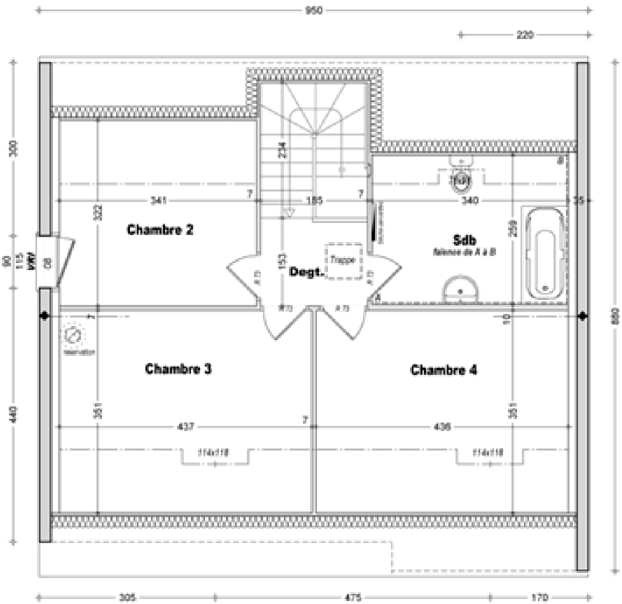


Elevation East

Figure 7.16. Technical drawings of the initial design.



Ground floor



1st floor

Figure 7.17. Initial design technical drawings

7.4.2 Daylight analysis of the initial design

Daylight factor initial design

Figure 7.18 and Figure 7.19 show the daylight factor (DF) levels obtained in the house with the default window configuration.

Results show that the ground floor has DF averages ranging from 0.7% at the bottom of the staircase to 3.2% in the kitchen area. The DF levels obtained on the upper floor were quite low with values ranging from 0% at the top of the staircase to 3.0% in the bedrooms facing south.

Main findings

- Ground floor daylighting performance: low, unacceptable in specific areas.
- First floor daylighting performance: low, unacceptable in specific areas.
- It is proposed to add additional roof windows on the first floor.

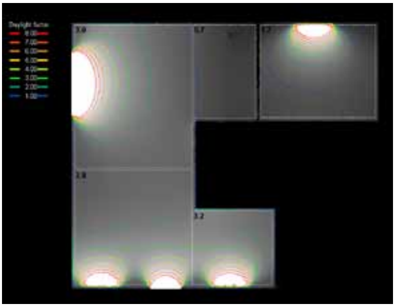


Figure 7.18. Daylight factor simulation of the ground floor (initial design).

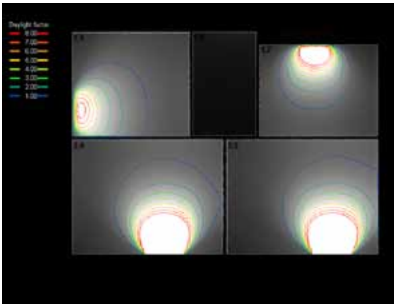


Figure 7.19. Daylight factor simulation of the first floor (initial design).

7.4.3 Energy and indoor climate analysis of the initial design

The energy performance is evaluated with regards to heating and lighting demand.

The results in Figure 7.20 show that the total energy demand of the house is 62.9 kWh/m². This meets the customers' expectations.

The results in Figure 7.21 show that 25 hours per year are out of the comfort range. This is acceptable and meets the customers' expectations.

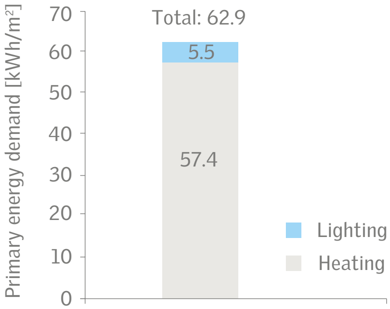


Figure 7.20. Energy performance of the initial design.

