DAYLIGHTING

of the

FINNISH TOWNHOUSE

Master's thesis
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Suomalaisesta rakennuskannasta ovat pitkään lähes kokonaan puuttuneet pienen mittakaavan urbaanit asumismuodot, joilla esimerkiksi Keski-Euroopassa on pitkä historia ja edelleen vahva asema. Viime vuosina kiinnostusta suomalaisen arkkitehtuurin ja kaupunkisuunnittelun piireissä on kuitenkin herättänyt townhouse-talotypologia, joka nähdään kerrostalo- ja omakotiasumisen etuja yhdistävänä asumismuotona, jolla voisi olla asuntovalikoimaa ja kaupunkirakennetta monipuolistava vaikutus. Townhouse-typologia on kuitenkin vaativa luonnonvalon käytön kannalta, sillä sille ominaiset kapeat julkisivut ja syvä runko tekevät päivänvalon saannin rakennuksen keskiosiin haastavaksi. Suomessa haasteellisuutta lisäävät luonnonvalon vähäisyys talvikaudella sekä suuret vaihtelut valaistusolosuhteissa vuodenaikojen välillä. Aihe on kuitenkin tärkeä, sillä valon tiedetään vaikuttavan ihmisten terveyteen ja hyvinvointiin monin tavoin. Viimeaikainen tutkimus on osoittanut valon vaikutusten olevan vielä merkittävämpiä ja laaja-alaisempia kuin aiemmin on tiedetty, ja niin ollen myös rakennetun ympäristön valaistusolosuhteiden merkitystä on alettu ymmärtää paremmin. Rakennusten valaistusolosuhteet ovat erityisen tärkeitä länsimaissa, joissa ihmiset viettävät suurimman osan päivästä sisätiloissa. Vapaa-ajasta suuri osa vietetään kotona, minkä takia erityisesti kodin valaistusolosuhteiden merkitys korostuu. Townhouse-talojen luonnonvalaistusta on tutkittu hyvin vähän, eikä varsinkaan suomalaista kirjallisuutta aiheesta ole saatavilla. Tässä diplomityössä tutkitaan arkkitehtisuunnittelun vaikutusta suomalaisen townhouse-talon luonnonvalaistukseen, ja pyritään löytämään suunnittelukeinoja, jotka edistävät terveyttä tukevan valaistusympäristön luomisessa. Keskeisessä roolissa ovat niin kaavoitus kuin rakennussuunnittelukin. Massoittelulla, aukotuksella ja pohjaratkaisulla on kaikilla merkittävä vaikutus luonnonvalon saantiin rakennuksessa. Rakennuksen runkosyvyyden rajoittaminen, tavallista suurempi huonekorkeus ja monimutkaisemmat julkisivumuodot ovat oleellisia keinoja luonnonvalon määrän lisäämiseksi. Pohjaratkaisun suunnittelussa keskeistä on välttää pimeiden kulmien muodostumista. Aputilojen ja väliseinien strateginen sijoittelu on ensiarvoisen tärkeää, jotta valoa saadaan ohjattua pitkälle tilaan. Myös riittävä ikkuna-pinta-ala on välttämätön. Sijoittamalla ikkunan yläreuna korkeammalle saadaan valoa johdettua syvemmälle tilaan. Suomen ilmasto on pilvinen, ja pilvisissä ilmastoissa erityisen tehokkaita luonnonvalaistuksessa ovat kattoikkunat. Yksi kattoikkunoiden vahvuuksista townhouse-talojen osalta on myös se, että niiden kautta voidaan johtaa valoa rakennuksen keskiosiin. Tämä diplomityö sisältää myös yksinkertaisen townhouse -suunnitelman, jonka avulla suunnitteluratkaisujen vaikutusta tilojen luonnonvalaistukseen testataan ja havainnollistetaan. Suunnitelman avulla havainnollisestaan myös luonnonvalaistusolosuhteita tyypillisessä suomalaisessa townhouse-talossa.

Avainsanat: suomalainen townhouse, luonnonvalo, päivänvalo, luonnonvalaistus, asuntosuunnittelu

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Master of Arts thesis abstract

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The townhouse has been a subject of active discussion in the field of Finnish architecture in recent years and has generated interest among architects and city planners. It is seen as a solution that would combine benefits of both detached houses and apartment blocks. Finland has long lacked an urban, small-scale typology like the townhouse, while in many other European countries, townhouses have been a common form of housing for centuries. Because townhouses typically have a deep building frame and narrow facades, ensuring adequate amounts of daylight in the house requires effort and skill from the architect. Daylighting of townhouses is especially challenging in a country like Finland, where the long and dark winters limit daylight availability for a large proportion of the year. Yet light is known to have significant effects on human health, and daylighting of a home will therefore influence the wellbeing of its occupants. Recent research suggests that these effects are even more wide-ranging than previously thought, and the increased understanding on the matter has underlined the need for more attention to lighting in the design of our living environment. This is especially important in developed countries where people generally spend a large proportion of the day inside. Yet to date, daylighting of townhouses in general has been researched relatively little. There is some literature on daylighting strategies for the Finnish climate, but this too is limited and provides very little for townhouses. This thesis examines how architectural solutions affect the daylighting of the Finnish townhouse and aims to find strategies that would help create health-supporting lighting conditions in the townhouse. Central design solutions studied include city and master plans, massing, fenestration and floor plan solutions. For improved daylighting, Finnish townhouses should have limited frame depth and increased room height. More complex facade forms allow for increased fenestration space. A sufficient window surface area is needed, and the upper frames of the windows should be higher in order to guide light deep into the space. Skylights are a powerful daylighting strategy and can be effective in guiding light into the building's core. Floor plan solutions should aim to avoid formation of dark areas in the core of the building: auxiliary spaces and dividing walls have to be placed strategically. This thesis also includes a simplified townhouse design that serves as a test house in descriptive and experimental research. In the experiments, the daylight conditions in a typical townhouse are studied. In addition, the effects of modifying the design according to the ideas discussed in the theoretical section are tested and demonstrated.

Key words: Finnish townhouse, daylight, natural light, daylighting, housing design

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TERMS & DEFINITIONS

DAYLIGHTING

Daylighting refers to the practice of bringing light inside a space and distributing it as desired to create a better illumination than artificial light sources provide. Daylighting strategies alter the light intensity, colour and views of the space and can help decrease the need for artificial lighting. (Public Technology Inc, p. 90.)

TOWNHOUSE

For the purposes of this research, the townhouse is defined as a single-family house with two to four floors, with side walls connecting it to neighbouring buildings, which are usually also townhouses. Townhouses typically have a relatively deep frame and narrow facades. The front facade opens to the street either directly at the edge of the site or with a narrow front yard in between. The house has its own entrance from the street as well as a private garden area. Definitions of ownership in townhouses varies according to source, but in this thesis, the townhouse is defined to include both independently owned versions and those that are part of a housing cooperative.

HEALTH

Health is a state of well-being that encompasses physical, mental and social aspects. (Sartorius 2006) identifies three definitions for health. Firstly, health can be understood as the absence of impairment or disease. Secondly, health can be a state that allows a person to meet the requirements of their everyday activities. Finally, health can be thought of as a balance the person has established within himself, or the equilibrium between the person and their physical and social environment. (Sartorius 2006.)

LIGHT

Light is visible electromagnetic radiation or radiant energy.

NATURAL LIGHT

Natural light consists of direct sunlight and ambient skylight, which is sunlight scattered in the sky. A key characteristic of natural light is that it changes in an oscillating pattern according to the passing of the day.

VISUAL COMFORT

Visual comfort is an individual's subjective experience of the quantity and quality of light in the individual's environment. A closely related term is visual comfort probability, which refers to the percentage of people that will find a given scene visually comfortable.

INTRODUCTION

"But the architects who are designing rooms today have lost faith in natural light. By becoming dependent on the light switch they are content with static light and forget about the endlessly changing character of natural light which transforms a room each second of the day."
Louis Kahn, (Stille und Licht , i.e. "silence and light"), lecture at School of Architecture of the Eidgenössische Technische Hochschule, Zurich, February 12, 1969).
(Boubekri 2014, p. 8)

Light is a prerequisite of vision and creates the foundation for the experience of space. It also gives the body signals about the time of day: light exposure is a central regulator of the human biological rhythms known as circadian rhythms (Webb 2006). Circadian rhythms, in turn, have a profound effect on many aspects of health. Direct effects of circadian rhythm disruption include sleep disturbances, tiredness, increased cancer risk, seasonal affective disorder (SAD) and possibly, cardiovascular disease and diabetes. (Rogers et al. 2015, p. 24.)

In recent years, interest in light's effects on human health and performance has increased, and these effects have been the focus of numerous studies. It has already been well-established that light has wide-ranging effects on people's physiology, behavior and mood (Webb 2006). What's more, it has recently been discovered that light's effects on health are more profound than previously known (Holzman 2010). As a result of the increased understanding on the relationship between health and light exposure, the mentality in lighting design has shifted from a heavy focus on visual tasks — these days, good-quality lighting has to meet a more complex set of criteria. Good environmental lighting has to be supportive of health, well-being, interpersonal relationships and aesthetic tastes, while still fulfilling visual requirements. (Bellia et al. 2011, p. 1984.)

The fact that light has the power to influence health, performance and mood means that paying attention to daylighting in architecture could bring major benefits for the users of a building (Webb 2006). Dieter Kunz, research director at Charité–Universitätsmedizin Berlin, also recognizes the significant gains that could be achieved by modifying lighting conditions: "Fascinating times are ahead of lighting industry, clinical chronobiologists, and architects, to mention just a few. By optimizing lighting regimes, we will be able to improve health, save energy, and improve learning and performance." (Kunz, cit. Holzman 2010). Many other scientists have also acknowledged the need for more consideration for the use of daylight in architecture. For example, Bellia et al. (2011, p. 1985) state as follows: "Many aspects of human physiology and behavior are dominated by 24 h rhythms that have a major impact on our health and well-being: sleep-wake cycles, alertness, performance patterns, core body temperature, production of hormones. Recent advances in photobiological science have provided unexpected insights into fundamental processes, starting a "cultural" revolution in both medical and technical fields that will probably lead to future changes in lighting recommendations." According to Charité – Universitätsmedizin Berlin researcher Dieter Kunz, the recent advances in the study of light's health effects have been so remarkable that this progress could be deemed the greatest innovation of the lighting industry since the light bulb (Kunz cit. Holzman 2010). Meanwhile, Thomas Jefferson University's neuroscientist George Brainard points out that the use of light in architecture should be redesigned with consideration of new discoveries about light's effects on human biology and behavior. According to him, this would benefit the health and wellness of people in the built environment. (Brainard cit. Holzman 2010.)

Before the invention of artificial light, times of rest and activity were predominantly determined by the daylight—dark cycle, according to the rise and fall of the sun (Webb 2006). Over the last few centuries, however, the lighting of our environment has undergone a massive revolution due to technological innovations and increased urbanization. As a result, the line between day and night has become increasingly blurred. Especially in urban areas, people are exposed to biological darkness during the day, because interior spaces often have suboptimal illuminance levels. In the meantime, electric lighting extends the apparent day length and produces unnatural brightness at night. (CIE 2004.)

When sufficiently available, daylight is the most energy-efficient light source (Galasiu & Veitch 2012), but buildings inherently create a lighting environment that differs from the lighting conditions outdoors. What's more, indoor artificial light designed to optimize visual performance does not necessarily meet the non-visual needs related to light (Webb 2006). In the Nordic countries, where people spend around 90 % of the day indoors and where winters are long and dark, the risk of insufficient exposure to daylight is particularly high (Rogers & al 2015, p. 24).

Lighting in homes can have a powerful impact on the light exposure of an individual, as it is a place where people spend a lot of time. For example, in Germany the average overall time spent at home is 15.7 hours per day, and similar values are found in the US (15.6 hours / day) and Canada (15.8 hours / day) (Brasche & Bischof 2005). In Finland, 65 % of leisure time is spent at home (Tilastokeskus 2011). Daylight is also valued by a large proportion of occupants. For example, the ENVI study (Hasu & Hirvonen 2015), which examined energy and environment attitudes of people in the Helsinki metropolitan area, found that the majority of Finnish residents surveyed considered it important that the home is well-lit. According to the survey, 45% found this very important and 42% somewhat important — meaning that for almost 90 % of those surveyed, brightness in the home was an important factor (Hasu & Hirvonen 2015b, p. 30—31). In Aalto University's Habitat Components — Townhouse study, the participants also identified natural flow of light as a more important factor than, for example, the width of the house (Huttunen et al. 2016b, p. 53). Similarly, Elitfönster Trendrapport 2012 found that Scandinavians like their homes to be open, airy and bright, and value daylight in particular (Elitfönster 2012).

Perhaps one of the most challenging building typologies in terms of daylighting is the townhouse. The townhouse is an urban, small-scale housing typology characterized by narrow facades and a relatively deep building frame. Townhouses typically have 2—4 stories and are connected to neighbouring buildings — which are usually also townhouses — at firewalls (Jalkanen et al. 2012, p. 9). Because of the narrow facades, fenestration space is limited, while the deep building frame makes it difficult to guide light into the building's core. Hence, availability of daylight in townhouses can easily become a problem if the architect does not pay attention to the issue during the design process.

The townhouse has its roots in Central European merchant houses of the Middle Ages, and it is still a common form of housing in many European countries (Ellilä 2014). Finland, however, has long lacked a dense, urban, small-scale housing typology. Although row houses have been common in Finland since the 1950s, they have been distinctively different from the European townhouse in certain aspects. Perhaps the most important difference is that they have mostly been located in suburban areas, whereas townhouses have traditionally been located in more urban areas (Jalkanen et al. 2012). What's more, while townhouses are characterized by a deep building frame and relatively narrow facades, the form of row houses can vary. Another difference is that townhouses are usually located at the edge of the plot by the street, whereas rowhouses may be placed further back.

In recent years, the townhouse has started to generate interest among Finnish architects and city planners and become an area of focus in the discussion and research on Finnish housing design (eg. Kuittinen 2015; Huttunen et al. 2011; Jalkanen et al. 2012; Manninen & Holopainen 2006). Projects such as "Tiivis ja matala" ("Dense and low") (2002—2005) by the Ministry of Environment; the URBA project (2007—2010) by Aalto University; the Helsinki Townhouse competition (2010) by Helsinki City Planning; and the large Habitat Components — Townhouse study that started in 2013 in Aalto University, have all drawn attention to the townhouse typology.

A key advantage of townhouses is that they offer many of the qualities of detached houses while also providing the benefits of an urban location, such as good public transport connections and proximity of services (Ellilä 2014). This seems to be well-aligned with Finnish housing preferences: small-scale houses are still the most popular form of housing in Finland (Sanaksenaho 2013), yet perhaps somewhat contradictorily, the benefits of a central location like services and transport connections are becoming increasingly important criteria in the selection of living settings (Strandell 2017). In the light of this information, it is not surprising that Helsinki sees townhouses as a way to create variety in both city structure and housing selection, and to producing tight-knit, small-scale housing areas (Manninen & Holopainen 2006).

Paying attention to daylighting of townhouses is particularly imperative in a country like Finland, where daylight is scarce in wintertime. Because of differences in climate — and, consequently, daylight conditions — as well as culture, foreign designs cannot necessarily be imported as such but need to be evaluated and adapted to be suited to a Northern location.

This thesis examines architectural strategies for the daylighting of the Finnish townhouse and the effect daylighting has on the townhouse's occupants. The thesis aims to clarify the main objectives in the creation of a health-supporting lighting environment in the home and explores architectural design strategies that could be used to advance these goals. What tools can a designer use to overcome the challenges posed by the townhouse typology and the Finnish climate? What factors in a townhouse design contribute to good daylighting of the interior spaces? Conversely, what factors or design solutions might impair daylight conditions of the dwelling? What issues need to be considered in the design process, to make the townhouse a functional enjoyable and health-supporting home throughout the seasons? This thesis examines townhouses that consist of only one dwelling, which is the traditional form of townhouses. However, many old townhouses have been converted into apartments and some new interpretations of the townhouse also include multiple apartments, but these are beyond the scope of this research.

The thesis is divided into two parts. The goal of Part 1 is to provide a short overview of daylight and its effects on humans in terms of health effects and user experience. This is not a comprehensive analysis — instead, it aims to focus on the issues that are most relevant for an architect working on a townhouse design. Having some background information is necessary in order to understand the motives behind daylighting goals and to be able to apply daylighting strategies in real design cases. The first chapter of Part 1, Chapter 1, starts out by introducing different ways of quantifying light that are likely to be useful in daylighting, and discusses the strengths and weaknesses of the various lighting metrics. The second chapter examines light's effects on health and the typical issues of the lighting conditions in the modern world in terms of its health effects. Chapter 3 explores what kind of a starting point the Finnish climate offers for daylighting. Chapter 4 has a stronger focus on architecture than the first three chapters: it discusses the use of daylight in architecture — both its history and how the perspective has evolved over time to what it is at the moment. This chapter also covers different standards and guidelines regarding the use of daylight. Finally, Chapter 5 aims to pull all the information of Part 1 together and define what a good daylighting environment would look like and what the key objectives in daylighting should be, taking into account both the well-being and enjoyment of the users as well as other factors such as energy usage.

In Part 2, the information on daylight from Part 1 is applied to the Finnish townhouse. The first chapter of Part 2, Chapter 6, provides a brief overview of the townhouse: its characteristics, history and role in the Finnish housing selection. The rest of Part 2 is focused on connecting the understanding of light back to the architectural design of Finnish townhouses. Chapters 7—11 cover design solutions including the masterplan, massing, floor plan, fenestration and outdoor spaces. The last chapter of Part 2, Chapter 12, examines daylighting systems, which are further strategies aimed to optimize lighting conditions beyond what is possible through the basic design tools covered in the other chapters. The final chapter, Chapter 13, presents conclusions and discussions based on the findings in earlier chapters.

To investigate the effects of different design solutions more deeply and to better illustrate them, this thesis also includes a simplified Finnish townhouse design. This “test house” aims to represent a typical Finnish townhouse, the kind of which could actually be built in Finland. The motivation behind this goal is to produce data that will be relevant in the design of real future townhouses in Finland. Another key goal in the design of the test house was to include a variety of different daylighting situations — a variety of spaces with different daylight conditions — in order to get more comprehensive data and explore the effects of different design solutions within the same house. A detailed presentation of the test house is included in Appendix A.

The purpose of the test house is to serve in experimental and descriptive quantitative research. The goal of this research is to objectively analyze the starting conditions for daylighting of the Finnish townhouse and the effect that modifying the townhouse design according to daylighting theories has on daylighting. The descriptive section aims to quantify daylight conditions — referring to the amount and distribution of daylight — in a typical Finnish townhouse. For this reason, it is important that the test house represents a typical case instead of one already optimized for daylighting. This way, we can get data on, for example, which areas of the townhouse have the highest risk of inadequate daylight levels. Meanwhile, the goal of the experimental research is to produce information on which design solutions are most effective for improving daylight conditions in the townhouse.

In the chapters covering the effects of different design solutions, the test house is used to both test and illustrate these effects. Here, the effect of modifying the test house design according to the suggestions made in the theoretical part is compared to the starting point, the original version of the test house. Where applicable, the results of this comparison can then be reflected on and also compared to the hypotheses found in the literature. Each modification is analyzed separately, meaning that the modifications are not accumulated in the design. Instead, each modification is individually compared to the starting point — in other words, a univariate analysis for each modification is performed. This strategy makes it possible to analyze which modifications have the most significant effect on the daylight conditions of the townhouse.

The effects are tested in the form of changes to daylight factor and illuminance levels as well as the distribution of light in the space. These changes are calculated using VELUX Daylight Visualizer, a software developed specifically for analyzing daylight conditions in buildings. The software takes into account geographical location, orientation and weather conditions.

Apart from the experiments with the test house, this thesis relies on written sources, including books, reports and research articles. Since there is relatively little literature on daylighting of townhouses specifically— let alone daylighting of townhouses in Finland — the thesis combines literature from three different perspectives: on the townhouse typology in Finland, on architectural daylighting, and on light’s effects on health. The goal is to combine this cross-disciplinary information and present it in a way that is understandable and relevant for an architect wishing to design a health-supporting townhouse in Finland.

While there is plenty of literature on the use of light in architecture, Finnish resources on the subject are remarkably scarce. As a result, the most important sources on daylighting have been foreign — mainly European and Northern American — comprehensive works that broadly examine principles of daylighting, and this knowledge is then examined from a Finnish perspective. While many sources are aimed at different climate conditions, most of the more comprehensive works also discuss what this means for other geographical locations. Perhaps the most important sources in this category are "Daylighting design: planning strategies and best practice solutions" by Mohamed Boubekri (2014) and"Daylighting: Architecture and Lighting Design" by Peter Tregenza and Michael Wilson (2011). The application of the information to the Finnish context for this thesis was also supported by the course "Valoisa asuintila" ("Bright Living Space") by Aalto University in 2016, which focused on daylighting of an urban apartment in Finland.

In contrast to daylighting, the townhouse typology has been intensively researched in Finland over the last few years, as was already mentioned. The most prominent sources in this category have been the multi-part Habitat Components — Townhouse study that started in Aalto University in 2013 and the Energy-Efficient Townhouse study, which is a part of Aalto University's AEF research project.