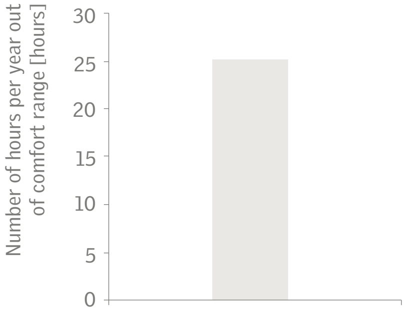


Figure 7.21. Thermal comfort performance of the initial design.

7.4.4 Daylight analysis of the new design

A new design including more roof windows on the first floor has been elaborated based on the findings of the initial daylight analysis.

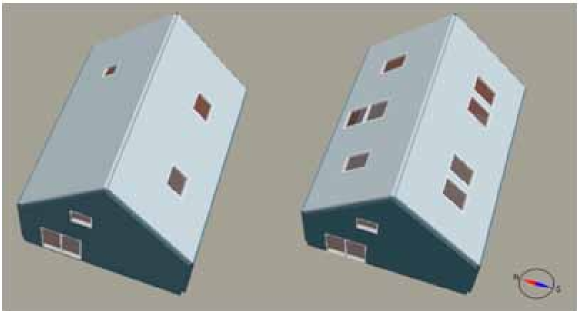


Figure 7.22. Model of the initial design (left) and the new design (right).

Daylight factor new design

Figure 7.23 and Figure 7.24 show the DF levels obtained in the house with the new window configuration.

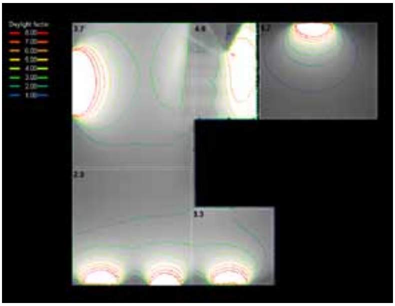


Figure 7.23. Daylight factor simulation of the ground floor (new design).

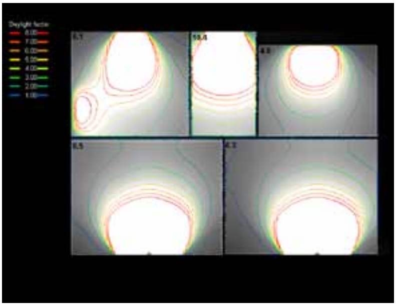


Figure 7.24. Daylight factor simulation of the first floor (new design).

Results show that the ground floor DF levels have been significantly improved at the bottom of the staircase where the average DF went from 0.7% to 4.0%, and in the living room area where the average DF went from 3.0% to 3.7%. The addition of roof windows to the first floor also provides a generous increase in the daylight provisions of all rooms on that floor and permits to reach average DF of 5% and more, see table 7.25.

Main findings

- Ground floor daylighting performance: good, the addition of roof windows results in a significant improvement of the daylight provisions in the darkest corner of the ground floor and help raise the daylight factor levels in the living room area. The increase in daylight at the bottom of the staircase balances the light coming from the double door in the façade.
- First floor daylighting performance: very good, the addition of roof windows permits to reach average DF above 5% in all rooms except for the bathroom where the DF is 4.6%. The completely dark staircase area is now very well daylit.

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Initial design	1.5%	0.0%	1.7%	3.0%	3.0%
New design	6.1%	10.4%	4.6%	6.5%	6.3%

Table 7.25. Daylight factor of the first floor, comparison of the initial design with the new design.

Luminance comparison

Figure 7.26 shows a comparison of the luminance levels obtained in the staircase area for the situation with and without additional roof windows and demonstrates that the addition of roof windows permits to drastically improve the daylight conditions in this area of the house.

The photorealistic images can be used to show the appearance of daylight in the room, whereas the false colour images can be used to make an objective comparison of the luminance levels.

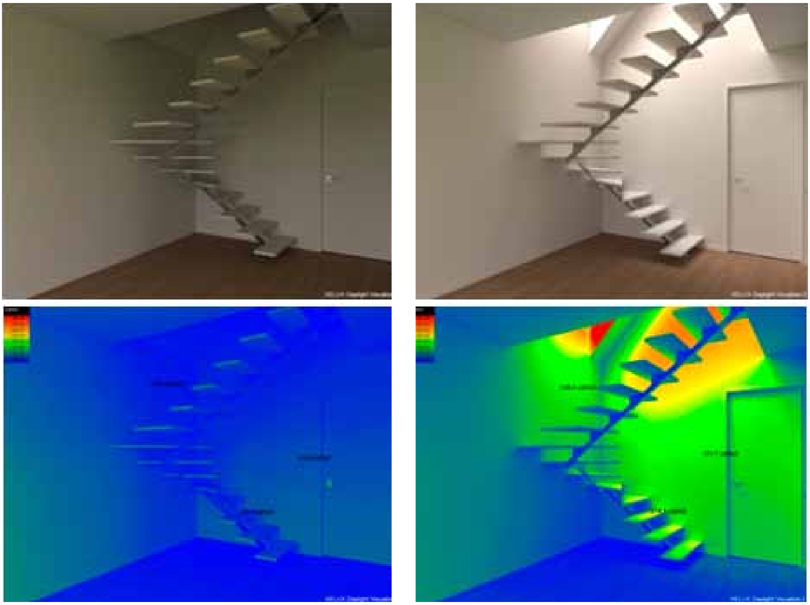


Figure 7.26. Luminance comparison of the situation with (right) and without (left) additional roof windows.

7.4.5 Energy and indoor climate analysis of the new design

The results of the new design are compared to the initial design. Two variants of the new design are considered; with and without awning blinds on the roof windows facing south.

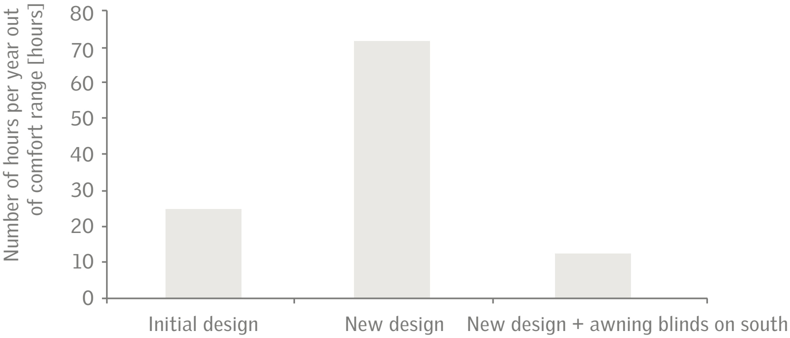


Figure 7.27 Thermal comfort performance of the initial design compared to the new design with and without awning blinds towards south.

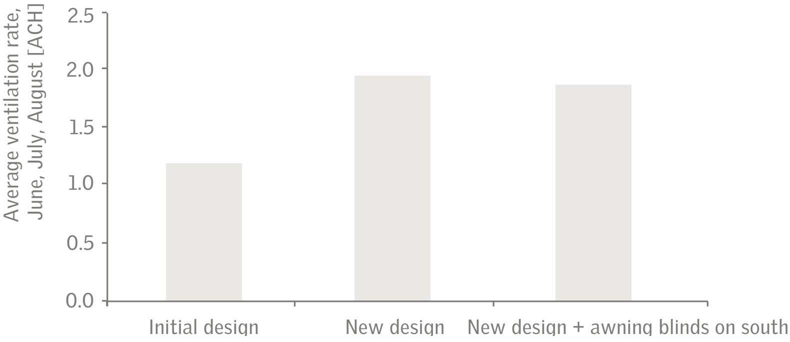


Figure 7.28 Performance of natural summer ventilation of the initial design compared to the new design with and without awning blinds towards south.