When it comes to light's effects on health, the most important sources have been publications that examine the subject from an architectural perspective. For example, the "Ocular lighting effects on human physiology and behavior" by the Commission Internationale de l'Eclairage (CIE) (2004) discusses light's effects on health from a design perspective. Some of the more comprehensive books on architectural lighting that served as important resources, such as "Daylighting design: planning strategies and best practice solutions" by Boubekri (2014) and "Illuminating: natural light in residential architecture" by Corrodi, Spechtenhauser and Auer (2008) also have a heavy focus on the user's health.

PART 1:

UNDERSTANDING DAYLIGHT

1

MEASURING LIGHT

This chapter provdies an overview of lighting metrics most commonly used in a daylighting context. In addition to explaining the lighting metrics, this chapter also discusses their strengths, weaknesses and applicabililty.

1.1 LIGHTING METRICS

Luminous flux / luminous power

Luminous flux or luminous power is the measurement of the **perceived power of light**. It takes into account the human eye's sensitivity to different wavelengths, and thus measures not the total power of electromagnetic radiation but the perceived amount of visible light. Luminous flux is measured in **lumen (lm)**.

Illuminance

Illuminance is the **total luminous flux on a surface**, per unit area. While luminous flux corresponds to the quantity of light, illuminance is the quantity of light relative to the size of the illuminated surface. It is measured in **lux**, which is lumen per square meter.

What is most interesting about illuminance is that in contrast to many quantities related to light, such as irradiance (which is the amount of electromagnetic radiation per unit area), illuminance is not an objective measure of a physical quantity. Instead, the lux values are adjusted according to the sensitivity of human eye to different wavelengths of light. Therefore, a green light and a red light with the same irradiance value would not have the same illuminance value, as the human eye is more sensitive to green light. This means that illuminance indicates, above all, how well a human eye could see under given lighting conditions. Examples of typical illuminance values are 500 lux in an office, 10 lux at twilight, and as much as 100 000 lux outdoors in direct sunlight. (Keim

2016.) The illuminances that are most commonly examined are those of horizontal surfaces (RT 07-10912 2008, p. 1).

Luminous intensity

Luminous intensity is the wavelength-weighted measurement of **power emitted by a light source** in a particular unit per solid angle. It is adjusted for the sensitivity of the human eye, based on the standardized luminosity function. The SI unit for luminous intensity is **candela (cd)**.

Luminance

Luminance indicates **how bright a surface will appear to the perceiver**, as it measures the luminous power detected by the eye, when looking at a particular surface from a particular angle. In more specific terms, it is a photometric measurement of luminous intensity per unit area of light travelling to a certain direction, describing the amount of light passing through or being emitted or reflected from a surface in a given angle. In the SI system, luminance is measured by **candela per square meter (cd/m^2)**.

Luminous efficacy

Luminous efficacy describes how efficient the light source is at producing visible light, and it is the **ratio of luminous flux to power**. Consequently, the SI unit for luminous efficacy is **lumens per watt**. Because of the spectral sensitivity of the human eye, not all wavelengths of light are equally visible. In effect, the luminous efficacy describes the light source's efficacy in converting energy to electromagnetic radiation and the capacity of the eye to detect this radiation.

Colour temperature

Colour temperature is a characteristic of visible light. The SI unit for colour temperature is **Kelvin (K)**. The higher the colour temperature is, the colder the light. For example, the colour temperature produced by a lit match is around 1700 K, while an LCD screen is typically around 6500—9500 K. Daylight ranges from 1850 K at sunrise or sunset to up to 15 000 — 27 000 K when the sky is at its brightest.

Daylight factor

Absolute illuminance does not tell the whole story when it comes to the user's experience of brightness, because the human eye adjusts to the brightness of its surroundings. This means that outdoor illuminance has a significant impact on the perception of brightness indoors. Therefore, a more accurate predictor of the users' perception of brightness than a lux number is a measurement called the daylight factor (DF). It describes the ratio of indoor horizontal illuminance to outdoor horizontal illuminance (Mardaljevic et al. 2013). Direct sunlight is excluded from the calculations (Tregenza & Wilson 2011, p. 52). The daylight factor is therefore independent of weather conditions at the time of measurement (Boubekri 2014, p. 44—45). Depending on the source, recommendations of daylight factors for a well-lit space range from 2—5 %. Recommendations for daylight factor values are discussed further in chapter 5.

Daylight Glare Index

The Daylight Glare Index (DGI) is a function of the luminance, size and location of glare source (Boubekri 2014, p. 52). It attempts to measure glare but has not proved to be accurate enough. Some researchers have proposed alternate indices, but at the moment, there are no well-established ways to quantify glare. (Bellia et al. 2011, p. 1985.)

1.2 APPLICABILITY OF METRICS

Daylighting has traditionally been thought somewhat separately from electric or artificial lighting. The parameters most commonly used in daylighting include the luminous flux and illuminance levels needed for different purposes as well as luminous efficiency, which is related to energy usage. (Bellia et al., p. 1985).

Traditionally, the above-mentioned photometric parameters have been used to meet visual requirements. This approach, however, is not sufficient to optimize things like visual comfort and performance or the non-visual effects of light. To get a better picture of the individual's visual experience as well as the effects that given lighting conditions have on their health, a broader set of parameters must be evaluated. An example of such a parameter could be the illuminances received at the eye. (Bellia et al. 2011, p. 1986.) Therefore, it has been proposed that there is a need for a different perspective on lighting, focusing chiefly on the quantification of light received at the eye. Some efforts to quantify the relative sensitivity of the human circadian sensor and the spectral response function have been made. (Bellia et al. 2011, p. 1987—1991.) However, many of the quantification functions are rather complex and not particularly usable as a regular tool for architects, and difficult to apply directly to building design.

Many of the other techniques used for predicting daylight have historically also been quite problematic and difficult to use. These days, though, daylighting design is made much easier by the wide variety of computer simulation programs that are available for this purpose. One example of this kind of dynamic simulation technology is Daylight Autonomy (DA), which calculates the percentage of a given time frame when a chosen minimum illuminance level is produced on working plane by daylight. This method is useful when assessing potential energy savings that could be gained if the required illuminance can be achieved without electric lighting. (Boubekri 2014, p. 45—46.)

Another method is the Useful Daylight Illuminance (UDI), which is based on a similar idea as Daylight Autonomy. The UDI method measures the percentage of time when the interior daylight illuminance is between 100 and 2000 lux throughout the whole room. The thinking behind this method is that illuminances under 100 lux are of little use while those over 2000 lux would be excessive and prone to cause thermal or visual discomfort. (Boubekri 2014, p. 45—46.)

Interestingly, most of the early studies and literature on daylighting dates back to the late 19th century Scandinavia and Northern Europe, where ambient skylight is the predominant form of daylight. As a result, ambient skylight has remained the starting point of many later studies on daylight as well. (Boubekri 2014, p. 45—48). When applying data from studies and analyses, it is always important to be aware of what kind of climate conditions this information was based on, since daylight conditions are highly dependent on geographical location and climate.

2

LIGHT AND HEALTH

This chapter aims to provide an overview of how light affects people's physical health and psychology. This topic is complicated and diverse, which means that we are only scratching the surface. However, the goal here is to give an architect or designer a basic idea of light's importance, so that they understand why paying attention to daylighting can have a significant effect on the building's users. An understanding of the key ways light affects our physiology and psychology is vital: applying recommendations to real design cases will be much easier if there is an understanding of the motivations and goals behind the recommendations.

2.1 BIOLOGY OF VISION

The eye receives light information through photoreceptors. The amount of light in the retina affects the visual system, which allows humans to perceive the space and its details. The two most well-known photoreceptors are rods and cones, which enable the visual system by detecting visual information. The visual system reacts to the visible spectrum of light and is most strongly affected by green light (Rogerset al. 2015, p. 23).

It is important to understand that the human eye adjusts to the brightness of its surroundings. Therefore, the actual illuminance is not necessarily an accurate predictor of perceived brightness. (Corrodi et al. 2008, p. 134.) As already discussed, tools like the daylight factor have been developed specifically to account for this adjustment in daylighting calculations and analyses.

2.2 NON-VISUAL EFFECTS OF LIGHT

For many decades, the only known photoreceptors were rods and cones. That was until a third type of photoreceptor of the retina, the intrinsically photosensitive Retinal Ganglion cell, ipRGC, was discovered around the turn of the 21st century, although evidence suggesting its existence had been available for long before.

The ipRGC is a receptor containing a photopigment called melanopsin, which is sensitive to short-wavelength radiation. Both animal and human studies have shown that short-wavelength radiation affects a wide array of neuroendocrine and neurobiological systems. In effect, the ipRGC is focused on capturing the non-visual information of light and transmitting this information to the regulation of the circadian system. (Bellia et al. 2011, p. 1985—1986.) The neural pathway that regulates circadian rhythms is anatomically separate from the pathway that governs vision (Commission Internationale de l'Eclairage (CIE) 2004, p. 4). Through the non-image-forming system, light exposure can have a multitude of effects on the circadian system (Chellappa et al. 2011). While the visual system is most sensitive to green light, the strongest influencer of circadian rhythm regulation is blue light (Holzman 2010, Rogers et al. 2015).

2.2.1 CIRCADIAN RHYTHMS

Circadian rhythms are biological rhythms with a cycle of approximately 24 hours, and they have a central role in human physiology and behavior. (Bellia et al. 2011, p. 1985). The circadian system regulates the rhythm of many biological functions, such as sleep-wake cycles, hormone secretion, body temperature, intestinal function, glucose metabolism, and immune function (Voigt et al. 2013). Through its effects on the circadian rhythm, light exposure can influence all of these biological processes, as well as mood and behavior (Fabio et al. 2015). It is also likely that many of light's effects on health are yet unknown (Halonen & Eloholma 2005).

Without regulating signals from the environment, the circadian rhythm would be slightly longer than 24 hours in most individuals, which is why the system needs to be reset daily to keep the body in time with the natural environment (Potter et al. 2016). The resetting of the circadian rhythm is regulated by external cues, called zeitgebers (the German term for "time giver") (Webb 2006). The light—dark cycle is the most significant zeitgeber (Potter & al 2016), but other factors — such as sounds, social cues, caffeine and meal times — can also affect circadian regulation (Commission Internationale de l'Eclairage (CIE) 2004, p. 2; Shanahan & Czeisler 2000, p. 1).

Light exposure can have an advancing or delaying effect on the circadian rhythm. The strength of the effect is influenced by the duration and intensity of exposure. (Bellia et al. 2011, p. 1985—1986.) Light exposure in the morning tends to advance the rhythms, while night-time exposure has a delaying effect (Commission Internationale de l'Eclairage (CIE) 2004, p. 4). For example, exposure to compact fluorescent lights can have a significant effect on circadian physiology. Besides the phase-shifting effect on circadian processes, light exposure also influences alertness and cognitive performance, and could improve performance at home or work. (Chellappa et al. 2011.)

While well-timed light exposure has beneficial effects on the regulation of circadian rhythm and cognitive performance, light exposure can also have deleterious effects when the signals are not accurately timed. When the circadian system is disturbed by irregularities, the rhythm is altered (Bellia et al. 2011, p. 1986). This disruption of the biological timing is called circadian rhythm disruption (Potter & al. 2016).

Circadian rhythm disruption is prominent in modern societies and can promote the development or progression of many inflammatory and metabolic disorders (Voigt et al. 2013).

The light—dark cycle is the chief regulator of the circadian system. Therefore, light exposure patterns that are not aligned with the circadian rhythm have the power to cause disruption of the circadian rhythm. Two prominent issues regarding circadian disruption in modern societies are insufficient exposure to light during the day and increased exposure to artificial light at night-time. (Potter & al. 2016.) People in industrialized societies spend a large proportion (around 90 %) of the day indoors. This means that they may not be able to fully enjoy the powerful and beneficial effects that daytime exposure to daylight has on physiology and behavior. One example is the production of vitamin D. Vitamin D is synthesized in the body in response to UV-B radiation. The large proportion of time spent indoors in industrialized countries contributes to the prevalence of low vitamin D status. (Potter et al. 2016.)

Potter & al. (2016) estimate that people of modern societies get exposed to around four times less light during the day, compared to settings where daylight is the only source of light exposure. Insufficient light exposure during the day and exposure to artificial light at night may contribute to disrupted sleep. Disruption of sleep promotes reduced energy expenditure and increased energy intake as well as insulin resistance. (Potter et al. 2016.) Sleep loss can also increase the risk for cardio metabolic disease (Aho et al. 2016).

In the meantime, night-time light exposure affects about 75 % of the global population. Potter et al. (2016) estimate that in modern societies, the intensity of light people are exposed to between sunset and sleep is twice as high compared to exposure to only daylight. This also seems to have significant effects on sleep. In people with the same sociocultural background, electric lighting correlates with increased light exposure shortly after sunset on workdays, as well as with delayed sleep onset and shortened sleep duration. Night-time light exposure is also suspected to be a contributor to the obesity epidemic. (Potter et al. 2016.)

The most powerful influencer of circadian rhythm is blue light (Holzman 2010, Rogers et al. 2015). Blue light is defined as light with a wavelength between 400—495nm. This is close to the peak sensitivity of the human circadian system, which is between 440—500nm (Figueiro et al. 2005). According to Dieter Kunz, a research director from Charité–Universitätsmedizin Berlin, the exposure to blue light should be higher during the day, as this could help increase productivity and learning. At night, in contrast, the blue portion should be decreased to avoid deteriorating sleep (Holzman 2010).

Most people have probably experienced some of the temporary effects of circadian rhythm disruption, such as tiredness, memory disruption and cognitive confusion (Bellia et al. 2011, p. 1986.) Circadian rhythm disruption may, however, also have more serious health consequences: according to Dieter Kunz, “A growing body of evidence suggests that a desynchronization of circadian rhythms may play a role in various tumoral diseases, diabetes, obesity, and depression” (Kunz cit. Holzman 2010). It is also believed that circadian rhythm disruption may contribute to reduced neuropsychological capabilities (Boubekri 2014, p. 11). Potter et al. (2016) argue that a significant proportion of the global population has an increased risk of circadian rhythm disruption caused by environmental factors. According to the researchers, the consequences of circadian rhythm disruption are profound, and unless the issue is addressed, will continue to cause health problems, including a myriad of metabolic ramifications.

A key effect of night-time light exposure is the suppression of melatonin production. Melatonin is a hormone tightly linked to circadian rhythm regulation, a biochemical signal of night to the body. Melatonin release is associated with sleepiness. (Bellia et al. 2011, p. 1985—1986.) Light exposure has the power to suppress melatonin production acutely, but the effect is dose-dependent. (Commission Internationale de l'Eclairage (CIE) 2004, p. 5—6.) Bright white light at an intensity of 2 500 lux — which is considerably brighter than normal interior lighting, but still clearly lower than typical outdoor illuminance, which is measured in tens of thousands — has been shown to acutely suppress melatonin secretion (Holzman 2010). Through the effects on melatonin, light exposure may affect other biological functions as well. For example, melatonin has an effect on the metabolic activity of certain cell types, which is thought to be related to the correlation between night-time, work-related light exposure and increased breast cancer risk. (Bellia et al. 2011, p. 1985—1986.)

2.2.2 PSYCHOLOGICAL EFFECTS

As a result of exposure to daylight, feelings of wakefulness are produced by the limbic system. The limbic system is most sensitive to the red spectrum of light, around 630 nm wavelength (Rogers et al. 2015, p. 23). Light can also influence mood (Tregenza & Wilson 2011, p. 5), and bright light exposure can alleviate depression and other mood disorders. Some evidence indicates that blue light may have an especially powerful effect. (Holzman 2010.)

Seasonal affective disorder, commonly abbreviated as SAD, is a depression phenomenon related to decreased light levels and the short days of the winter season. It is yet another example of light's effects on the human endocrine system, where imbalances of the hormone melatonin and the neurotransmitter serotonin lead to seasonal changes in mood and sleep. Sufferers of SAD have been found to have higher levels of melatonin during the day, which can cause fatigue and sleepiness. They may also experience decreased serotonin levels and symptoms associated with it, such as negative emotional states and deteriorated performance. (Boubekri 2014, p. 33.) In Finland, 1 % of the population suffers from repeating spells of SAD during the winter time, and in addition, 10—30 % experiences milder symptoms without an actual depressive state (Duodecim 2018).

Besides mood, daylight conditions can also influence the productivity of work. Studies showing benefits of daylighting for work productivity have sparked increased interest in the subject. Work performance, however, is not always easy to quantify. The earliest studies in work productivity were done on factory workers, where the output can typically be used as a marker of performance. Performance in simple office work, such as clerical jobs, can sometimes be measured by output, but in the growing service-based industry, quantification of performance is often more complicated. Therefore, alternate markers such as absenteeism and human costs have been adopted. (Boubekri 2014, p. 24.) These days, employees' satisfaction with their working environment is also considered an important factor in measuring their productivity (Leblebici 2012, p. 38).

2.3 LIGHT & USER EXPERIENCE

Quantifying the users' experience of a space is not always easy. Architectural research on user experience has centered around post-occupancy evaluations (POEs), but this approach has been criticized since the users typically have a vested interest in the building. In addition, research has shown that people are not always able to accurately predict their preferences or experiences. Instead, it seems that people typically only become fully aware of their environment when there is a prominent problem with it. (Boubekri 2014, p. 48.)

Some methods have been developed to measure the users' experience and their reaction to the lighting conditions of the space. Compared to skylight, sunlight's effects are more difficult to quantify, and alternative methods are needed. One way to measure the effect of sunlight is to assess the reactions of occupants in a room when presented with a light stimulus and analyzing their moods and emotions in the lighting environment. Another method that can be used to assess sunlight uses the percentage of the sizes of visible sun patches in a room in relation to its floor area. (Boubekri 2014.) In contrast to using the duration of sunlight penetration, the focus of the sun patches approach is on the visual stimulus produced by sunlight (Boubekri et al. 1991). A study that used this method and quantified the emotional responses of the users in an office building (Boubekri et al. 1991) showed that although people like sunlight, only moderate sunlight penetration is preferred in offices. According to the study, the optimal amount of sunlight penetration was 15—25 % of the floor area, as this produced the highest level of relaxation. Sun penetration that was either higher or lower created either distress or lower levels of relaxation. (Boubekri et al. 1991.)

3

THE FINNISH DAYLIGHTING CLIMATE

In this chapter, we take a look at how climate affects the choice of daylighting strategies and what kind of daylighting conditions the Finnish climate offers. Daylight conditions are highly dependent on both geographical location — primarily, the latiture — as well as the local climate. Therefore, in order to make successful design choices, it is of utmost importance to know and understand the local daylight context determined by the climate and geographical location.

3.1 HOW CLIMATE INFLUENCES DAYLIGHTING

When it comes to daylighting, the most important characteristics of a climate is the ratio of sunlight to skylight, the two components of daylight. The rays of direct sunlight are mostly parallel, and the direction of light can be accurately predicted based on location, time and date. Skylight, on the other hand, is the sun's light that has been scattered and dispersed in the atmosphere. As a result, skylight is ambient light, coming from multiple directions and creating soft, almost unnoticeable shadows. Ambient light is the primary source of light in cloudy climates. Because of these differences between sunlight and skylight, the balance between the two in the local climate determines the approach to daylighting. In cloudy climates, diffuse daylight will be the main source of daylight, whereas in clearer climates it's usually best to use reflected sunlight. (Tregenza & Wilson 2011.)

Global illuminance is the total illuminance outdoors, a sum of the illuminances produced by direct sunlight and indirect skylight (Tregenza & Wilson 2011, p. 70). In Southern Finland, the global illuminance on a clear day is 85 000 — 90 000 lux (RT 07-10912 2008). Global illuminance is affected by latitude, season, time of day and weather. It quite closely correlates with the amount of solar radiation. (RT-055.30 1976.)

However, the degree to which sunlight is scattered, dispersed and absorbed is affected by the composition of the atmosphere. Gases, water vapor, aerosols, dust and solar altitude are the most important factors influencing scattering and absorption of sunlight. (Navvab al. 1984.) This effect is quantified by the illuminance turbidity of the atmosphere. The more pollution, moisture and other particles there are in the atmosphere, the greater the turbidity — in other words, the more the sunlight is scattered, which in turn causes the sky to appear brighter. Illuminance from the sky increases, while sunlight's illuminance decreases. (Tregenza & Wilson 2011, p. 66—68.)

The Finnish climate is mostly cloudy: during all months, there are more cloudy days (when at least 80 % of the sky is overcast) than there are clear days (when a maximum of 20 % of the sky is overcast). Cloudiness is most common during fall and winter, especially in November and December, while May and June have the highest number of clear days. (Ilmatieteen laitos.) Because of the cloudiness, the majority of the available daylight in Finland is ambient skylight. Most usable daylight is received from above, at angle of 20° at minimum, and the amount of daylight in an interior space is highly dependent on window surface area. (RT 07-10912 2008).