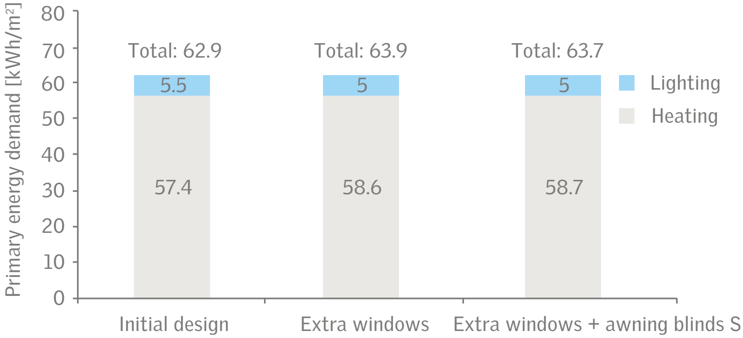


Figure 7.29 Energy performance of the initial design compared to the new design with and without awning blinds towards south.

Figure 7.27 shows an increase in hours out of the comfort range for the new design without awning blinds. However, by using awning blinds, the thermal comfort performance of the new design is better than the initial design.

Figure 7.28 shows the performance of natural ventilation in the summertime as a means to prevent overheating. The new design has more windows and thus increases the performance, which is the background for the improvement of the thermal comfort performance.

Figure 7.29 shows the energy performance. The heating demand is increased slightly, while the lighting demand is reduced. The total primary energy demand is practically unchanged in the new design compared to the initial design, but delivers a substantial improvement of the indoor climate with better air quality and improved thermal comfort.

The new design with more roof windows uses solar shading to improve the indoor climate without compromising the energy demand.

7.4.6 Final design

The use of VELUX Visualizers shows that the new design with additional roof windows will permit to reach the building performance requirements set for daylighting, energy and indoor climate performance. The addition of roof windows and the use of proper solar shading provide a generous increase in daylight availability, better natural ventilation rates and less hours where the temperature is uncomfortable while keeping almost the same total energy consumption. It was shown that roof windows can seriously improve the daylight and indoor climate performance of a building without increasing its energy consumption.

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Dayligt factor (DF) 38
The DF expresses – as a percentage – the amount of daylight available in the interiors compared to the amount of unobstructed daylight available at the exterior under standard CIE sky conditions.

dB(A) 86
Sometimes you see decibel in dB(A) instead of decibel in dB. The (A) means that you have a total sound level (consisting of many individual frequencies), which is "A-weighted" and thereby equals human subjective perception of sound.

Decibel (dB) 86
Decibel is the unit used to measure sound level and decibels is a logarithmic unit used to describe a ratio.

Draught 70
Unwanted local cooling caused by air movements. Typically occurs with air velocities higher than 0.15 – 0.30 m/s.

Dynamic simulation 80
A computer calculation that does calculations for a period of time with time steps, typically 1 hour. Examples are VELUX Energy and Indoor Climate Visualizer.

Electromagnetic spectrum 9
A continuum of electric and magnetic radiation encompassing all wavelengths.

Energy balance 100
The balance between heat loss and solar gains for a window.

Energy consumption 93
The energy consumed to supply the energy demand.

Energy demand 93
The needed energy.

Energy Performance 104
The total energy demand of a building including heating, cooling, hot water, electrical light and other electrical equipment.

Experienced temperature 78
A temperature calculated from the PMV value to illustrate what temperature it would be equivalent to.

Forest certification schemes **124**
Certification scheme that promote sustainable forest management. FSC and PEFC are the most important and they are evaluated by an independent third-party certification body.

Glare **13**
Glare is a sensation caused by an uncomfortably bright light source or reflection in the field of view, which can cause annoyance, discomfort, or loss in performance and visibility.

I **101**
Usable solar gain reaching a window in kWh/m^2.

Illuminance **34**
Illuminance is the measure of the amount of light received on a surface. It is typically expressed in lux.