Differences in daylight availability between the seasons are significant in Northern Europe (Corrodi et al.2008, p. 130). In Finland, illuminance levels vary between 85 000—90 000 lux on a clear day and a couple thousand lux on a typical winter day. (RT 07-10912 2008, p. 2.) The levels are highest in the spring and summer and lowest during the fall and winter (RT-055.30 1976). In the winter months, the sun shines from a very low angle: on December 22nd the sun's angle in Helsinki on only about 6,5° (Lappalainen 2010, p. 27). The angle has a significant effect on the brightness outside. When the sun is at zenith (directly above) it is more than three times brighter than at the horizon. (Corrodi et al. 2008, p. 130.) When the sun is higher, the illuminance on ground is higher even if the weather is overcast. This is because as the elevation increases, the path of the rays becomes slightly shorter and the angle at which they hit the ground or the clouds becomes closer to perpendicular (Tregenza & Wilson 2011, p. 65). Another speciality of our Northern climate is snow, which can reflect back as much as 70 % of the radiation it receives (RT-055.30 1976, p. 1). Thus, it can make winter days considerably brighter.

3.2 DIRECT SUNLIGHT

Sunlight is composed of visible light, infrared (thermal) radiation and ultraviolet light. The amount of sunlight reaching the ground depends on solar angle, the transmittance of the atmosphere, and orientation and direction of the receiving surface. (RT-055.30 1976, p. 1—2.) Because of the large distance between the sun and the Earth, the sun's rays reaching the Earth are nearly parallel (Boubekri 2014, p. 11). As a result, direct sunlight produces sharp shadows. In Finland, the illuminance provided by direct sunlight is around 70 000 lux at maximum, which is over 100 times brighter than a typical interior space (RT 07-10912 2008, p. 2).

The sun's position in the sky is measured by two angles, solar azimuth and solar elevation, which is also called solar altitude. The solar azimuth refers to the sun's relative direction along the local horizon. It is measured as the angle between a reference line toward either North or South and a shadow cast by a vertical object. The solar elevation or solar altitude, on the other hand, is the angle between the horizon and the sun. (See Diagram 3.2.)

Direct sunlight is very strong and poses a high risk of glare. Sunlight can be guided deep into the building, but it is challenging to control due to its constant change. (RT 07-10912 2008.) Sunlight's intensity decreases as the amount of pollution and water vapor in the atmosphere increases, because they cause the light to be scattered and dispersed to a greater degree (Tregenza & Wilson 2011, p. 66). Naturally, clouds also have a diminishing effect on the amount of light: on a cloudy day, the ground receives 25—50 % of the amount of light on clear day. (RT-055.30 1976, p. 1—2.) The light is diffused, and shadows are soft on non-existent. (Boubekri 2014, p. 12.)

3.3 INDIRECT, AMBIENT SKYLIGHT

Sky is the Earth's atmosphere that is illuminated by the flow of energy from the sun. The perception of a blue sky around an orange-red sun is produced because the molecules that constitute the upper atmosphere have a wavelength-dependent scattering effect on the sun's rays: blue light is dispersed more than red light. (Tregenza & Wilson 2011, p. 60—67.)

While direct sunlight is nearly parallel, skylight arrives from multiple directions. This is because the particles in the atmosphere absorb, reflect and scatter part of the solar radiation. The more particles there are in the atmosphere, the greater the dispersed sky radiation is. (RT-055.30 1976, p. 1.)

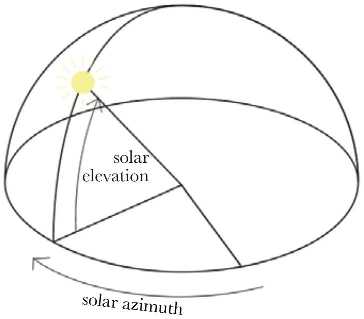


Diagram 3.2
Sun's position is determined by two angles: solar azimuth and solar elevation.

As the Finnish climate is mostly cloudy, most of daylight is ambient skylight. The illuminance produced by indirect skylight is much weaker than that of direct sunlight — in Finland, around 10 000—20 000 lux in cloudless conditions and around 40 000 lux when the sky is partly cloudy. (RT 07-10912 2008, p. 2). On a cloudy day, the ground has 25—30 % of the illuminance of a clear day (RT 055.30, 1976). However, while sunlight lights the space 5—10 times more brightly, the ambient light of the sky provides continuous light that is unlikely to cause glare and is thus ideally suited for lighting interior spaces (Corrodi et al.2008, p. 131). The challenge is, though, that the interior illuminance produced by diffuse skylight is highly dependent on window surface area and diminishes radically as the distance from the window increases (RT 07-10912 2008).

A clear sky is brightest around the sun, has a bright ring slightly above the horizon and is the darkest in the areas that are opposite to the sun. Heavily overcast skies, on the other hand, are usually brightest at the zenith and darkest near the horizon (see diagram 3.3). If the illuminance turbidity of the atmosphere can be predicted, the illuminance produced on the ground by a clear sky can be calculated. The presence of clouds, however, causes such randomness that accurate predictions are not possible. (Tregenza & Wilson 2011, p. 68.)

The effect of clouds also varies between latitudes: because the clouds in colder climates are typically much less tall than in warmer climates, they cause less light to be reflected back into space. Therefore, at a given solar elevation, the diffuse horizontal illuminance is usually higher at temperate latitudes than in tropical areas. Yet this effect is more than compensated for by the lower solar elevations at temperate latitudes, which causes diminished illuminance levels. There are also differences between continental and maritime regions: the skies of continental areas are usually more homogenous and change less rapidly than those of coastal areas, which are affected by winds from the oceans. (Tregenza & Wilson 2011.) The Finnish climate is a hybrid of continental and maritime climates. Furthermore, Finland is located at a point where polar and tropical air masses meet, and the weather is prone to rapid changes, especially in the winter. (Ilmatieteen laitos.)

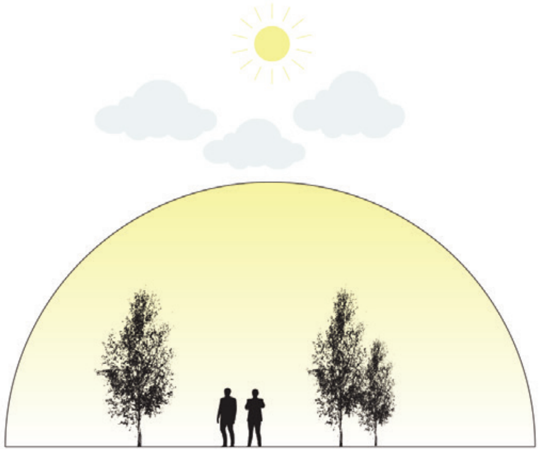


Diagram 3.3
When the sky is overcast, luminance at zenith is aboubt three times higher than luminance at horizon.
Based on: Tregenza & Wilson 2011

4

DAYLIGHT IN ARCHITECTURE

This chapter takes a look at daylighting in architecture throughout the history, and illustrates how the perspetive on daylighting has changed an evolved over centuries to what it is now. This will help in understanding the current paradigm and reflecting it against the past. Being familiar with daylighting ideologies of the past can also help the architect to question certain design traditions and customs by being able to see what kind of context they have evolved in. By combining the understanding of light's effects on human physiology and psychology and the role of geography and climate with the understanding of daylighting ideologies, we can make much more conscious and informed design choices and better advance daylighting goals.

4.1. A BRIEF HISTORY OF DAYLIGHTING

Before the advent of electric lighting, daylight was, by necessity, a key factor in building design concepts. In ancient Persia, Arabia, Greece and the Roman empire, houses were designed around a courtyard that offered increased access to daylight. In Greece, the availability of daylight for all citizens was a central objective of town planning. In the Roman empire, the writings of Vitruvius in the first century B.C. and his ideas around daylight had a great impact on the future generations of architects. (Boubekri 2014, p. 8.)

One massive wave of changes in architecture came with the industrial revolution, which led to mass migration as people moved from the countryside to cities to work in the new factories. Need for housing increased sharply and led to the pressure to produce densely populated housing areas. (Boubkeri 2014, p. 9.) In the end of the 1800s, buildings became taller and areas grew denser, which led to reduced sky view in the internal spaces. Yet daylight was still the preferred source of illumination. (Mardaljevic et al. 2013, p. 1.)

After the invention of the first incandescent lamp by Thomas Edison in 1876, lighting spaces without daylight became considerably easier. Some building professionals even regarded daylight as a somewhat unnecessary luxury, that could be economically and easily replaced by artificial light. (Boubekri 2014, p. 9—10.)

During the Modernist era, old ways of building were rejected in favor of modernity. Glass and steel were now better available, and advances in construction technology allowed more freedom for architects, making longer spans and bigger openings possible. The modernist philosophy embraced economically efficient, hygienic and healthy solutions in building and emphasized the availability of daylight and fresh air. (Boubekri 2014.)

In the 1970s, the energy crisis shifted the perspective from the heavy reliance on artificial light in buildings. Environmentalism and concerns for resources gave birth to what later developed into our current green architecture ideals. Gradually, interest in daylighting and energy conservation grew and started to shift architectural practices. These days, political measures and certifications such as LEED (Leadership in Energy & Environmental Design) underline the need to consider energy issues in the design of buildings. Energy efficiency is not seen only as a way to bring economic savings but also critical in terms of environmental sustainability. (Boubekri 2014, p. 10—11.)

In recent years, interest in light's effects on human health and performance has increased. As a result of new discoveries, and thereby increased understanding of the relationship between light and health, the mentality in lighting design has shifted away from focusing only on visual tasks. These days, good-quality lighting has to meet a more complex set of criteria and be supportive of health, well-being, interpersonal relationships and aesthetic tastes, while still fulfilling visual requirements (Bellia et al. 2011, p. 1984). The International Commission on Illumination (CIE) also mention in their report "Ocular Lighting Effects on Human Physiology, Mood and Behaviour" (2003) that in the late 1990s, their emphasis shifted from the visual effects of lighting to a broader perspective encompassing human needs, architectural objectives, economic constraints and energy consciousness. In their work, the human needs include maintaining good health, visual tasks and task performance, interpersonal communication, as well as aesthetic appreciation. (Commission Internationale de l'Eclairage (CIE) 2004, p. 1.)

These days, the creation of flexible indoor lighting is also supported by advancements in lighting technologies such as LEDs, which lend themselves to a broad range of lighting goals. While this thesis only discusses daylighting, it should be noted that especially in a country like Finland, where days during the winter are very short, artificial lighting will inevitably play a significant role in lighting. In addition to interior spaces, LEDs can be used to light urban spaces and produce, for example, flexible street lighting. This is beneficial for the lighting of homes as well, since lighting from the outside will almost always travel inside to some degree and is therefore a significant factor especially in urban settings.

4.2 STANDARDS AND GUIDELINES

While standards on electric lighting can simply give illuminance recommendations for different tasks, the changing nature of daylight makes it difficult to establish standards regarding its use (Boubekri 2014). It is widely accepted among researchers that the standards and recommendations on daylight use in architecture have to be improved and updated. (Mardaljevic et al. 2013, p. 1) Most existing lighting standards merely establish minimum illuminance requirements, typically based primarily on the needs of relevant visual tasks. (Boubekri 2014, p. 44.) What's more, many of the standards fail to take into account the actual, context-dependent availability of daylight (Mardaljevic et al. 2013, p. 1).

Some of the existing standards establish guidelines for lighting but are mainly focused on artificial lighting. For example, the European Standard EN 12464-1 deals with electric lighting systems mainly in workplaces. Another standard, the European Code "Energy performance of buildings — energy requirements for lighting" is related to possible energy savings through the use of daylight and specifies methods for quantifying energy usage by lighting in buildings. Furthermore, there are few recommendations dealing with simultaneous use of daylighting and electric lighting. (Bellia et al. 2011, p. 1985.)

Furthermore, lighting standards are typically poor when it comes to dealing with sunlight. This is partly due to the fact that lighting standards and analyses have traditionally been based on overcast sky conditions. To successfully assess and make more comprehensive prescriptions about sunlight, both qualitative and quantitative assessment models are needed. In addition to the quantitative assessments that lighting standards typically deal with, more qualitative aspects of the user experience, such as glare risk, should also be considered. (Boubekri 2014, p. 45—47.)

The daylight factor is interesting as it was developed in the early part of the 20th century in order to avoid dealing with the changing nature of daylight in calculations (Boubekri 2014, p. 44). As such, it is well suited for use in more general standards and recommendations on daylighting. Some European counties, such as Germany and the UK, have already established comprehensive codes specifically for daylighting, though they are not supposed to be taken as prescriptive orders but are mainly intended to provide information (Gago et al. 2015, p. 2). From a Finnish perspective, probably the most interesting and relevant case is Estonia due to its geographical proximity and similar climate. In 2008, Estonia established a standard giving rather specific orders about the use of daylight in residential buildings. According to the standard, all rooms in residential buildings must have a daylight factor of at least 2 %. The standard also states that in each dwelling, at least some of the rooms should have a minimum of three hours of continuous, direct sunlight. In tightly built areas, this time may in some cases be diminished to 2,5 hours or divided into two sections, but still an uninterrupted period of at least two hours of direct sunlight is required. (Voll et al. 2010, p. 1—2.) Some other recommendations about daylight factor goals set by other European countries are presented in chapter 5.

One of the more prominent daylighting guidelines, established by the Building Research Establishment Assessment Method (BREEAM) has two ways to measure successfulness of daylighting. The first criterion deals with daylighting and requires a specified minimum average daylight factor that should be reached on 80 % of the relevant area at desk height. The required daylight factor values are determined according to latitude. In areas at less than 40° latitude, the required daylight factor is 1,5, whereas a daylight factor of 2,2 is needed at latitudes over 60°. These values are the criteria for the "First credit" offered by BREAAM, but they also have other credits with more demanding criteria and therefore, higher daylight factor requirements. In addition, there are different requirements for single-storey and multi-storey buildings — for the former, a higher DF is required in order to achieve the same credits. (Mardaljevic et al. 2013, p. 4.) The second part of the BREAAM guideline states that in the same 80 % of the relevant area of desk height, an average of 200 lux should be achieved for a minimum of 2650 hours per year. Furthermore, at least 60 lux should be achieved for the same 2650 hours per year at the worst-lit spot of the area. (Mardaljevic et al. 2013, p. 4.)

Mardaljevic et al. (2013) propose a new guideline, which aims to decrease the likelihood of misunderstanding and game playing, which, the authors state, has been an issue with some of the earlier daylighting guidelines. The idea of their proposal is to take into account the actual availability of daylight when determining lighting goals. They aim to do this by prescribing a target daylight factor based on what would provide a 300-lux illuminance in local conditions. The 300-lux value was chosen for it has repeatedly been found to correlate with experience of well-lit space. According to their guideline, this daylight factor should then be achieved at desk height in the relevant area for half of the daylight hours in a year. The daylight hours are defined as the 4380 highest diffuse horizontal illuminance values. (Mardaljevic et al. 2013.)

An interesting attempt to introduce standards on daylight use and to promote a user-centered approach to building design is the WELL Building StandardTM developed by the International WELL Building Institute<https://www.wellcertified.com/en>. The standard covers many aspects of designing a health-supporting building, including lighting. With regard to lighting, the aim is to minimize the disruption to the body's circadian system, advance good sleep quality, ensure adequate visual acuity and improve productivity. While the WELL Building StandardTM is not an official, legal standard but a certification offered by a corporation, it can be a useful resource for designers as it provides a broad range of detailed, practical guidelines for design decisions such as transmittance value of windows, window sizing and includes recommended lux values for different spaces. It also provides explanations of the motives and arguments behind these guidelines and thus offers a resource with actionable information conveyed in a compact and easily understandable format. A notable benefit of these guidelines is that they also cover topics that are missing in many other daylighting guidelines, especially older ones that were developed before the current extent of medical research on light's biological effects, such as minimizing light at night time. (https://www.wellcertified.com/en, 12.1.2019.)

In Finland, relatively few standards related to daylighting exist at the moment. Some guidelines, regulations and recommendations are made by Rakennustietosäätiö (RTS). For example, RT 07-10912 (2008) aims to provide information on ways to get daylight inside in a controlled way, make its distribution more even, affect the quality of the light and prevent adverse effect of incorrect lighting. Meanwhile, SIT 63-610044 (2007), deals with characteristics of light and light's importance for humans as well as lighting principles and solutions in different kinds of spaces. Further guidelines exist to cover areas such as sun shading, use of blinds and curtains and measurements of illuminance. However, outside the resources produced by the RTS, there is relatively little Finnish literature that would discuss daylighting in relation to the user's wellbeing.

4.3 ENERGY CONSUMPTION

The building sector plays a central role in the alarmingly rising energy usage rates. In the US, for example, buildings account for over 40 % of energy consumption and over 45 % of CO2 emissions (Boubekri 2014, p. 14—15). In Europe, the residential sector uses around 25 % of total energy and contributes substantially to CO^2 emissions. Artificial lighting comprises around 14 % of electricity consumption in the EU and 19 % worldwide. Within a building, electric lighting can make up as much as 35 % of total electricity consumption. Furthermore, artificial lighting generates heat and can therefore increase cooling needs, further contributing to energy consumption. (Gago et al. 2015, p. 2.) However, the issue of heat generated by artificial lighting is becoming less of a concern with the advancements and increased efficiency in artificial lights, especially LEDs. In Finland, electrical lighting in houses consumed 1770 GWh in 2016, which was 2,6% of the total energy consumption of housing (66 997 GWh) and 21,3 % of total energy consumption consumed by in-house appliances (8 295 GWh) (energy consumption also comprises natural gas and liquid gas in addition to electricity) (Suomen virallinen tilasto (SVT), 2016 (retrieved 25.2.2019.)

Daylighting can be used to significantly change the energy consumption of the building, while simultaneously offering comfort and health benefits for occupants. It is a cost-effective way to achieve savings in both energy consumption and CO^2 emissions. (Gago et al. 2015, p. 2.) As Gago et al. (2015, p. 11) conclude: "Through a well-designed, controlled use of daylight, employing technologies or systems which ensure the penetration of light throughout the whole building, energy consumption designated to lighting and air conditioning can be kept at a minimum." According to the report by Gago et al. (2015, p. 3), modification of window size, for example, can bring at least 10 % savings in electrical energy consumption. Daylight is especially useful in reducing peak demand, as the highest demand for lighting tends to coincide with highest daylight availability (Boubekri 2014, p 22), as most people are working and doing other chores that require good lighting during daytime.

Because daylight is variable in nature, it has to be controlled in order to be used in place of electrical lighting. Uncontrolled and poorly designed use of daylight can end up having a negative impact on the environment through, for example, increased need for cooling and the subsequently increased energy consumption. However, many current systems for controlling daylight have excessively focused on minimizing the negative effects such as the heat load but ignored the possibility to utilize the positive effects of light. This approach typically leads to insufficient levels of daylight in interior spaces, resulting in increased reliance on artificial lighting and therefore, increased energy consumption. (Gago et al. 2015, p. 2.)

The townhouse typology also has qualities that align well with environmental sustainability goals. Because of the decreased building surface area, it is more energy-efficient than detached houses. Along the same vein, a central location in a dense city structure— which is typical for townhouses — helps decrease people's transportation needs and therefore supports the creation of a more sustainably city. (Pulkkinen 2011, p. 10—11.)

5

WHAT IS GOOD LIGHTING?

This chapter aims to combine the knowledge an understanding of the first four chapters and provide ideas about what good daylighting is in practical terms. We will explore different ideas about the key daylighting goals from different experts and researchers. This chapter provides both qualitative and quantitative criteria that could be used to determine what a good lighting environment is like. However, as we will learn, this is not a black-and-white question, but instead, a complicated, context-dependent issue, which means that the architect needs to have a good understanding of the subject in order to choose the strategy wisely.

No fixed criteria can be defined for good lighting, as it is always dependent on the context. Therefore, it is more useful to examine the suitability of a lighting scheme for its purpose. The effects of light on people's physiology always depend on timing and the quality of the light. (Corrodi et al. 2008, p. 129). Similarly, the experience of pleasantness of the lighting depends on the volume, quality and distribution of light (Peltonen 2002, p. 30).

It is also important to recognize that lighting needs are continuously changing according to activity and time of day. Therefore, lighting conditions in the house should not merely meet a fixed standard of quality or a required level of brightness. Good lighting is always dependent on context, so lighting should be flexible. Flexibility in general — referring to the ability of the space to adapt to different kinds of use (Tarpio 2015, p. 4) — has been a central theme in architecture in the recent years and is also important in daylighting.

However, some general principles can be established. For example, it can be stated that good lighting enables vision without glare and also guides the user's gaze, attention and observations (Corrodi et al. 2008, p. 129). Typically, the most important thing in the daylighting design process is recognizing the risks of the design solutions (RT 07-10912 2008, p. 2).

5.1 INTERIOR ILLUMINANCE

The lighting conditions of a room depend on three factors: the proportion of sky visible from the room (sky component), exterior surfaces that reflect light in, and the light reflections inside the room. However, the lighting conditions of a particular part of the space is most strongly tied to the amount of sky visible from this part. (Corrodi et al. 2008, p. 134-143.)

A common difficulty in daylighting is low levels of daylight in the back of the space, while the areas in front of the window can be excessively bright. Another common risk is periodically excessive levels of light in the space, if the quality of daylight is not adequately taken into account in the design process. (RT 07-10912 2008, p. 2.)

Several studies have looked into interior illuminances in an attempt to develop recommendations for lighting design. A number of studies indicate that an illuminance of 300 lux correlates with user experience of well-lit space (Mardaljevic et al. 2013, p. 8). When working on a computer, it appears that an interior illuminance of 100—300 lux is deemed appropriate by users (Galasiu & Veitch 2006). For comparison, the typical illuminance outdoors of a bright day is considerably can be as high as 100 000 lux.