Indoor air quality (IAQ). **43**
The characteristics of the indoor climate of a building, including the gaseous composition, temperature, relative humidity and airborne contaminant levels.

Infiltration **65**
Uncontrolled ventilation through leaks in the building envelope.

Infrared (IR) **9**
Electromagnatic radiation with a wavelength longer than that of visible light.

kWh **93**
An energy unit. Commonly used to quantify used energy, for instance for pricing energy.

kWh/m² floor area **93**
The total energy demand for the building per m^2 heated floor area.

kWh/m² window area **94**
Unit of the energy balance of windows.

Life cycle assessment (LCA) **119**
A model to assess the environmental impact of a specific process or product.

Luminance **36**
Luminance is the measure of the amount of light reflected or emitted from a surface. It is typically expressed in cd/m^2.

Lux (lx) **34**
Unit of illuminance. One lux is one lumen per square meter (lm/m^2).

Mean radiant temperature **72**
The area weighted mean temperature of all surrounding surfaces.

Melatonin **15**
Melatonin is the most important hormone of the pineal gland and can be described as the body's signal for the nightly dark phase. It promotes sleep in humans and activity in nocturnal animals

MET **72**
Activity level of the occupants. Measured in MET, short for metabolism.
[1 MET = 58.2 W/m^2]

Operative temperature **78**
A temperature that describes the total thermal environment and can be compared across cases.

Particulate matter (PM) **43**
Small airborne particles (x = dimension of the aerodynamic diameter).

Parts per million (ppm) **57**
An expression used a.o. to quantify the concentration n of a specific gas (for example CO_2) in atmospheric air. 1 ppm = 1 mL in 1 m^3 (1000 L)

Predicted Mean Vote (PMV) **78**
An index that predicts the mean votes of a large group of people regarding thermal comfort. 0 is neutral, +3 is too warm and -3 is too cold.

Predicted Percentage Dissatisfied (PPD) **78**
A quantitative prediction of the percentage of people dissatisfied with the thermal environment.

Renewable energy **96**
Energy produced by renewable sources, such as sun, wind or biomass.

Running mean **73**
A weighted average over a period of time. The newest period has the largest weight.

R_w **90**
The sound insulation value, R_w expresses the ability to reduce noise from outside to inside the building. The sound insulation is expressed in dB.

Seasonal Affective Disorder (SAD) 18
Also called winter depression. A mood disorder caused by low light levels in winter.

Sick Building Syndrome (SBS). 45
Term sometimes used to describe situations in which building occupants experience acute health and/or comfort effects that appear to be linked to time spent in a particular building, but where no specific illness or cause can be identified.

Sound Pressure Level (SPL) 91
Sound pressure level is a logarithmic measure of the effective sound pressure. The sound pressure level is expressed in dB.

Stack effect 58
Also called chimney effect. Ventilation principle that uses buoyancy of warm air.

Surface reflectance 28
A number telling how much light is reflected from a surface.

Ultraviolet (UV) 9
Electromagnatic radiation with a wavelength shorter than that of visible light.

VELUX ACTIVE Climate Control 100
A sensor based control system for controlling internal and/or external shading products. Part of a dynamic window system.

VELUX Energy Balance control 100
A time schedule for controlling internal and/or external shading products. Part of a dynamic window system.

Ventilation rate 56
An expression of how many times the air is changed per hour. Tells nothing about the efficiency of the ventilation.

Visible transmittance (τ_v) 29
The amount of daylight coming through a window is referred to as the visible transmittance (τ_v) and is dependent on the composition of the window pane.

Volatile organic compounds (VOCs) 43
Compounds that evaporate from the many housekeeping, maintenance, and building products made with organic chemicals.

Watt (W)
An energy unit. Often used to express how much energy a component uses. E.g. a 60 W light bulb or a 200 W heat pump.

Window system 99

A window system is looking at a window and its accessories as a combined unit. This could be shading devices or other devices that change the parameters of the window as a whole.