5.2 DAYLIGHT FACTOR

At least in France and the UK, the daylight factor (DF) has been used as the basis of regulations for daylighting. For example, France recommends a DF of 1,5 % for education spaces such as classrooms. The UK prescribed a daylight factor of 2,0 % for classrooms, but the recommendation was later withdrawn as it became clear that in rooms lit from only one side, this could be difficult to achieve. (Boubekri 2014, p. 44—45.) According to Corrodi et al. (2008, p. 138), a DF of 2—3 % represents a well-lit interior space. In contrast, a DF of 1 % could be deemed to be the bare minimum (Rogers & al. 2015, p. 26). However, if the space is to be lit primarily by daylight, a much higher DF is required — according to Littlefair (2011, p. 53), a DF of at least 5 % is needed in these cases to ensure adequate daylight.

While the above-mentioned numbers are a good starting point, they are primarily based on daylight conditions of areas at lower latitudes than Finland. As the typical outdoor illuminance in Finland is much lower than in these areas, it is necessary to aim for a higher daylight factor: since the daylight factor is the percentage of outdoor illuminance, with lower outdoor illuminance levels a higher DF is required to achieve the same lux levels. For example, DeKay (2010, p. 40), suggests a DF of 4,5 % for 54. Northern latitude. Finland is located between 60. and 70. Northern latitude, meaning that a high enough DF is essential to prevent the interior spaces from being very dark for a large proportion of the year. In Estonia, this has already been acknowledged: in 2008, Estonia established a standard demanding all rooms in residential buildings have a daylight factor of 2 % or more (Voll, Kõiv & Sergejeva 2010, p. 1—2). RT 07 -10912 (2008, p. 1) states that the typical goal is a daylight factor of 1—5 %, but at least the lower end of this recommendation is rather low compared to the other recommendations that have been presented here.

5.3 NATURAL VS ARTIFICIAL LIGHT

Daylight gives the body signals about the passing of time and the time of day. Tregenza & Wilson (2011, p. 5) go as far as to suggest that this information provided by light is even more important than the radiation itself. They also emphasize the importance of variations in light, as it stimulates the senses and gives the body cues in a way that humans have adapted to. However, little research has been done on this subject (Tregenza & Wilson 2011, p. 5). Some studies suggest that a lower level of light can be tolerated in spaces lit by daylight than in those lit by artificial light, but the reason for this is unknown and may involve both physiological and psychological processes. (Tregenza & Wilson 2011, p. 20.)

In general, is seems that daylight is preferred to artificial light by most people (Galasiu & Veitch 2006; Tregenza & Wilson 2011). It has also been suggested by some research that people believe that working in daylight causes less stress and discomfort (Galasiu & Veicth 2006).

5.4 GLARE AND CONTRASTS

Tregenza & Wilson (2011, p. 4) have studied people's most common complaints about lighting. These include disturbing glare on screens, glare caused by sunlight, no possibility to open a window or adjust blinds, too little light in indoor spaces, dissatisfying views, lack of privacy and new buildings that obstruct the light.

The distribution of light within a space often has a greater impact on the user's experience of brightness than the actual amount of light. Big contrasts, typically resulting from a strong light source, can cause glare. Glare can be caused directly, indirectly or through reflection. Direct glare is a result of a light source in the field of vision, while indirect glare is caused by high luminance surfaces. Reflection glare, on the other hand, is a result of light being reflected from reflective surfaces. (Tillberg et al. 2015 2002, p. 30.)

Disability glare is an excessive amount of light entering the viewer's eye and impeding vision. Discomfort glare, on the other hand, is glare that is uncomfortable or distracting but does not significantly impair performance in visual activities. Discomfort glare is typically caused by excessive contrast between a light source and background or an object and background. (Boubekri 2014, p. 50.) A softer and larger light source will generally result in better visual quality. Improved visual quality results in less eye strain and improved ability to function and perform tasks. (Public Technology, Inc. 1996, p. 94.)

RT 07-10912 (2008, p. 3) states that avoiding excessive contrasts and too high illuminances in the field of vision should be one of the key goals in daylighting. Reasonable contrasts, however, are deemed pleasant. (RT 07-10912 2008, p. 3.)

As mentioned earlier, glare can be quantified using the Daylight Glare Index (DGI), where glare is a function of the luminance, size and location of glare source, background luminance, and the viewing direction in relation to the source. However, some research indicates that the formula is not fully applicable in cases where the window or the light source is parallel to the viewer's line of sight. Furthermore, it is also not accurate in cases where glare is produced by a non-uniform light source, such as a window with venetian blinds. Some researchers have also suggested that in cases where the glare source is large, the DGI should be independent of background luminance. Their argument is based on the fact that a large glare source is likely to have a considerable effect on the background luminance. Lastly, the DGI formula may not be usable in cases where direct sunlight enters the space. (Boubekri 2014, p. 52.)

Glare protection needs extra attention on high latitudes, where the sun often shines from a low angle. However, people tend to tolerate glare from daylight better than that of artificial light, especially if there is a pleasant view to compensate (Galasiu & Veitch, 2006). In addition to glare, urban housing design should be concerned with protection from unwanted light pollution caused by street lights, lit billboards and advertisements, among others. These are light sources the inhabitants of a house tend to have no control over, and therefore, the dwelling should provide the users with ways to block unwanted sources of external light. This is important particularly in bedrooms. However, it is interesting and promising from a housing design perspective that the paradigm shift in lighting design applies not only to buildings but also urban spaces. The approach in street lighting, for example, is becoming increasingly user-centered and concerned with adaptability in an attempt to decrease light pollution and to reduce energy consumption (Heiskanen 2017, p. 9).

Technologies enabling intelligent lighting as part of a smart city are evolving fast, and the topic has generated interest in Finland in the recent years. Aspects of intelligent urban light have been researched by, for example, Heiskanen (2017) and Kaikkonen (2016). If urban lighting of the future is more adaptable and case-specific, it will also support good lighting in homes. The tone of light in outdoor spaces can, for example, become warmer as the evening progresses and unnecessary artificial light at night time can be minimized.

5.5 DAYLIGHTING OBJECTIVES

As new discoveries on light's effects on human health have been made, the focus in lighting design has shifted away from merely attempting to fulfil visual needs and sustainability or energy-efficiency goals. Instead, a more comprehensive approach has been adopted, where the broad range of non-visual effects of light is also be taken into account. (Bellia et al. 2011.)

One attempt to conceptualize this kind of more holistic approach has been made by the International Association of Lighting Designers (IALD). It has introduced a term called Human Centric Lighting, a concept that connects light with health and well-being. As implied by the name, the focus is on people and the aim is to balance visual, emotional and biological needs of the user, as opposed to mainly thinking of sustainability and energy efficiency goals as has been common in the past. This human-centric approach calls for awareness of the non-visual psychological and physiological effects of light, many of which have only recently been discovered. (Ladopoulos & Shaw, p. 1.) Human Centric Lighting does indeed well summarize what today's designers should aim for in order to create health-supporting buildings, including homes, for the users.

Though other researchers have used different terms, there is a good amount of research on healthy lighting and its various aspects. Here, we will explore some proposed ideas and criteria for healthy lighting found in the current literature. The purpose of this chapter is to gain a more complete understanding of what the goals in daylighting design should be. However, new research on light's effects is carried out all the time and researchers keep discovering more on the subject, so the criteria is likely to change or at least get more refined in the future.

As discussed before, two important issues with typical lighting conditions in modern societies are insufficient exposure to light during the day and increased exposure to artificial light at night-time. Because a large proportion of time is spent indoors, exposure to bright daylight tends to remain too low, whereas increased light exposure in the evening and during the night may cause circadian rhythm disruption and have a detrimental effect on sleep. (Potter & al. 2016.)

Commission Internationale de l'Eclairage (CIE) proposes the following principles for healthy architectural lighting design:

- "The daily light dose received by people in Western countries might be too low
- Healthy light is inextricably linked to healthy darkness.
- Light for biological action should be rich in the regions of the spectrum to which the nonvisual system is most sensitive.
- The important consideration in determining light dose is the light received at the eye, both directly from the light source and reflected off surrounding surfaces.
- The timing of light exposure influences the effects of the dose." (CIE 2004, p. 28—29.)

Like Potter et al. (2016), Commission Internationale de l'Eclairage (CIE) argues that in Western countries, people in urban areas are exposed to biological darkness during the day when interior spaces do not have adequately high illuminance levels, while electric lighting extends the apparent day length and produces unnatural brightness at night. They report on data suggesting that both the reduced daytime light exposure and the increased night-time light exposure have potential detrimental physiological and psychological effects. They also call for more attention to light quality and timing in the design of our environment. (Commission Internationale de l'Eclairage (CIE) 2004, p. 6, 28—29.)

Galasiu and Veitch (2012) report on the above-mentioned criteria defined by the CIE, and also offer some more recent conclusions related to lighting needs:

- “Human well-being relies on regular exposure to light and dark each day.

- Daylight is the most energy-efficient means to deliver the light exposure, when it is available.

- Uncontrolled daylight also can cause problems: veiling luminances that reduce visibility, visual discomfort, thermal discomfort.

- The optimal pattern of light and dark exposure, as well as the limits at which daylight control is needed, probably varies for different populations defined by age and individual differences.

- The desire for daylight as the source of the light exposure also depends on how the openings affect the space appearance, on the function of the space, and on cultural norms about privacy, enclosure, and view.

- A view of outdoors is also a contributor to well-being, particularly if it is a nature or an attractive view. Separation from the sky and the outside world is to be avoided.

- Using daylight to deliver useful light is sustainable only in concert with the effects on the building envelope, ventilation, and overall energy balance. These require climate-based and locally specific solutions that respect other building system considerations and regulations.”

Based on their summary, Galasiu and Veitch underline the importance of establishing a light—dark pattern that supports good physical and mental health and of examining how homes can create environments with healthy light exposure (Galasiu & Veitch 2012). Meanwhile, Tregenza & Wilson (2011, p. 5—6) define four key needs of people with regard to daylight, which are as follows:

- A 24-hour cycle, including both light and dark

- Exposure to bright light, also in wintertime

- Connection to outdoors inside a building

- Avoidance of glare, which causes discomfort and difficulty noticing danger

Tregenza and Wilson emphasize that the importance of each need depends on the building type and the circumstances of the user (Tregenza & Wilson 2011, p. 6). They also define three additional goals for the use of light in housing design: the suitability of the building for the local climate, the preservation of the natural variation of light and the opportunity for the users to adjust the lighting conditions.

RT 07-10912 (2008, p. 3), sets the following criteria for daylighting design:

- Ensuring sufficient amounts of light and window surfaces, according to the use of the space

- Aiming for reasonably even distribution of light within the space, and ensuring that the surfaces have a pleasant and appropriate luminance

- Avoiding bright areas in the field of vision that might cause glare, and restricting flow of light into the space as needed

Quite similar goals for daylighting are presented by Boubekri (2014, p. 12), who proposes the following objectives:

- “Increasing daylight levels in the core area of the building
- Having the right amount of daylight for the appropriate time duration
- Protecting the occupants against excessive glare
- Allowing a good view to the outside
- Minimizing solar heat gain in the summer while maximizing it in winter.”

The design goals always depend on geographical location and climate as well as the immediate surroundings. Because of the long, dark winter of the North, building designers of the area should aim to maximize daylight in the winter and try get light in from the brightest parts of the sky. (Johnsen & Watkins 2010, p. 2.)

PART 2 : DAYLIGHT *and* THE FINNISH TOWNHOUSE

6

THE FINNISH TOWNHOUSE: BACKGROUND

This chapter is focused on the townhouse typology. We discuss the characteristics of the townhouse, focusing especially on ones that influence daylighting. To gain a better understanding of the townhouse, how it came to be and why it is like it is, this chapter also covers the history of townhouses. An important topic is also the townhouse in the Finnish context, as well as the history of small-scale urban living in Finland. This will help in understanding the Finnish housing design tradition and the lack of experience of townhouses in Finland.

6.1 DEFINITION

The Habitat Components — Townhouse study conducted in Aalto University over the course of the last few years, set out to define the townhouse as its own, distinct typology. Based on the different parts of the research project, a list was derived, describing the characteristics defining a townhouse. The chosen characteristics were based on the traditional European forms of the townhouse and shared by townhouse typologies in different countries to a sufficient degree. The list includes the following features:

- "Own plot or independence of the housing unit, if it is part of a housing cooperative
- Several floors (2 – 4 floors in the study, could be more, but the size of the dwelling becomes unnecessarily large)
- Built to adjoining neighbouring units (density, uniform facade facing street)
- Own, defined, home-specific yard area (back yard and potentially front yard)
- Own entrance to the street and yard
- Multifunctionality (may include work, business and storage space, in addition to living area)
- Individual architectural appearance or autonomy of varying degree on decisions pertaining to appearance
- Non-centralised parking (parking space in conjunction with the dwelling, on the property or street parking in front of the property)"

(Huttunen et al. 2016b, p. 8.)

Townhouses are typically deep and narrow: a typical facade is 5—10 meters long. The plot can be as narrow as 4—5 meters (Ullrich 2016, p. 18), whereas the depth of the plot ranges from 15 meters to 25—30 meters (Jalkanen et al. 2012, p. 50). While the townhouse residence, according to the definition used here, always has its own entrance and a private backyard, there can also be shared outdoor spaces. In contrast to row houses placed further into the site, the townhouse's facade is typically aligned to the street, and is located either right next to the street at the edge of the site or close to it with a narrow front yard in between.

A typical townhouse block is composed of two opposing townhouse rows, between which private or shared yards and gardens are located. To create a more complex form, the rows can follow a zigzag line, or the buildings can be grouped into strings of varying length. (Jalkanen et al. 2012, p. 24.) Townhouses can also be located in the same block with apartment buildings.

Other key features of townhouses include efficient land use and the density of the urban structure they create (Huttunen et al. 2016b, p. 8). The dense and low city structure created by townhouses resembles that of pre-modernist times, without forgetting the achievements of modernisms, such as better daylight conditions (Ullrich 2014, p. 78).

Image 6.1
Townhouses in Amsterdam.

6.2 A BRIEF HISTORY OF THE TOWNHOUSE

The townhouse typology traces its roots back to European typologies involving 2—4 storey-high houses that joined with neighbouring buildings (usually also townhouses) at firewalls but were each located on their own site. Traditionally, townhouses are placed by the edge of the street, and form efficient, string-like city blocks. (Jalkanen et al. 2012, p. 21.)

The name "townhouse" originates from Great Britain, where it was originally used to refer to the upper class' urban residences — "houses in town" of the 1900th century. (Ellilä 2014, p. 7). At the time, people were moving from the countryside into the cities at an accelerated pace. This resulted in formation of large working-class areas with increased density, poor quality construction and social issues. As a result, the upper class of the Victorian era, such as merchants and craftsmen, started moving away from the cities and into the suburbs and countryside. Yet during the so-called social season, they needed to stay in the cities for important evening events, which led to them having a separate urban residence, the "house in town". (Manninen & Holopainen 2006, p. 9.) In addition to the Britain, the Netherlands and Germany also have a long tradition of townhouse architecture. What's more, especially the Netherlands and Germany are now experiencing a second wave of interest in the typology (Huttunen et al. 2016b, p. 7).

In the Britain, townhouses were the predominant housing typology up until the 20th century (Huttunen et al. 2016b, p. 24). The history of English townhouses goes back to the Middle Ages and the row houses, aristocratic boarding houses and merchant houses of the time. At the time, cities were growing and therefore becoming increasingly dense, which made street facade space limited. As a result of trying to open as many buildings to the street as possible, the characteristic narrow and deep plot of townhouses was formed. The city structure of small row houses was also a step from a society based on self-reliance towards a more modern system of services and industries. (Huttunen et al. 2016b, p. 22.)

The British terrace houses of the working class were initially built by developers and as a result, more uniform architecturally, even though they were independently owned. Over the course of their history, the appearance of terrace houses evolved, and more individuality and variation started to emerge in their architecture. Meanwhile, the upper-class residences in the Britain, as well as the Dutch and German traditional merchant houses, were both individually owned and designed, and therefore visibly different from neighbouring buildings. (Huttunen et al. 2016b, p. 7.)

The townhouse has also historically been, and still is, a common typology in the Netherlands. The Netherlands transitioned away from agriculture and towards urbanization very early compared to many other European countries. As early as the 17th century, half of the population was living in cities. As a result, the country has a long history of urban merchant houses with commercial space on the ground floor. Just like in the Britain, street facade space was limited in urban areas, and so the merchant houses became long and narrow. They could, however, be expanded vertically when needed. (Ellilä 2013, p. 11.) Row houses and townhouses have become an established and popular form of housing because they align well with the Dutch living preferences: private backyard, entrance at ground level and intimate connection with the street and social life are all considered important. Production of new dense, low-rise areas has also been purposefully increased by housing acts such as the Vinex act of 1994 (Ellilä 2014, p. 13).

Germany has a long history of townhouse-like Bürgerhauses, which date back to the Middle ages and only began to disappear during the Baroque period. While the German townhouse is not directly related to the Bürgerhaus typology, they have many similarities, including deep building frame, narrow plot and vertical orientation. (Ullrich 2014, p. 27—39). After being forgotten for a long time, the urban attached house started to receive attention and interest once more. As a result, construction of townhouse-type small-scale buildings in city centers gathered speed in the 1980s. In today's Germany, urban living is incredibly popular. There is also a strong political interest favoring townhouses in order to maintain a socially mixed city structure and to prevent suburbanization. (Huttunen et al. 2016b, p. 16.)

The townhouse typology also spread to Northern America, first from the Netherlands and then from the Britain with the immigrants moving across the Atlantic. In the US and Canada, the term townhouse is used to refer to many kinds of urban small-scale housing. In the metropolitans of the East Coast of the US, a townhouse zone runs around the denser core of the city. (Manninen & Holopainen 2006, p. 11.)

Townhouse-resembling, small-scale buildings were common also in the Nordic countries, especially in Sweden, up till the mid-19th century. In the 19th century, Helsinki was also dominated by small-scale wooden houses, though they differed from townhouses in many ways. Later on, partly influenced by new trends from Berlin and Paris and partly as a result of the pressure to increase land use efficiency, these typologies started disappearing. The majority of the small-scale buildings in city centers got demolished. Currently, however, there is interest in reviving small-scale urban living in the Nordic countries. (Manninen & Holopainen 2006, p. 12—13.)

The long history of townhouses in Central European countries has clearly influenced culture and living standards, as to this day, the Netherlands and the Britain are still committed to small-scale housing in dense areas despite their high population density (Huttunen et al. 2016b, p. 9). In the Netherlands, small-scale housing has historically been strongly preferred to apartment buildings. Especially row houses offer a way to enjoy some qualities of detached house living but at a more affordable price. As row houses are typically smaller than townhouses, they are also more affordable. However, an upside of townhouses is a higher degree of individuality and a more central location. (Huttunen et al. 2016b, p. 11—12). The Netherlands has also enforced many policies pertaining housing with the goal of offering affordable homes for the middle class and families with children, as well as to make urban areas more enticing places to live for these groups (Huttunen et al. 2016b).

6.3 THE TOWNHOUSE IN FINLAND

6.3.1 SMALL-SCALE URBAN HOUSING IN FINLAND

While townhouses have been the traditional norm in many European cities, this urban row house typology has long been missing in Finnish cities. In fact, Finland is all but missing hybrid typologies and typologies that are between apartment buildings and detached houses in terms of scale.

Finland has long been an agriculture-focused country, where very little was built during the Middle Ages. Urbanization happened late, mostly during the reconstruction period after World. War II. Compared to most other European countries, the shift happened at a very rapid pace. Finland practically transferred from an agricultural society to post-industrialism, missing the between-period dominated by industrial livelihoods. (Manninen & Holopainen 2006, p. 16.) This resulted in high pressure to produce masses of new housing in cities very fast. This development can be seen as one of the key reasons for the missing small-scale urban housing typologies. With low population density, there has not been similar pressure for dense building even in urban areas. Furthermore, the ideal in Finnish housing has long been a detached, single-family house, which has further decreased interest in more urban typologies.

In the 19th century, Helsinki was also dominated by small-scale wooden houses, but they differed from townhouses in many ways (Manninen & Holopainen 2006, p. 13). In fact, all old cities have originally been based on small-scale buildings, but over time they have mostly been demolished and replaced by higher-rise buildings, especially in central areas. In Finland, this development has been especially common, owing to the common use of wood as a material and fast urbanization, as well as technological advancements and architectural ideologies. In contrast, in countries where stone has been the main building material and the quality of building has been higher, small-scale buildings are still common even in central areas. (Pulkkinen 2011, p. 6.)

During the first wave of urbanization, city planning was influenced by ideals from St. Petersburg, Berlin and Wien. At the turn of the 20th century, the focus was on efficient land use. As a result of several fires in cities dominated by wooden buildings, skepticism towards urban small-scale housing prevailed. (Manninen & Holopainen 2006, p. 13.)

Though the interest in row houses started to slowly increase in Finland in the beginning of the 20th century, few plans actually came to fruition in the first few decades (Jalkanen et al. 2012, p. 9). Eliel Saarinen, for example, was interested in row houses. He deemed that private housing in the cities should not be designed by the same principles. He saw them as a suitable form of housing for urban areas: it had many of the benefits of detached houses that people had been used to in the countryside, such as strong sense of home and opportunities for personalization. In 1915, Saarinen developed a plan for Haaga-Munkkiniemi area involving row house buildings that strongly resemble townhouses. However, only one part of the plan was eventually built on Hollantilaisentie in Munkkiniemi, Helsinki. (Ellilä 2014, p. 15.)

In the 1950s, row houses started to become more common and over the next few decades, they started to become an established, though minor, part of Finnish suburbs. Yet these buildings differed from townhouses in that they did not follow the street line — in fact, the relationship between the street and the building was seen as rather unimportant. Instead, the architects focused on the terrain and the surrounding nature (Jalkanen et al. 2012, p. 9.) Up till the 1950s, it had been common that buildings were placed by the edge of the street or that their facades at least followed the direction of the street. During the reconstruction period, however, ideals in housing design underwent a paradigm shift due to new modernist and functionalism ideals. Urban schemes were deemed undesirable, and the ideals favored more open solutions, such as free-standing tower blocks. Airiness, spaciousness and proximity to nature were important, and guided formation of new suburban areas further away from the city center. Modernists also paid plenty of attention to daylighting: distances between buildings were dictated by light angles. (Manninen & Holopainen 2006, p. 16-17.)

In the 1970s, the Danish taetlav, a dense, low-rise housing typology, started to awake interest in Finland. A few buildings following the Danish example were built in suburban areas. These were mostly small-scale apartment buildings, row houses and detached houses that were built more densely than before, and also with more focus on the street line. Yet the townhouse typology was still missing.

At the turn of the 21st century, interest in low-rise but dense building increased once more. Yet an urban row house typology was absent in areas built at the time, except for a few select areas. However, the few townhouse-type buildings that were built did raise interest, though — especially ones built in Säterinmetsä, Espoo. (Jalkanen et al. 2012, p. 9.)

6.3.2 THE ROW HOUSE VS THE TOWNHOUSE

Though Finnish row houses, especially multi-storey versions, can in many ways be very similar to townhouses, in townhouses the building frame is typically deeper and the facades shorter than in row houses. Townhouses are also usually located at the edge of the site, by the street, while row houses may be further away from the border. (Sanaksenaho 2013.) Another key difference is that the townhouse — as the name suggests — has traditionally been a typology of urban areas, while Finnish row houses have typically been located in suburban areas (Jalkanen et al. 2012, p. 21, 51). Many of the planned townhouse projects in Finland are also located further away from city centers, which raises the question of how mixed functions — the mix of work, living and services that is a core part of townhouse areas in Central European countries such as

Germany — can be achieved in these new areas. Similarly, availability of public transport in these areas will strongly influence the sense of urbanity in an area. (Huttunen et al. 2016b, p. 19).

Another difference between the European townhouse and the Finnish row house is that the former is typically been independently owned, while the Finnish row house is usually part of a housing cooperative (Jalkanen et al. 2012, p. 21). As a result, Finnish row houses have traditionally been quite uniform in terms of architecture, and an individual home-owner's power over design solutions has been very limited. In contrast, in the case of individually owned townhouses, the design solutions for each house can be made independently and be more varied as a result. Another distinct difference is that in Finnish row houses, the focus has been on shared outdoor spaces rather than house-specific, private yards (Huttunen et al. 2016b, p. 7).

6.3.3 THE TOWNHOUSE & FINNISH CITY PLANNING

In recent years, the townhouse as a new urban area row house typology has gained the interest of both the city planning and residents, although contractors have been more hesitant (Jalkanen et al. 2012, p. 9). Several studies on the typology have been conducted in recent years, perhaps the most notable being the large *Habitat Components — Townhouse* study conducted in Aalto University. The typology has also been popular among city planners wishing to create new, low-rise dense areas, and if the plans eventually come to fruition, Finland will soon have tens of thousands of townhouses (Sanaksenaho 2013).

As already mentioned, townhouses form dense and urban city structure (Huttunen & al. 2016b, p. 5), and represent a mid-scale typology that has been largely missing in Finland. It is therefore not surprising that Helsinki City sees townhouses as a way to diversify housing production. The townhouse provides a way to create more urbanity in the more suburban areas, or, conversely, to produce more small-scale forms of habitation in more dense and urban areas. (Jalkanen et al. 2012, p. 9—12.) Townhouses can be a way to create areas that resemble traditional European urban living. Having entrances and windows open directly to the street produces a closer connection between houses and public spaces, which can enhance natural control of public areas. (Mälkki 2010, p. 136.) The townhouse also offers a way for the city to better respond to the high demand for detached housing — it has been estimated that around 100 small-scale houses could be built annually in Helsinki, but it is likely that there would be demand for 500 houses or more per year. (Jalkanen & al. 2012, p. 14). At the same time, adjoining buildings are favorable in terms of better land use efficiency (Pulkkinen 2011, p. 10).

Townhouses can be used as the main typology of a new area, but they are also well-suited for infill building on already built areas (Ellilä 2014, p. 49). Dense, small-scale housing also aligns well with environmental sustainability goals, since adjoining townhouses are generally more energy-efficient than detached houses (Ellilä 2014, p. 26, 67). This is due to the decrease in the building's surface area (Pulkkinen 2011, p. 10). As discussed in chapter 4, appropriate daylighting is a way to further decrease energy usage and environmental effects of the house.

The first new townhouse areas have already been built in Helsinki and new ones are under constructions in areas such as Alppikylä and Ormuspelto. Many more projects will be completed in upcoming years, in both suburban and downtown areas. The majority of planned or completed townhouse projects are located in Eastern Helsinki, and most of it is infill development on largely built areas, except for larger new project areas such as Kruunuvuorenranta. (Jalkanen et al. 2012, p. 9, 17). Östersundom, which was transferred from Sipoo to Helsinki 2009, is designed to have a particularly high proportion of townhouse-type buildings — 22 % of total floor area — according to a functional zoning plan published in June 2018 (Helsingin Kaupunki. Kaupunkiympäristö, 2018, p. 36).

6.3.4 THE TOWNHOUSE & THE FINNISH INHABITANT

Small-scale houses are still the most popular form of housing in Finland (Strandell 2017, p. 86). Their popularity is probably largely due to the freedom they provide — the owner of a single house can make decisions about the house and its maintenance much more freely than in housing cooperative apartments. Furthermore, they provide privacy and peace as well as a private backyard, which are highly valued in Finland. (Jalkanen et al. 2012, p. 21.)

Yet not everybody can afford a detached house. Some may not be willing to live in areas further away from city centers or get a car, which might be necessary in order to live in a detached house (Strandell 2017). What's more, location and transportation connections seem to be increasingly important criteria in the selection of housing — even among those who prefer small-scale housing. The Finnish Resident's Barometer 2016 presents dense, small-scale housing — such as row houses and townhouses — as a solution to the contradicting preferences regarding, for example, a private backyard and proximity of services (Strandell 2017, p. 89.) Indeed, the townhouse combines upsides of both apartment buildings and detached houses: in terms of environment, the townhouse as an urban typology is close to apartment buildings, but in terms of the dwelling itself, it is closer to detached houses (Ellilä 2014, p. 33).

Considering the benefits of the townhouse as a mix of detached houses and apartment buildings, it is hardly surprising that as much as 56 % of the respondents of The New Finnish Dream Home study felt that they could live in a townhouse (Huttunen et al. 2016a p. 54). Similarly, 52 % of the responders in the 2015 ENVI study (Hasu & Hirvonen 2015b, p. 15) either completely agreed or mostly agreed that the townhouse would suit them or their family well. The Resident's Barometer 2016 also concludes that there would be demand for townhouse-like alternatives that combine the private yard with good services (Strandell 2017, p. 110). Understanding what the target group is like will also influence daylighting solutions, since daylighting needs are always dependent on how the space is used. For example, a relatively open floor plan may be, on average, better suited for a solo dweller or a childless couple than a large family.

Families with children are often regarded as the primary target group of townhouses. In their 2006 report on townhouse construction in Helsinki, Manninen and Holopainen also theorize that the first Finnish townhouse dwellers are likely to be pioneers of sorts, people who are ready to try out a new form of housing (Manninen & Holopainen 2006, p. 41). In the expert interviews of the New Finnish Dream Home study (Huttunen et al. 2016a, p. 25), wealthy couples and families with children were often mentioned. As multi-storey dwellings, townhouses are typically not well-suited for senior citizens (Huttunen et al. 2016a, p. 25), or people with accessibility limitations (Ellilä 2014, p. 67).

The 2015 ENVI study (Hasu & Hirvonen 2015) examined attitudes toward the townhouse and in the analysis, the responders were divided into four groups, which were the same ones that were used in The New Finnish Dream Home study (Huttunen & al. 2016a). These groups were generated from a fourfold table where the two axes were 1) preferences toward an urban, dense area versus a more suburban environment and 2) preference for more local social interaction versus less. According to the ENVI study, the townhouse generates interest among all the four groups, though the urban-minded and the those who preferred more social interaction indicated greater interest. The greatest interest towards the townhouse was among people under 45 years old, while those over 60 were the least interested. Family situation or gender did not significantly influence responses. (Hasu & Hirvonen 2015b.)

While the townhouse offers many appealing qualities for the Finnish housing selection, it should be kept in mind that ways of living and the needs and values related to living are culture-specific and therefore, imported typologies may not be directly suited to other cultural contexts. In the Britain, the townhouses of the upper class as well as the terrace houses of the working class are a creation of a specific societal context, and the same is true for the townhouse typology of the Netherlands. (Huttunen et al. 2016b, p. 9).

In addition to being adapted to a different cultural context, imported typologies are also designed for different geographical and climate conditions. With the narrow and deep townhouse typology originating from more countries with more daylight, it is clear that adaptations must also made to better tailor it to the distinctly different Finnish climate where daylight is much less available for large proportion of the year.

A notable upside of townhouses is that similarly to detached houses, they enable increased control over the house's design for its occupants. This is important as opportunities for individuality and personal identity expression have been found to be key factors in townhouse living in both European countries and Finland, which is why solutions for individualization should be offered in townhouse projects (Huttunen et al. 2016b, p. 81). In the Netherlands, for example, it is common that townhouse buyers get to choose from five to six pre-selected alternatives, which creates variety in the building cluster even though the houses are not fully individualized (Väliniemi et al. 2009). Another benefit of the townhouse is that in contrast to an apartment building, it can often be expanded later, which increases its adaptability (Mälkki 2010, p. 139—140).

Particularly smaller-scale townhouse developments are well suited for individual builders as well as group-based construction, though larger ones and those located in downtown areas will probably continue to be produced mostly by larger development companies. Due to design challenges posed by the narrow and deep form as well as the need to join neighbouring houses, the townhouse would also be well suited to be produced as prefabricated houses, which continue to gain popularity among individual house builders. Availability of prefabricated townhouse models would help construction for both individual builders and group-based construction. (Jalkanen et al. 2012, p. 9—12, 26.)

Dwellings in 2—3 storey-high townhouses are typically somewhat large. With three stories, the dwellings are typically 150 m^2 or more. Three-storey-high row houses have been quite rare in Finland, and many developers have been skeptical whether there is demand for houses of that size. However, three-storey solutions may be well suited for families with older children. Space that is separate from the rest of the dwelling may also be useful for people who need space for working of hobbies at home. Yet in Helsinki, it's necessary to also offer small or mid-sized apartments, according to local needs. (Jalkanen et al. 2012, p. 21.) According to the Finnish Dream Home study, people in the Helsinki metropolitan area are looking for an apartment under 120 m^2 (Huttunen et al. 2016a, p. 54). Smaller apartments can be created in townhouses by adding side apartments (sivuasunto) or by having dwellings on top of one another at the ends of the townhouse row. Other solutions include two-storey-high spaces and partial top stories, which may also allow the house to be expanded later. Split-levels offer variety but are harder to solve in terms of accessibility. (Jalkanen et al. 2012, p. 21.) Limiting the number of floors is also critical when aiming to create smaller but functional dwellings.

7

MASTERPLAN

This chapter is the first one that focuses solely on design strategies for daylighting. We will start from a larger scale and move toward smaller. Therefore, we start off with this chapter on master planning. Master planning plays a central role in daylight conditions of individual buildings. Therefore, the architects working on the master plan need to have an understanding of how their decisions will affect possibilities at the scale of building design. Along the same vein, it is important for architects working on a building design to understand the base conditions laid out by the master plan.

7.1 SHADING EFFECT OF THE SURROUNDINGS

Daylight availability should be a consideration already at the master planning stage, because the decisions made at this level lay the foundation for lighting conditions of each building. For example, exterior obstructions and the directions to which each building opens are often largely defined by the master plan. (Vikberg 2014, p. 48.) The width of the street, for example, defines the distance between the buildings are therefore greatly influences their shading effect on one another (Boubekri 2014, p. 60).

In order to successfully daylight a building, it is critical to study the shades cast by the environment. Surrounding buildings, vegetation and the terrain all influence shading and can diminish visibility of the sky, thus making the interior spaces darker (Corrodi et al. 2008, p. 131). These factors are the primary cause of poor daylighting of interior spaces (Brandi 2006, p. 20). According to Boubekri

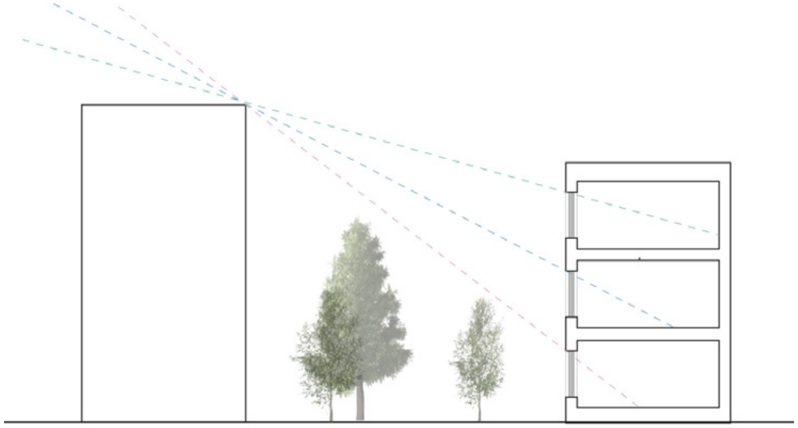


Diagram 7.1a
No-sky line on different floors of the townhouse.
Based on: Tregenza & Wilson 2011.

(2014, p. 59), the building opposite can decrease the daylight factor in the front of the room by up to 50 % and at the mid-zone of the room, as much as 70 %.

RT-055.33 (1975) presents a manual way to calculate shades according to location and time. The method involves choosing appropriate values from a chart according to the case and drawing lines on diagrams. This is a simple and usable method. These days, however, many computer programs commonly used for design provide a way to quickly generate shade analyses. Especially in cases where the environment is 3D-modeled somewhat accurately, it is very fast and easy to get plenty of data on shading, which can then be used to guide design solutions from the very first stages.

A good and simple tool that does not require access to any software is the no-sky line (see diagram 7.1a). The line represents the visibility of sky within a space and reveals which areas get direct skylight and which areas have no view of the sky. The amount of sky view correlates with adequate levels of daylight. (Tregenza & Wilson 2011, p. 91) This is because the shading effect of an obstruction depends on how much of the sky view it blocks. If the neighbouring buildings are a sufficient distance away or are relatively low-rise, they might have little or no effect on the no-sky line and therefore, little effect on daylighting of the space. (Brandi 2006, p. 20.)

As a general rule of thumb, buildings further away than three times their height above the designed building's window do not have to be taken into account (see diagram 7.1b). Buildings on the north side of the building are also unlikely to have a considerable effect. (Littlefair 2011, p. 17.) In Finland, the distance between buildings should be at least as much as the height of the opposite building measured from floor level, but exceptions can be made in master plans. In all cases, there must be at least eight

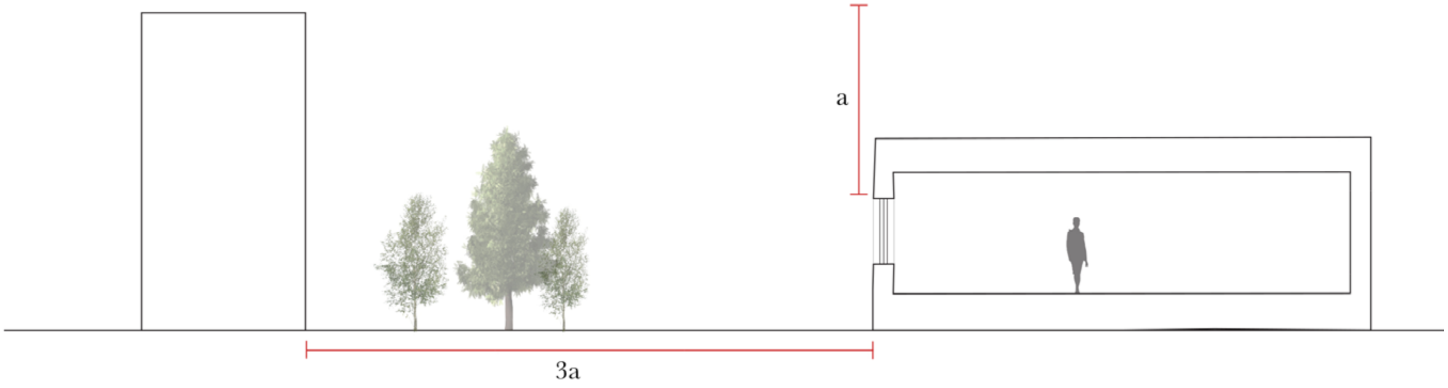


Diagram 7.1b
Buildings further than three times their height above the designed building's window do not usually have a significant effect on daylight conditions in the building.

meters of unbuilt space in front of the window. (The National Building Code of Finland, 127/2018, § 5.)

As townhouses are a typology of urban areas, the effect of surrounding buildings is especially important. When making master plans, higher buildings should be placed on the north side, with the buildings getting lower toward the south (Littlefair 2011, p. 15). The best spot for a townhouse could therefore be in the southernmost part of the street or the building cluster if there are higher apartment buildings in its vicinity.

The arrangement of buildings is particularly important in cases where townhouses and apartment buildings are combined in the same block. In these cases, the townhouses are at a disadvantage in terms of daylighting, since the apartment buildings are typically higher and thus, can have a significant shading effect on the lower-rise townhouses and their yard areas. Another key issue in mixed-typology blocks is avoiding unwanted lines of sight from the higher apartment buildings to townhouses or their yard areas. This can be solved by high fences or outdoor buildings, but this is problematic in terms of daylighting. If fences or shrubs are added around the townhouse's backyard in an attempt to increase privacy, availability of daylight and especially straight sunlight in the garden is further compromised. According to Hasu (2009, p. 52), high fences are also considered unpleasant by the residents. From this viewpoint, it is advisable to limit the height of the apartment buildings that are located next to townhouses, or at least carefully consider the townhouses' daylight conditions in the development of both the masterplan and the site plan. Placing the townhouses in the southernmost part of the block and arranging the yard areas so that shading elements on the south side are minimized is another way to increase daylight availability for the townhouses.

In addition to distance between buildings, the reflectance of the neighbouring buildings' facades also has a significant effect on how much it reduces daylight indoors. If the surface material has a high reflectance, the loss of light will be substantially reduced (Boubekri 2014, p. 59). Therefore, the facade materials should be taken into account when making an analysis of daylight conditions of a building. Preferably, the choice of surface material should also be considered on the masterplanning stage, and the recommendations or orders given on the matter should be based on the density of the area.

7.2 SHAPE OF THE TOWNHOUSE BLOCK

The formation of the townhouse row is also an important factor in an individual dwelling's daylight conditions. In the simplest case, the townhouses are arranged in a straight row, which only allows them to open in two directions. In contrast, arranging the houses in a zig-zag line makes it possible to open each dwelling to three or four directions. Compared to a straight line, the zig-zag formation also offers more privacy especially in the backyards, since views from neighbouring yards are decreased (Väliniemi et al. 2009).

If there is a marked elevation difference between the house's ground floor level, it is often necessary to arrange an accessible entrance through the backyard side. For this reason, it may be necessary to limit the number of townhouses in one row and group the houses in to strings with a route to the backyard side in between (Jalkanen et al. 2012, p. 26). The maximum acceptable length of the accessible route around the backyard will define how many houses can be grouped into one continuous string.

It has also been suggested that to better comply with accessibility regulations, it may sometimes be that Finnish townhouses cannot be connected at the side walls at all (Pulkkinen 2011, p. 10). Not connecting the buildings may be somewhat against the traditional townhouse characteristics but is favorable from a daylighting perspective: it allows the buildings to open in a greater number of directions. To create the characteristic, continuous street facade, other elements such as canopies, pergolas or vegetation can be used to act as connecting elements between buildings.

8

SHAPE OF THE BUILDING

In this chapter, we move from the master planning scale to the building design level. This chapter focuses on the big picture and key design solutions such as massing, facade shapes and room height. These design solutions lay the foundation of daylighting and will affect all later, more detail-level daylighting strategies.

8.1 MASSING

Townhouses are typically narrow — the facades can be as few as four meters long — and have a deep building frame (Jalkanen et al. 2012, p. 1). The width of Finnish townhouses has typically been between four to ten meters (Ellilä 2014, p. 62). The scarcity of facade surface combined with a deep building frame poses a big challenge for the architect with regard to daylighting. It is, however, possible to achieve good daylighting even in building 12—15 meters deep (Brandi 2006, p. 34). Luckily, the townhouse typology allows for a wide range of variations in both the interior layout and the exterior architecture (Jalkanen et al. 2012). The flow of light can be enhanced by careful design of the building mass: for example, more complicated facade forms allow for greater window surface volume, albeit with the downside of increased heat loss. Atriums, on the other hand, can allow the light to enter from multiple directions and improve daylighting especially in deep buildings. (Corrodi et al. 2008, p. 132—133.) The effect of atriums and inner courtyards can be enhanced by choosing a light colour for the exterior walls, which reflects the light better than darker shades (Köster 2004, p. 66). Atriums can be hard to fit into a narrow townhouse, but similar benefits can be achieved with a zig-zagging facade form that creates an inset outdoor space within the building frame.

Frank Lloyd Wright proposed and ideal width for a building’s wing in terms of daylighting to be 13 meters (Public Technology, Inc. p. 94). Compared to this, the townhouse’s typical width of around seven meters is strikingly high, especially considering that in contrast to a typical building wing, windows cannot be placed on the side walls. Though townhouses that are only one room wide can be functional when well-designed, they are not ideal in the Finnish daylight conditions. The extremely narrow and deep shape makes daylighting highly challenging as façade surface available for fenestration is dramatically scarce in relation to the space's depth. Especially in urban areas, the width of the yard-side facade is critical since fenestration on the street side can often not be increased beyond a certain point without risking privacy. Furthermore, a sufficient width also allows for a more complicated facade form.

The daylighting issues created by the deep building frame can be demonstrated using the no-sky line. The no-sky line indicates the portion of the space that has a view of the sky, which roughly represents the area that has good levels of daylight. As the depth of the space increases, the size of the area with no view of the sky decreases (See diagram 8.1).

The WELL Building Standard™ requires that 75 % per cent of all regularly occupied areas are within 7,5 meters from view windows (International WELL Building Institute <https://standard.wellcertified.com/light/right-light> 13.12.2018). This would be doable even in many deeper-framed townhouses. According to another rule of thumb, in a space that has windows on two opposite walls, adequate daylighting is achieved in the entire space if its depth is equal to five times the height of the window above desk level (80cm) (Tregenza & Wilson 2011, p. 92). This rule also well illustrates the effect of modifying the ratio between room height and room depth.

From a daylighting perspective, it is advisable that the Finnish version of townhouses would be on the wider side and the depth of the building frame should be limited — in other words, the footprint of Finnish townhouses should rather be closer a square than a long and narrow rectangle. The ratio of depth to width and depth to room height is more important than the absolute measures; ratios conducive to daylighting can be achieved in both smaller and larger townhouses.

8.2 FACADES

Just like zigzagging forms in the townhouse block make it possible to receive light from a greater number of directions, applying a similar philosophy to the design of an individual building's façade will be advantageous

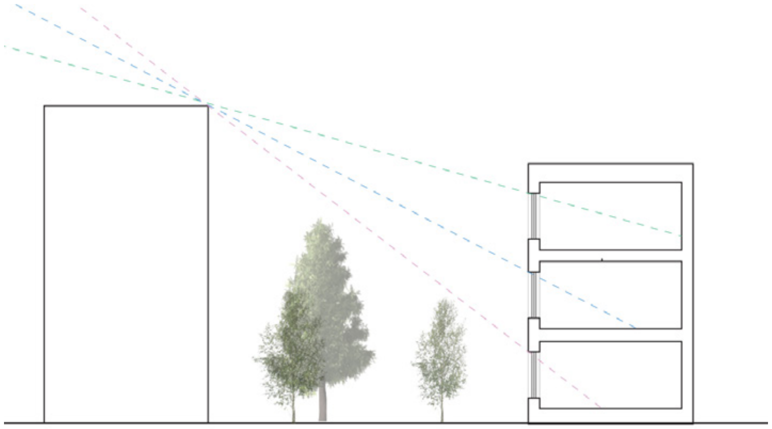


Diagram 8.1
No-sky lines on different floors of the townhouse.
Based on: Tregenza & Wilson 2011

in daylighting design. As the facades of townhouses are typically narrow, designing a more complicated façade form will also increase façade surface available for fenestration and enable a higher window surface area. Both larger zig-zagging forms as well as smaller ones such as bay windows, make it possible to guide light into the interior space from multiple directions. This has three major benefits. Firstly, the space can receive sunlight for a greater duration of time — or a space that couldn't initially receive any direct sunlight because of its orientation may be able to receive through the side of a bay window. Secondly, glare risk is diminished because light can be guided in partly from the side of the bay window, outside the field of vision. Finally, receiving light from multiple directions also decreases contrasts in the space, thus further decreasing glare risk.

The optimal orientation of a building's facades is a difficult question, and both east-west and north-south orientations have their pros and cons. A benefit of east-west orientation is that all parts of the building will receive at least some sunlight. On the other hand, the sun shining from a low angle from east and the west is prone to cause glare, but different means of shading implemented to prevent this would be likely to have a negative effect on the views. For this reason, Corrodi, et al. (2008, p. 131) recommend that the main facades of a building open toward south and north. They do, however, make an exception for areas less than 700 meters above sea level, as they tend to be cloudier and mistier and can benefit from opening toward east and west. (Corrodi et al. 2008, p. 131.) Köster (2014, p. 70) also recommends opening row houses toward east and west, so that rows can be built close to one another

Image 8.2
Many old buildings in urban areas utilise bay windows to receive light from multiple directions and to open longer views along the street.

without excessive shading. The orientation of townhouses is often defined by the street, but the architect can influence the opening by shaping the facades or the massing of the building to achieve desired orientation.

Southern light is a good choice for maximizing sunlight in the dwelling during winter months (Corrodi et al. 2008, p. 131). In the Northern Hemisphere, it is recommended to open the building toward south as the need for heating is high (Peltonen 2002, p. 61). The south façade receives two to three times more sunlight than the north façade, and 1,5 times more than east and west facades (Westerholm 2018, p. 51). The facade can be shaped to form sun shades with vertical or horizontal planes. Examples of these are extensions of eaves and wall-like formations next to windows. The geometry of these structures should be calculated according to the solar conditions so that the forms will be effective in shading the windows. (RT 07-10912 2008, p. 8).

However, it has also been argued that the rigid theories about optimal facade orientation will not lead to optimal solution in real design cases. That is because the mechanical application of orientation principles completely ignores relevant, case-dependent factors such as site location, local weather and wind conditions, aesthetic aspirations and program requirements. (Corrodi et al. 2008, p. 59.)

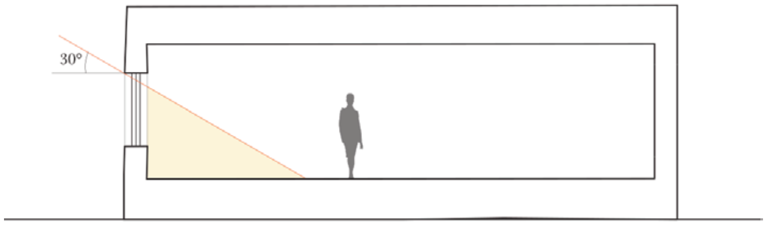


Diagram 8.3
Areas that lie within a 30° angle of the upper edge of the window will receive good amounts of daylight.
Based on: Corrodi & Spechtenhauser 2008.

8.3 ROOM HEIGHT

The ratio of room height to room depth plays a key role in determining daylight availability in the space. In cases where the height of the space is limited, the depth of the space must be carefully considered. (Corrodi et al. 2008, p. 137.)

The current regulations in Finland require a room height of at least 2500 mm in housing, though in bungalows and detached houses 2400 mm is accepted. In addition, a small proportion of the room can be lower than this, but not less than 2200 mm. (RT 93-10923 2008, p. 4.)

Room height sets the limit for the height of windows, and the height of the window and its vertical location in the wall both play a key role in determining how daylight enters the space. When determining the dimensions of the space, it is useful to remember the rule of thumb that only areas that lie within an angle of 30° from the upper edge of the window will receive a good amount of daylight (see diagram 8.3) (Corrodi et al. 2008). This effect of window position is discussed further in chapter 10.

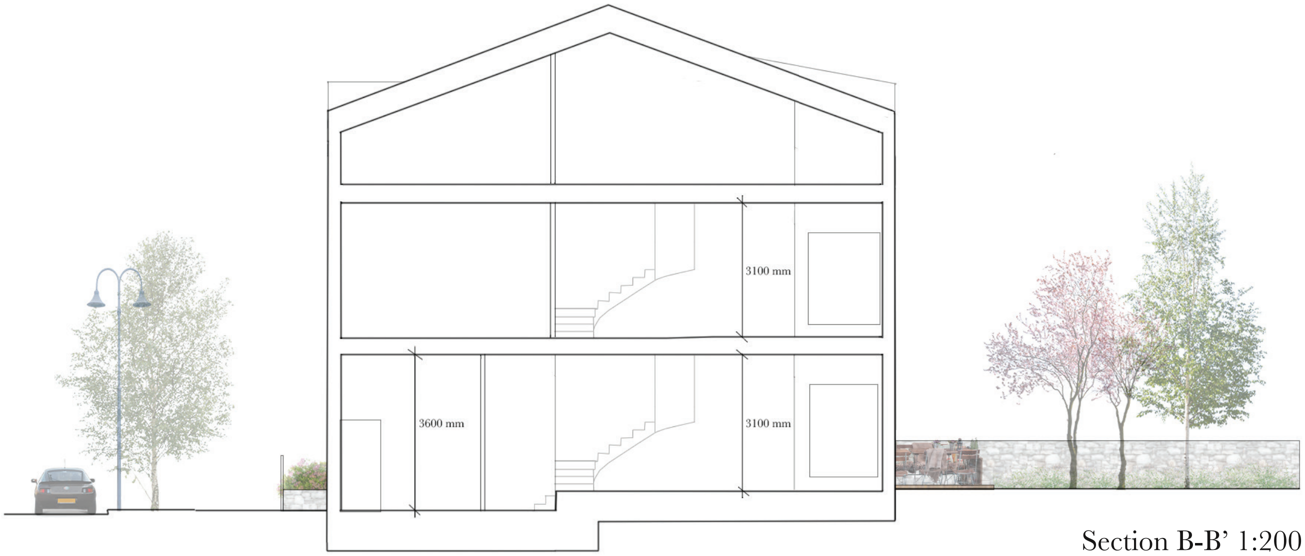
EXPERIMENT 1:

INCREASING ROOM HEIGHT

In this experiment, the storey height of the ground floor and the 1st floor was increased by 500 mm, from 3000 mm to 3500 mm. As a result, room height increased from 2600 mm to 3100 mm. Note that the multiusable space on the ground floor by the street (top left corner) has its floor at street level, 500 mm lower than the rest of the ground floor. Therefore, it has a room height 500 mm above that of the rest of the house.

As discussed, increasing room height is a highly efficient strategy for increasing the amount of daylight in the building. Especially on the 1st floor, we can see that the size of the area with a daylight factor above 1 % has significantly increased.

We can also see that the primary effect of increased rom height primarily increases the depth of the illuminated area, which is one of the key goals in daylighting of townhouses. To a lesser degree, the width of the illuminated areas is also increased: this is easy to see, for example, in the master bedroom (top left corner on the 1st floor), but it seems that increasing room height is not a particularly effective tool for this or, for example, eliminating dark corners on the window wall.



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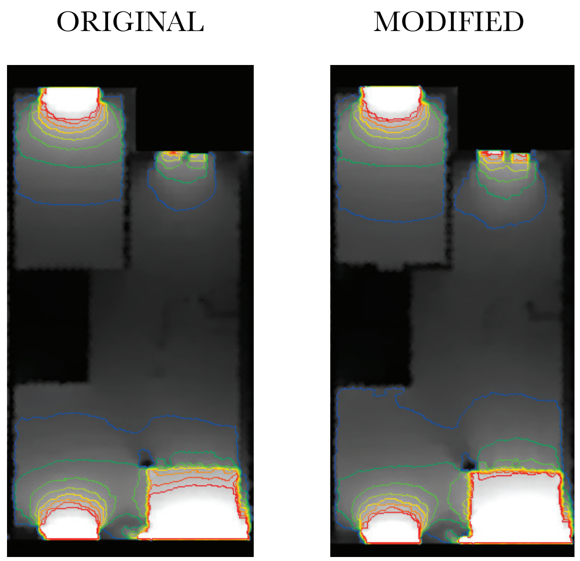
However, we can also note that despite a significantly increased room height, the daylight conditions in the house are still not where we would like them to be. Only a small portion of the interior spaces has a daylight factor over 2%, which is often considered the lowest recommendable level. What's more, as was already mentioned, a northern location like Finland means that outdoor illuminances are low and higher daylight factors are needed to achieve the same illuminance that could be achieved with a lower daylight factor in another climate.

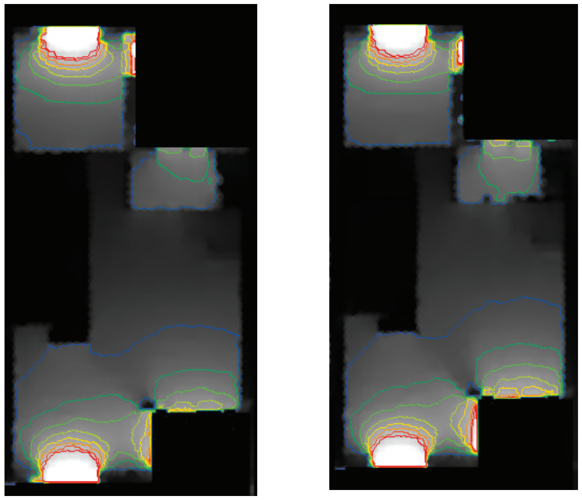
It seems that while increasing room height is an effective strategy for improving daylight conditions in townhouses (and often likely to be necessary to reach a suitable height-to-depth ratio of interior spaces), further strategies are still needed.

It may be that combined with other strategies for improving daylight conditions, increasing room height could have powerful synergtistic effects. For example, an increased room height allows for the upper frame of the windows to be located higher from floor level. The plan in this thesis is to test each modification individually. In future research, it would be interesting to investigate how combining design modifications affects the dayligh conditions.

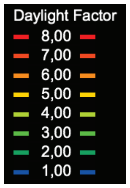
Even though it is not sufficient by itself for improving daylight conditions of townhouses, room height plays a significant role especially in modifying the dimensions of deep and narrow spaces typical of townhouses. After all, modifying the room height changes the ratio of depth to height, one of the most definining characteristics of a space in tems of daylight conditions.



1 st floor



Ground floor



Increased room height also increases opportunities for modification later on in the building's life. Especially the ground floor benefits from a higher-than-average room height, as it can then be more easily converted to office or commercial space. Increasing room height on the ground floor is also advisable from daylighting perspective, since the ground floor receives the least daylight and is typically most affected by the shading effect of the surroundings.

Double-height spaces are also a good way to increase daylight on the ground floor. In the Netherlands, many new townhouses have living rooms that are at least partly double height or even penetrate all the stories, which increases spaciousness in the often very narrow dwellings (Ellilä 2014, p. 53).

8.4 CEILING & ROOF DESIGN

The shape of the ceiling has a critical role in its reflective capacity and therefore, the daylighting of the whole space. It is perhaps the simplest way to affect light distribution. A ceiling that slopes from the high point at a skylight or window functions similarly as a ceiling that is high throughout the space. A curved ceiling can also make a dramatic difference for daylighting. (Public Technology, Inc. 1996, p. 100.)

Roof design can have a considerable effect on the availability of daylight in multi-storey row houses. Good results have been achieved through manipulation of roof angle. (Corrodi et al. 2008.) Littlefair (2011) recommends a low roof angle for better daylighting.

The functionality of some daylighting systems, such as the light shelf, depends on the roof design. They should therefore be taken into account early on in the design process. daylighting systems, including the light shelf, are discussed further in Chapter 12.

Repeating roof structures — beams or other structural elements — can act similarly to blinds or louvres when appropriately dimensioned. Especially in spaces with a transparent roof material, roof structures can be a good way to avoid excessively high illuminance levels. (RT 07-10912 2008, p. 11.) Below, some roof design strategies that can be used to improve daylighting. are presented.

SAWTOOTH ROOF

The sawtooth roof (Illustration 8.3.2a) uses a series of repetitive clerestories which create a more evenly distributed illumination over a larger surface area. The sawtooth openings are generally oriented north, which provides a diffuse and uniform daylight. If the sawtooth is to be used for heating purposes through solar gains in a colder climate, the most opportune direction is south. South-facing sawtooth openings do, however, often require control systems to prevent glare and undesirable reflections. Good strategies for solar control include overhangs, diffuse glazing materials, louvres, blinds and shades. (Public Technology, Inc. 1996, p. 95.)

ROOF MONITOR

The roof monitor typically utilizes a stepped roof form, which allows the light to enter from several directions at once. The mechanism of action for roof monitors is partly similar to light shelves, where the roof acts as a reflector of light. Again, it is necessary to consider the need for control systems. Typically, it is beneficial to have overhangs on southern, western and eastern openings. Extension of the roof plane into the interior space can also be advisable, as it can enhance the reflection of light from surfaces while protecting against direct sunlight. (Public Technology, Inc. 1996, p. 95.)

9

FLOOR PLAN & SPATIAL ARRANGEMENTS

"There will also be natural propriety in using an eastern light for bedrooms and libraries, a western light in winter for baths and winter apartments, and a northern light for picture galleries and other places in which a steady light is needed; for that quarter of the sky grows neither light nor dark with the course of the sun, but remains steady and unshifting all day long."
Vitruvius Book 1, Chapter 2

This chapter gets one step further in the daylighing of the Finnish townhouse. The previous chapter discussed the largest-scale building design decisions, such as massing, which lay the foundation for the next level of design: floor plan and spatial arrangements, which are the topic of this chapter. While we move in this order, from larger scaler toward smaller, floor plan and spatial arrengements are often designed in synergy with the shape of the building. This is advantageous and also allows for the different levels of daylighting decisions to be designed in tandem.

9.1 DAYLIGHT CONDITIONS ON DIFFERENT STORIES

Availability of daylight on different floors of the building can be studied using the no-sky line (See diagram 9.1a). The no-sky line effectively illustrates which part of the space has a view of the sky. The sky view is affected by the vertical location of the window and the presence of obstructing elements in the surroundings. In a multi-storey building, daylight is most available in the highest levels and, depending on the surroundings and decisions made in the master planning stage, less available or even poor on the lower levels. It is therefore usually advisable to place the spaces that need the highest amount of light highest up, and the spaces with less of a need for daylight in the lower stories. Yet the best solutions always depend on the design case, as the buildings surroundings, available views and the garden plan all have a strong effect on the actual amount of light. Even in the lower stories, the availability of daylight can be improved by careful design.

In any case, having multiple stories provides opportunities that are not possible single-level dwellings where there is no way to utilize the more opportune angle of light at higher levels. In the 1930s, German architect Walter Gropius analyzed different building typologies and deemed the apartment building to be the best one because he saw it as more airy, sunny and abundant in "green space" where children could play and be noisy without disturbing others (Corrodi et al. 2008, p. 62—63). Gropius' analysis focused on apartment buildings, but similar principles can be applied to high and narrow townhouses. Other advantages of multi-storey townhouses that it is possible to design rooms that are several stories high and have really high windows which bring light deep into the space.

Located at street level, privacy on the ground floor of a townhouse is rather vulnerable, though the situation can be improved by planning a front yard, an elevation difference or a visual barrier. Traditionally, the ground floor of townhouses has been used for commercial purposes. (Blomqvist 2016, p. 45—47.) The ground floor may also be a good place for an office, which is less bothered by views from the street and may even benefit from them (Hasu 2009, p. 201).

Designing the ground floor so that it could later be converted to commercial or working space is one way to increase adaptability of the building. (Jalkanen et al. 2012, p. 21—22.) One key way to increase adaptability is to increase room height on the first floor. This aligns well with daylighting objectives: increasing the room height is an excellent way to increase the amount of daylight since the first floor always has the highest risk of poor light levels.

Friedman and Whitwham (2012) divide the house into public, semi-public and private spaces. According to their analysis, a living room or dining room, for example, are public, while a bedroom is private. Friedman and Whitwham argue that the most public areas of the townhouse belong to ground or cellar level, while the more private areas should be located higher up. This order could be turned upside down, though, in cases where the townhouses is on sloping ground and the connection to the street is from the top floor (See diagram 9.1b). In these cases, the most private spaces could be placed on the lowest levels where they might also enjoy a connection to the outdoor spaces. (Friedman & Whitwham 2012.)

Having spaces where people spend a lot of time on the top floor is also advantageous because these spaces typically benefit most from skylights. In some ways, sloping sites may be ideal for the townhouse, as placing rooms such as the living room higher up allows them to have more daylight while bedrooms would logically be at the darker, lower floors — in other words, it seems that here the privacy needs align somewhat better with the daylight needs.
In addition, especially south-facing slopes provide more daylight than flatland— the difference is especially notable in the wintertime, when the sun shines from a low angle (Peltonen 2002, p. 57).

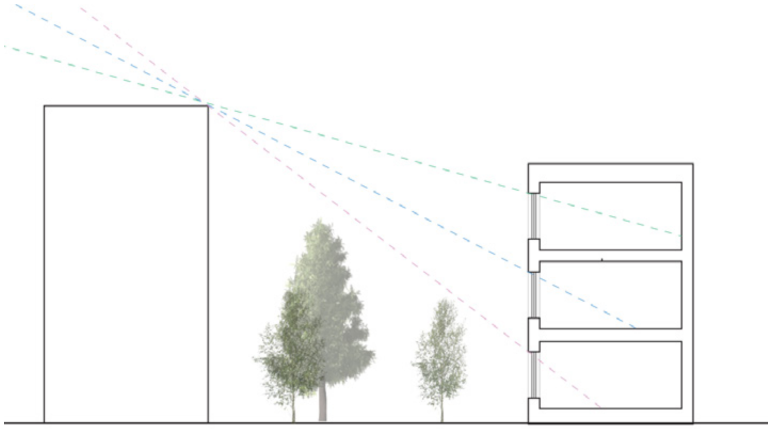


Diagram 9.1a
No-sky lines on different floors of the townhouse.
Based on: Tregenza & Wilson 2011

In Finland, it is recommended that for accessibility reasons, the first floor would have all essentials for sleeping, eating and bathing, to serve as a so-called survival floor. This usually leads to placing the kitchen and the living room on the ground floor and bedrooms higher up, even though in terms of daylight and views, a better location for them would be on the higher floors. (Jalkanen et al. 2012, p. 27—28.) Indeed, successfully combining accessibility requirements with optimal daylighting is one of key the challenges in townhouse design and requires case-by-case consideration from the designer. In general, the current building regulations, such as those pertaining to fire safety and accessibility, are not designed with multi-storey, small-scale housing in mind, but are primarily aimed at detached houses and apartment buildings, which have traditionally dominated the Finnish housing selection. In addition, as multi-storey dwellings, townhouses are not generally not the ideal form of housing for those with accessibility limitations (Ellilä 2014, p. 67).

In the Netherlands, townhouses and row houses have traditionally had the more public spaces such as living room, dining room and kitchen, on the ground floor and more private spaces, such as bedrooms, on the upper floors. The top floor can be often be modified for different uses, such as work or hobbies. (Ellilä 2014, p. 52.)

However, it should also be kept in mind that regardless of daylight conditions, some spaces may need to be located on the ground floor for functional reasons. One example is the kitchen, were groceries need to be carried on a regular basis, though adding an elevator to the house also usually solves the problem. Another consideration is connection to the backyard, which is typically only available on the ground floor. In a 2015 survey of 15 Finnish people, the

Diagram 9.1b
Amount of daylight and privacy on different floors of the townhouse located on a flat site (left) or a sloping site (right).

researchers found that many wished for a connection to outdoors from the living room, the kitchen and the sauna (Huttunen & al. 2015, p. 73).

The traditional townhouse layout is highly adaptable, as evidenced by how commonly the older townhouses have been divided into apartment in Central European countries and the Britain. Typically, the stair is located so that other rooms are somewhat separate from circulation spaces, which increases adaptability and makes it possible to divide the house into apartments in the future. A townhouse that is designed today with a similar logic is well suited, for example, to be a house shared by multiple generations, as it's easy to divide more or less independent and private portion of the house (often one floor) where, for example, the grandparents could live. Alternatively, the multi-storey house can provide partly independent spaces for a maturing teenager or for work purposes. The ability to divide a part of the house or to separate an entire floor as its own entity also provides the opportunity to rent a portion of the house to outsiders, a possibility that generated interest in the Finnish Dream Home study workshops (Huttunen et al. 2016b, p. 47). In these cases, the logic of the design may resemble more that of apartment buildings, where there may an elevator or other private access to an apartment that is separate from the rest of the house. This strongly affects daylighting, since plenty of the flexibility of having several floors is lost. Since the array of variations with side apartments is vast and thus the consequences for daylighting are beyond the scope of this research, we will focus on townhouses consisting of only one dwelling, which was also part of the townhouse definition used in this thesis.

9.2 SPATIAL ARRANGEMENTS

Townhouses have narrow facades and long side walls, which are either completely or mostly connected to neighbouring buildings, leaving relatively little surface area for fenestration. As a result, floor plan solutions are typically limited in townhouses, and plenty of care is required from the architect in order to ensure functionality and quality of the design.

When it comes to daylighting, one key factor is the openness of the space: the less internal division (diving walls and other light-blocking structures) there is, the deeper daylight can flow to the core of the townhouse. The townhouse typology is structurally well-suited for open plans, as the outer walls can normally carry the loads with no need for additional carrying structures. Yet open plans can be challenging in terms of sound blocking and privacy. In some cases, the space can be divided by furniture or floor level difference. (Friedman & Whitwham 2012.) Among Finnish residents, many prefer an open kitchen and an adjacent dining area. Many also wish to have the living room next to these spaces, though some may prefer to have it on a different floor and thus leave space for a larger dining area. (Huttunen et al. 2016b, p. 47—49.)

According to the experiences of townhouse occupants, stairs are perceived to take up space and block the flow of light (Hasu 2010, p. 166). Therefore, their location is a key factor in the daylighting of the interior spaces. In the Netherlands, most townhouses and row houses have the stair in the middle part of the house next to one of the side walls. A benefit of this solution is that the better-lit ends of the house are left free to use for other spaces. Finnish townhouses often have a U-shaped stair, but straight stairs are also commonly used. In Finland, it is recommended that in addition to the stair, townhouses have an elevator or a reservation for one. (Ellilä 2014, p. 64.) Since the elevator is usually a solid block within the house, it is likely to have a light-blocking effect, and its location in the layout is therefore particularly crucial. The stair, in contrast, can be designed to be airier an open, which decreases its shading effect. A straight I-stair can create a more spacious experience of the interior space and also works well with interior elevator solutions (Hasu 2010, p. 166).

Location of auxiliary spaces such as bathrooms, toilets, saunas and closets have a central effect on the entire layout and its functionality. Within the narrow confines of the townhouse, it may be advisable to develop a zone-type layout, where rooms such as toilets, bathrooms and closets are grouped together, leaving other areas more open and thereby, also more flexible. A solution like this also provides opportunities for later modifications, and combined with mindful fenestration, can allow the entire building to respond to the changing and unpredictable needs of the future. (Jalkanen et al. 2012, p. 21—22.)

Blomqvist (2016) and Ellilä (2014) both discuss three floor plan categories related to location of auxiliary spaces: side zone, middle zone and end / corner zone (See diagram 9.2). In terms of daylighting, it is crucial to study the location of auxiliary and circulation spaces and analyze their effects on the flow of light.

The side zone type is adaptable and can allow the house to more easily be converted to smaller apartments later on (Huttunen et al. 2016b, p. 55). A benefit of the side zone type is that it leaves the rest of the space open and thus allows light to be guided in from both facades. In larger apartments, a longitudinal zone could also be placed in the middle of the house, which would minimize corridor space and allow bathrooms to be located by the facades (Ellilä 2014, p. 124). This solution is not ideal for daylighting purposes, as the remaining spaces will be narrow and the flow of light within the house is limited. In general, the side zone may not ideal for very narrow townhouses as it might limit the width of rooms too much (Ellilä 2014, p. 124). The middle zone type allows the other rooms to be spacious, but it also divides all the floors and prevents creation of large open spaces. A limitation of the middle

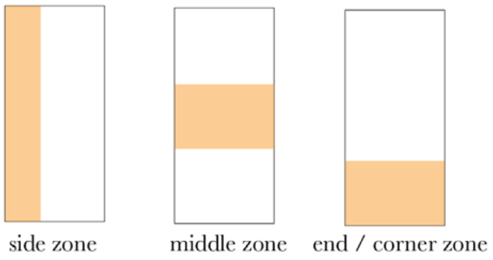


Diagram 9.2
Zone types for placemenr of auxiliary spaces.
Based on: Ellilä 2014

zone type is that dividing the house into smaller apartments later on will be more difficult. (Ellilä 2014, p. 124.) With the auxiliary spaces in the middle, they occupy the darkest part of the house, which leaves the areas close to facades completely free. At the same time, the depth of rooms on either side is limited and thus no part of the room is too far from the nearest window. A downside is that in most cases, the middle zone makes it impossible to open rooms in two opposing directions.

The end or corner zone type allows the house to be rather easily be converted to small apartments, since the stair can be at the corner and thus, can usually be separated from the rest of the spaces. Another upside is that the bathrooms can be spacious and have windows if they located by the facade (Ellilä 2014, p. 124). Having auxiliary spaces by the street facade also increases privacy in the house (Huttunen et al. 2016, p. 57). A downside of the end or corner zone is that it makes it difficult or often impossible to receive light from more than one side. What's more, the plan may be difficult to solve, especially in narrow apartments: dividing the apartment into multiple rooms is difficult without creating dark spaces in the middle of the house (Ellilä 2014, p. 124).

Friedman and Whitwham recommend that spaces of vertical circulation, such as the stairs, be placed so that at least the bedroom floor is reached close to the center of the floor. This allows us to have space for bedrooms at both ends of the townhouse. (Friedman & Whitwham 2012.) One obvious and important advantage of this solution is that the bedrooms are next to the facades and thus, it's easy to guide in daylight through the windows. It should be noted though that the floor plan of the townhouse can be solved in many ways, and there may not be a specific "bedroom floor". However, in Aalto University's *Habitat Components — Townhouse* study workshops, many participants wished to have the master bedroom and the children's bedrooms on the same floor (Huttunen et al. 2016b, p. 56).

Independent of the floor plan solution, it is always essential to consider the availability of daylight when deciding on the location of the bedrooms. The architect should also keep on mind that unlike other rooms, the bedrooms must also be able to be completely darkened. This issue needs special consideration in urban areas, where at least some artificial light is usually present at all hours. Because the need for darkening is repeated each night, it is highly important that it is easy and convenient for the occupant to do this. Therefore, solutions such as skylights or windows located high up the interior wall may not be well suited for bedrooms, unless a carefully designed control strategy is implemented.

The shape and location of each room plays a key role in its daylighting. Excessively deep spaces should be avoided, as ambient light travels poorly through the space to the rear areas. It is also recommendable to try and prevent formation of windowless corners in rooms. (RT 07-10912 2008, p. 5.)

A multitude of ideas and theories about the most opportune location and opening direction for each space in the house have been proposed by architects over the course of history. Peltonen (2002, p. 62) recommends dividing the spaces into zones based on their need for daylight and then accordingly, opening each space to the most opportune direction. The living room tends to have the highest need for daylight, especially in the afternoon. According to the traditional Modernist ideology, bedrooms should be opened toward east, while living and eating spaces should face south or west. Similarly, Littlefair (2011, p. 14) recommends that the living room and other similar spaces open toward south or west, with the kitchen facing east or north. (Littlefair 2011, p. 14.) In townhouses there is also a clear difference between spaces located on street side and those on the yard side: the former are typically more public and the latter more public (Huttunen et al. 2016b).

When designing office or other working spaces for the house, the designer should be aware that lighting requirements in these spaces are somewhat different from other rooms of the house. When working on a computer, the horizontal illuminance levels should be around 300—500 lux at most. Work areas should not receive direct sunlight. (RT 07-10912 2008, p. 3—5.) Other direct, bright light sources can also be reflected from work surface or computer screens and are therefore problematic in work spaces (Public Technology Inc, p. 94).

Adaptability has historically been a key strength of traditional townhouses in many countries and is the strength that has allowed the houses to survive through the many changes in society and living preferences. To this day, adaptability is an important characteristic in townhouses: in the New Finnish Dream Home study (Huttunen et al. 2016a), survey responders that were interested in the townhouse typology also expressed more interest in the adaptability of the home, such as the ability to make rooms larger or smaller (Huttunen et al. 2016a, 73).

An interesting case in terms of flexibility is a plan where rooms are somewhat equally sized and their purpose is undefined, which leaves it up to the occupant to decide how they want to use them. An advantage of this approach is increased flexibility, since the plan adapts to changing needs by altering the use of spaces, even though the plan itself does not physically change. This logic has traditionally been used in townhouses and is part of the reason why they are still used: they have been able to adjust to changing needs over the decades and even centuries. Krokfors has examined flexibility and adaptability in townhouses in her thesis (Krokfors 2006) and discusses the old townhouses of Amsterdam as one example of flexible, neutral spaces. Another way to provide flexibility is to design large, open spaces that can then be divided or used as one entity according to changing needs (Krokfors 2006). From a daylighting perspective, the challenge with this kind of layout is that the daylighting of each space cannot be optimized according to its function. This may result in aiming for average lighting conditions in each space, which can make the lighting conditions of the house rather monotonous and not optimized for any specific use. One way to approach daylighting of a house with undefined spaces might be to maximize flexibility of the lighting by installing control system and ways for the occupant to adjust the lighting through the use of daylighting systems (discussed in Chapter 12). In other words, as adaptability and flexibility increase, the daylight conditions also need to be increasingly adjustable in order conform to the varying uses of division of spaces.

10

FENESTRATION

This chapter is focused on one of the most important design area in daylighting: fenestration. Windows, whether side windows or skylights, are the main and often only way we let daylight into the interior spaces. As a result, fenestration has the power to modify the amount of daylight in the house from inadequate to excessive. Making changes to fenestration in later phases of the building's life can be costly and require a lot of work. Therefore, it is crucial to make the initial design decisions carefully and consciously.

Windows are considered an integral part of the house: according to Finnish building regulations, only a windowed space is considered a room. The surface area of the window must be at least 1/10 of the room's floor area. (The National Building Code of Finland, 127/2018, § 5.) In townhouses, the only places for windows are usually the two narrow facades and the roof, which makes the strategic planning of the fenestration all the more important (Friedman & Whitwham 2012).

Windows have traditionally been designed for three main purposes: views, ventilation and daylighting. The purpose of a window can be either one of these or a combination. It is difficult to optimize all three with a single window, which is why it can be beneficial to have a separate window for each function. This way, the size, shape, location and opening direction can be optimized for each purpose. (Corrodi et al. 2008.) In cloudy climates where sunlight is poorly available, a key objective is guiding in skylight (Johnsen & Watkins 2010). An efficient strategy for this is adding skylights, as they receive light from directly above, which is where the sky is brightest in cloudy climates. With side windows, the main challenges are transferring light deeper into the space and the need to protect from excessive sunlight and heat loads (Public Technology, Inc., 1996). Skylights can also be more effective in guiding light deeper to the core of the building, which is one of the biggest challenges in townhouses. Yet similarly to side windows, skylights may require additional control measures to prevent excessive levels of light or heat gains.

10.1 PRIVACY

Throughout the history, the dwelling has been a safe space for people and their property — a shelter from animals, other people and the forces of nature. To this day, peace and privacy in the home are key priorities for Finnish people (Jalkanen & al. 2015, p. 21). In the "The New Finnish Dream Home" study (Huttunen et al. 2016a, p. 75), over 80 % of those surveyed deemed it either important or very important that outsiders do not have a view into the house. Especially in dense urban settings, fenestration has to be designed carefully to avoid compromising privacy.

10.2 GLARE

Glare caused by fenestration can be decreased by placing the light sources away from the direction of gaze. Light can also be brought into an L-shaped space so that the light source is located around the corner and therefore not visible. Another way to bring in light without having the light source itself visible is from the side of a bay window. Glare from windows can also be further decreased by slanting the window inset. One of the best ways to protect from glare, however, is to open the space in multiple directions, which decreases contrasts within the room. (Corrodi et al.2008, p. 153—165.) Some research suggests, though, that people tolerate glare from daylight better than that from artificial light, especially if there is a nice view to compensate (Galasiu & Veitch 2006). However, especially when a window is exposed to direct sunlight, the need for glare protection must be considered.

10.3 OVERHEATING AND HEAT LOSS

The risk of overheating and heat loss has to be taken into account in the design of windows. To prevent overheating, effective shading in the southern facade has to be ensure. Windows facing east of west can also cause overheating, as sunlight from these directions is more difficult to control. (Peltonen 2002.) Balconies are one way to provide shading for windows, as they act as natural sun shades (Corrodi et al. 2008). Another simple way to exclude unwanted or excessive heat gains or sunlight is by overhangs, designed according to case-specific shading needs. Overhangs do, however, always decrease the amount of daylight in the space and should therefore be used with consideration. (Public Technology, Inc. 1996.) There are also many other daylighting strategies that can be used to control light in a window. These are discussed in Chapter 12 on daylighting systems.

10.4 WINDOW LOCATION

The location of the window in the facade has a pivotal effect on the building architecture, but here, we will only focus on fenestration in terms of daylighting of the interior space. When using this knowledge in a design, the architect will have to adapt the information with their other design objectives.

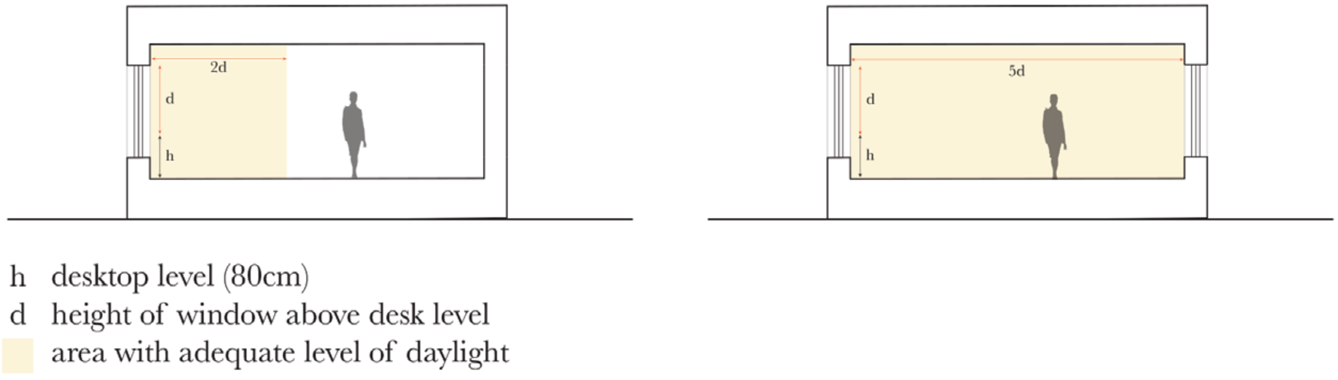
10.4.1 OPENING DIRECTIONS

A south-facing window creates a strong lighting that changes throughout the day (Baker et al. 1993). Sun protection is easy in south-facing windows: the sunlight arrives mostly from a high angle and can be blocked with a rather small shading element (Corrodi et al. 2008). A north-facing window, on the other hand, creates a weaker but more even lighting (Baker et al. 1993). Light from north is cool and does not pose much of an overheating risk. In contrast, windows facing east or west can cause problems as light from these directions is more difficult to control. Glare risk is high, and especially west-facing windows can cause significant overheating. (Corrodi et al. 2008.)

Although the Finnish climate is mostly cloudy, the potential exposure to direct sunlight should be taken into account in the placement of the windows. If a window is exposed to direct sunlight, protection from excess sunlight must be ensured through shading, scattering or dampening. Direct sunlight should be avoided in working areas but can be enjoyable in other places (RT 07-10912 2008, p. 3).

A good an even lighting can be achieved through the use of one main source of daylight — typically, a window or a window wall — and complimenting sources, such windows on the opposite wall, surfaces that distribute the light, or electric lighting (RT 07-10912 2008, p. 5). Guiding in light from multiple directions is one of the best ways to decrease contrasts. Even one additional source of light can have a significant effect. The most even illumination is achieved through symmetrically placed windows (Corrodi et al. 2008, p. 153—154.)

Opening the room in at least two directions also greatly increases the size of the well-lit area. If distance *d* is equal to the height of the window above working level (80 cm), strong sunlight on the working plane is available in an area that falls within a distance of *2d* from the window wall. This rule applies to spaces lit from only one side. If



h desktop level (80cm)
d height of window above desk level
🟨 area with adequate level of daylight

Diagram 10.4.1a
Size of the area with adequate daylight in a space light from one side or two sides..
Based on: Tregenza & Wilson 2011.

there are windows on two opposing walls, daylight will be available in a much larger area, equal to *5d* — which is more than twice the lighting depth of one window (*2d*) (see diagram 10.4.1a). (Tregenza & Wilson 2011, p. 92.) This means that by designing a space with windows on two opposite walls and setting the space's depth to *5d*, the entire space can be well-lit by daylight. Depending on the case, the architect may also be able to play around with room height and window placement to reach a desired balance between the space's depth and window height above desk level.

Let's say way have a townhouse with a building frame of 10 meters, and we have a rather open floor plan with windows on both of the two opposing facades. Our *5d* is equal to 10 meters, so to ensure good levels of daylight on the entire floor, we would need to have a *d* of 10/5 = 2 meters as the height of windows above the desktop level. This means the upper frame of the window would be at 2,8 meters from floor level, which is not possible in rooms with a standard room height of 2,5 or 2,6 meters.

Conversely, to illustrate the risk of inadequate daylight levels in a deep-framed townhouse, let's examine a case where the architect does not pay much attention to daylighting. We have a standard room height of 2,5 meters, a townhouse that is 13 meters deep — this was used, for example, as the deeper one of two townhouse versions in The New Finnish Dream Home study (Huttunen et al. 2015). The upper frame of the window is at 2,2 meters from floor levels, which means there is 1,4 meters of window above desktop level — so 1,4 is our *d* in this case. We could then calculate that the size of the area with adequate levels of daylight (or our *5d*) is 5 * 1,4 = 7 meters, which is only 54 % of the depth of our building frame. This means that almost half of the space would have inadequate levels of daylight.

If the room opens in two directions, one set of windows can receive light from an atrium or side corridor (RT 07-10912 2008, p. 5). Designing an atrium or side corridor for the building can therefore greatly enhance availability of daylight by providing a way to open more rooms in two directions. There is also a rule of thumb according to which a good level of illumination provided by daylight is available at a distance of about 2—3 meters from the window wall. This is a rough estimate, though, and the exact distance depends on the window's shape and size as well as the weather conditions. Boubekri (2014.) According to instructions in RT 07-10912 (2008, p. 4), the maximum recommendable depth of the room is 2—2,5 times the

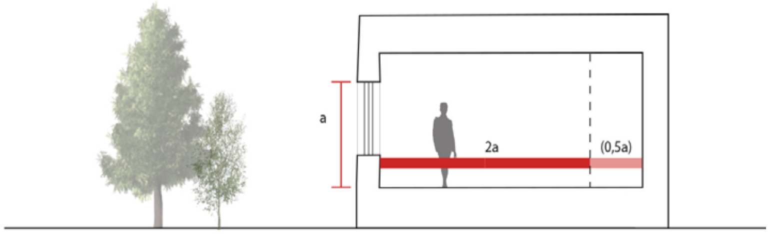


Diagram 10.4.1b
The maximum recommendable depth for a space lit from one side is 2—2,5 times the distance of the window's upper frame from floor level (RT 07-10912, 2008).

distance of the window's upper frame from the floor level, if the space is lit from only one side (see diagram 10.4.1b).

10.4.2 VERTICAL LOCATION

The most important factor for the window's effect on daylighting is the location of the window relative to floor level and the interior walls. The no-sky line can be a useful tool in determining the location of windows (Tregenza & Wilson 2011). The no-sky line indicates the portion of the room that has a view of the sky, and view of the sky can be used as a proxy for good levels of daylight.

A window located in the top portion of the wall lets light deep into the space. Therefore, the top third of the outer walls is a very opportune place for light windows (Brandi 2006). The more window surface there is in the upper part of the walls, the better the space will be illuminated (Corrodi et al. 2008, p. 138). The WELL Building Standard™, for example, requires that 40—60 % of window surface area is at least 2,1 meters above floor level (International WELL Building Institute <https://standard.wellcertified.com/light/daylighting-fenestration>). Ideally, a window located high up would meet the ceiling without a lintel, which allows the light to be better reflected from the ceiling and flow deeper into the space (Corrodi et al. 2008, p. 138).

The effect of placing the window higher up can be illustrated by the following 30° rule of thumb: if the space is lit from one side only, a good level of daylight is achieved in areas that are within a 30° angle from the upper edge of the window or closer. As a result, the depth of this area is about twice the height of the window's upper frame[1]. (diagram 10.4.2) (Corrodi et al. 2008, p. 133). Another version of this rule, sometimes called "the ubiquitous rule of thumb", states that a sufficient level of day lighting is achieved in areas where distance to the window is equal to 1.5—2.5 times the height of the upper frame of the window measured from floor level (Boubekri 2014, p. 56). As we go further away from the facade and the window, less and less sky will be visible and thus the risk of low lighting levels increases (Brandi 2006).

If the bottom of the window is also higher than normal, the contrast between the area in front of the window and the rest of the space is decreased (RT 07-10912 2008, p. 4). Placing the window higher up on the wall also enhances privacy, as it is less likely to offer a direct view in from the outside (Friedman & Whitwham 2012).

Windows below working level (80 cm) increase heat loss but do not notably contribute to daylighting. Therefore, placing windows too close to floor level is typically inadvisable. (Corrodi et al. 2008, p. 138—139.)
Naturally, the designer should also consider the views when deciding on the window locations. Ribbon windows high up the wall could show nothing but the sky, but it is recommendable to open views to the horizon as well. The bottom of a window intended for view should be no higher than 90 cm. (Corrodi et al. 2008, p. 141.)

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[1] The exact depth as calculated from the 30° angle would be the height of the window multiplied by √3 (≈ 1,73). However, the 30° rule is a rule of thumb and therefore, no such exact numbers can be inferred from it.

10.4.3 HORIZONTAL LOCATION

The horizontal location of the window can be studied with the help of the 45° rule. According to this rule, the window provides good illumination for areas located within a 45° angle from its sides. (Brandi 2006.) A window located in the horizontal center of the wall provides the most even illumination, while a window closer to the corner offers a lower risk of glare (Baker et al. 1993). Windows closer to the corner are also better at illuminating the rear areas of the room (Corrodi et al. 2008).

10.5 WINDOW SHAPE

The shape of the window has a lesser effect than its surface area (Corrodi et al. 2008, p. 138). The shape mainly affects the distribution of light in the space (Baker et al. 1993), though the height and width of the window affect do also affect the dimensions of the well-illuminated area (Boubekri 2014).

Illumination provided by a ribbon window is even parallel to the window wall throughout the day (Baker et al. 1993). A ribbon window placed high up the wall is a good solution in situations where the light source needs to be outside the field of vision. The downside is that the illumination depth can be somewhat limited, and that compared to vertical windows, the illuminance distribution is usually also inferior if there is less window surface area in the upper part of the walls. (Corrodi et al. 2008).

A vertical window provides better illumination for areas further away from the window but poses a greater risk of glare compared to a ribbon window. Illumination from a narrow and high window also varies more over the course of the day. (Baker et al. 1993). Boubekri (2014) recommends high windows especially for deep buildings, as they offer a way to guide the light much deeper into the space. If the window is too narrow or located too low, the light angle will be small and views outside will also typically

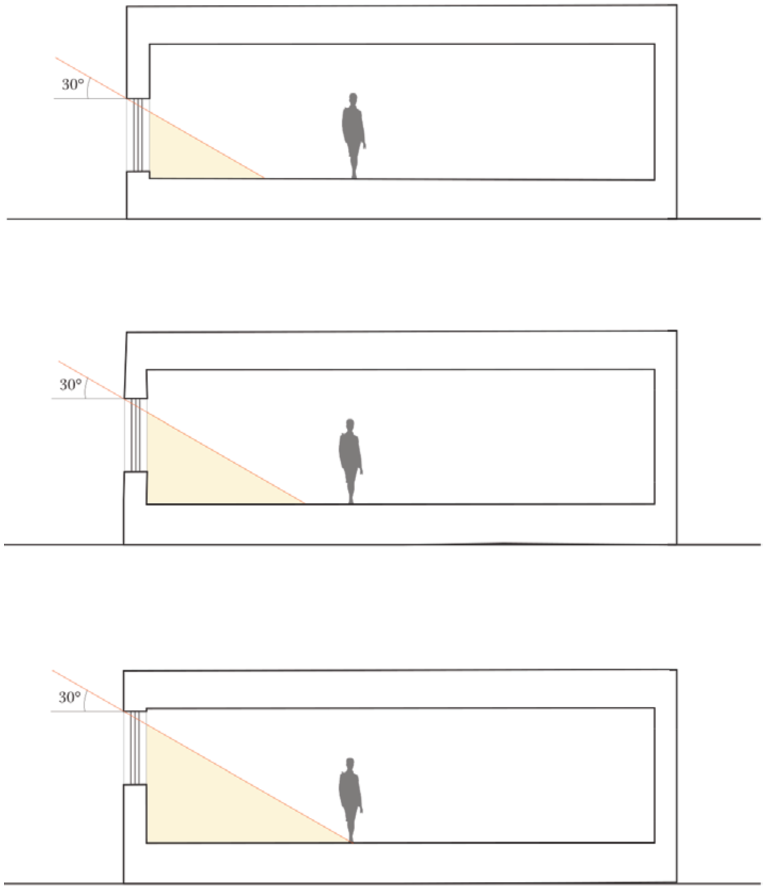


Diagram 10.4.2
Size of the area with adequate levels of daylight, depending on the vertical location of the window.
Based on: Corrodi & Spechtenhauser 2008.

EXPERIMENT 2:

VERTICAL LOCATION OF WINDOW

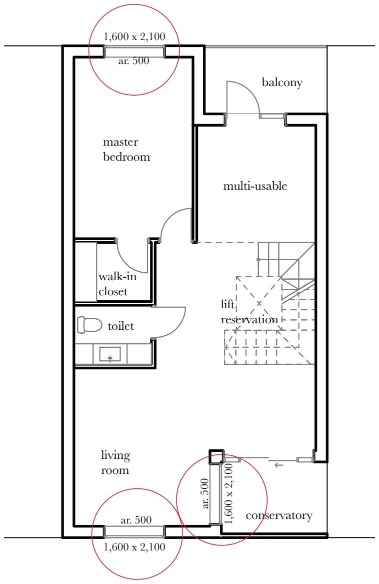
In this experiment, the effect of changing the vertical location of windows in the test house was studied. All windows on the ground floor and the first floor, except for the side window in the multiusable space by the street (which serves as a revervation for a door) were raised 200 mm higher. This means that bottom of each window was 500 mm above floor level instead of 300 mm above floor level as in the original model. The size and dimensions of the window remained unchanged.

The windows and doors where modifications were made are indicated by the red circles in the attached floor plan drawings.

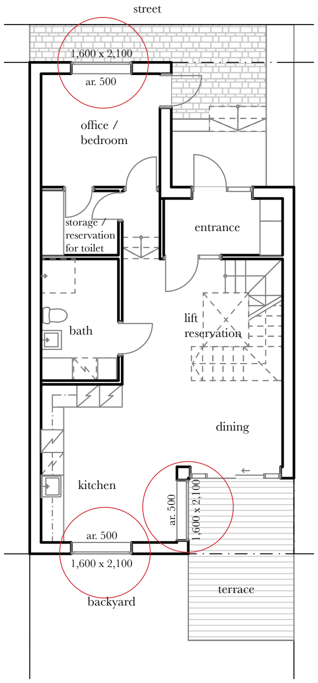
The windows on the 2nd floor were not changed as their height was already limited by the roof shape. All doors and windows adjacent to doors were also unchanged.

Note that the multiusable space on the street side has its floor lower 500 mm than the rest of the ground floor, and the difference between this room's floor level and the bottom of the space's window is 500 mm more.

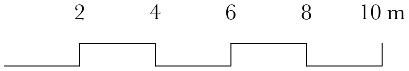
In this case, lifting the windows 200 mm higher meant that the windows now meet the ceiling: in other words, they are as high as they could possibly be. As discussed, having the window reach ceiling level is advantageous, because it means that light can now be reflected from the ceiling more



1st floor 1:200



Ground floor 1:200



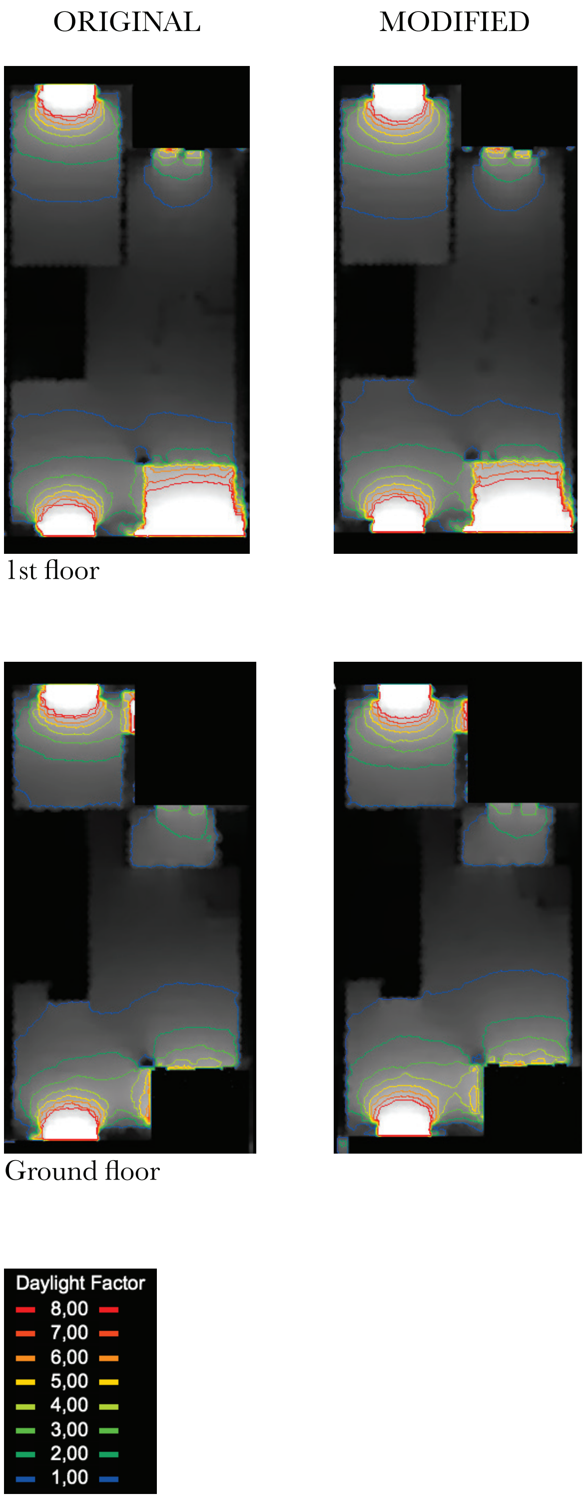
efficiently and reflected deeper into the space.

We can see that even a modest change in the windows' vertical elevation has a clear effect on the daylighting of the space. For example, in the original model, about half of the multiusable space on the ground floor by the street had a daylight factor below 2 %, whereas in the modified version this area is clearly smaller.

The increase in daylight is clear in other spaces as well. As the DF zones grow proportionally, the change is most substantial with the largest, 1 % and 2 % zone limits as the absolute growth is highest.

Yet similarly to the experiment on increasing room height, we can also notice that despite the significant increase, the daylight factors are not what they should be according to most recommendations discussed earlier. Only a minor part of interior spaces has a daylight factor over 2 %, for example. Therefore, we can say that in a townhouse with these dimensions, even higher-than-average windows placed high up are not a sufficient daylighting strategy on their own, but need additional measures to improve daylighting conditions to desired levels.

However, as was mentioned in the experiment on modifying room height, increasing room height will allow the upper frame of the window to be located higher as measured from floor level. Thus, combining these two strategies has synergistic effects that could be explored further in future research.



be poor (RT 07-10912 2008, p. 5). In a space lit only from one side, the best option might be a wide ribbon window that meets the ceiling without a frame and thus illuminates the ceiling. To provide views, another, more vertically shaped window could be added. (Corrodi et al. 2008.)

10.6 WINDOW SIZE

In cloudy climates, the amount of daylight in a space is highly dependent on window surface area and the distance to the nearest window. Similarly, the amount of sky visible and the location of the windows are also closely correlated with interior illuminance produced by diffuse skylight. Each space should have sufficiently large windows in order to have good levels of daylight. However, large windows also require strategies for controlling the light to avoid adverse effects. (RT 07-10912 2008.) Window surface area also affects energy efficiency through its effect on overheating and heat loss. Yet energy efficiency goals should not lead to decreased daylight in townhouses, if the townhouse is to remain an appealing form of housing in Finland. (Kuittinen 2015).

According to Vikberg (2014), the window surface area should be higher in the lower floors and smaller in the higher ones. This way, the lower floors can enjoy daylight, while the higher ones are better protected against overheating.

Smaller windows pose a lower risk of glare. With medium windows, large contrasts can be created between the window and other surfaces, which increases glare risk. In comparison, a wall-sized window creates less of a contrast and the risk of glare is smaller as the eye adjusts to the illumination levels. A wall made completely of glass can, however, excessively increase illumination levels and thus the risk of glare. (Corrodi et al. 2008.)

When deciding on the size of a window, one must take into account both the absolute glass surface area and the ratio of window size to the size of the space. In terms of absolute size, a window less than 0,5 m^2 could be considered small, 0,5-2 m^2 medium and over 2 m^2 large. (Baker et al. 1993.) According to recommendations for the UK by Tregenza & Wilson (2011, p. 122), each room should have a window with a surface area of at least 1 m^2, that is exposed, at minimum, to an average of 30 minutes of sunlight daily between 1st November and 31st January. In Finland, it is difficult to have exposure to direct sun light in the winter months, especially in dense urban areas. To achieve sufficient illumination levels, the window surface area must be high enough, and a window 1 m^2 in size does not offer as much daylight in Finnish winter as in the UK — to achieve the same goals, a larger window needs to be used.

Corrodi et al. (2008, p. 138—139) recommend a relative size of 40—50 % of wall surface areas for windows located only on one side of the room. A relative size of 20 % could be considered a bare minimum, while increasing the size to 50—60 % is acceptable but does not offer much extra benefit. (Corrodi et al. 2008, p. 138—139.) The WELL Building Standard™ requires a window-wall ratio of 20—60 % (30—60 % in living rooms, 20—40 % in bedrooms), measured on external elevations. The standard guidelines also state that with percentages over 40 %, external shading or adjustable opacity glazing is needed to protect against heat gain and glare. (International WELL Building Institute <https://standard.wellcertified.com/light/daylighting-fenestration>.) All these recommendations are, however, somewhat raw estimates and the optimal window surface area will always depend on case-specific factors such as geographical location, opening direction of the windows and shading elements around the building.

The above-mentioned rules are, however, not developed specifically for a Northern location. One could argue that since days are so short for a large proportion of the year, recommendations in Finland should require higher window surface area. According to Finnish building regulations, windows have to be at least 10 % of the room's floor surface area (RT-10923 2008, p. 5). This could, however, be considered quite low in a climate where winters are long and dark. It is also important to remember that in Finland, the sun shines from low angle during the winter months whereas during summer time, days are very long. This is should bae taken into account when determining shading needs.

10.7 SKYLIGHTS

A skylight is an opening in the building's roof. Depending on the roof shape, it may be horizontal or sloping. A skylight effectively captures sunlight from directly above and allows this light to enter the building. (Gago et al. 2015.) In cloudy climates, skylights are typically better for daylighting than side windows, as the sky is brightest at zenith and as a result, skylights illuminate the space 2—3 times more effectively than side windows (Corrodi et al. 2008, p. 178). Compared to side windows, skylights are also more effective in guiding light into the building's core. (Public Technology Inc. 1996). RT 07-10912 (2008, p. 4) also recommends use of skylights when possible.
An advantage of the townhouse typology is that contrary to apartment buildings, there are no apartments above, which makes it possible to use skylights. Skylights in an open, high space can also be used to create a light well throughout several or all floors. One good place for such a skylight could be above a U-shaped staircase (Friedman & Whitwham 2012). It should be noted though, that ambient skylight travels relatively poorly through light wells (RT 07-10912 2008, p. 5), so care must be applied in the design process to make the skylight effective and avoid a narrow tunnel-like shape that decreases the amount of light.

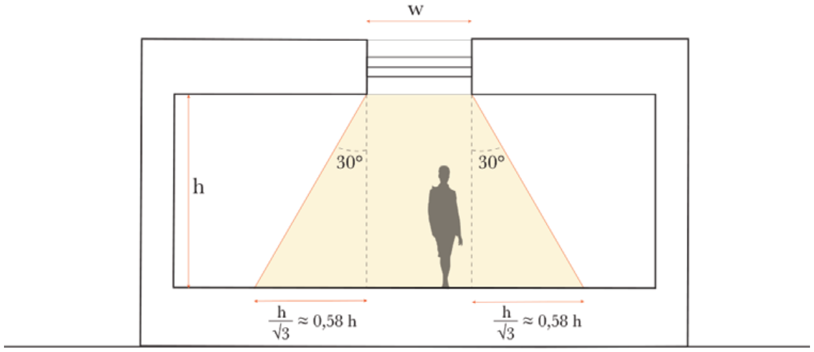


Diagram 10.7.1
The size of brightly light area under a skylight.

EXPERIMENT 3:

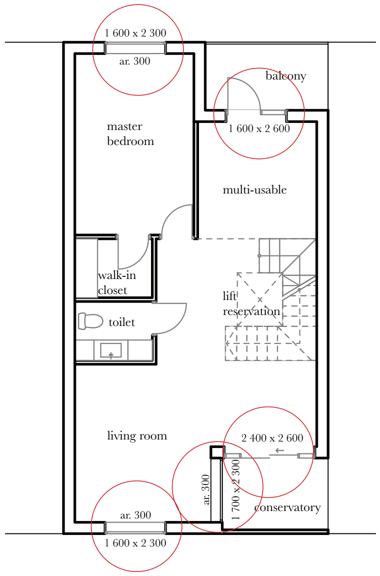
INCREASING WINDOW HEIGHT

In this experiment, the height of all windows and outer, windowed doors on the ground floor and the 1st floor (two on each) was increased by 200 mm. The windows were 2100 mm high in the original model and 2300 mm high after the modification. The height of the doors was increased from 2400 to 2600 mm, or in the case of the door of the multiusable office / bedroom space, from 2100 mm to 2300 mm.

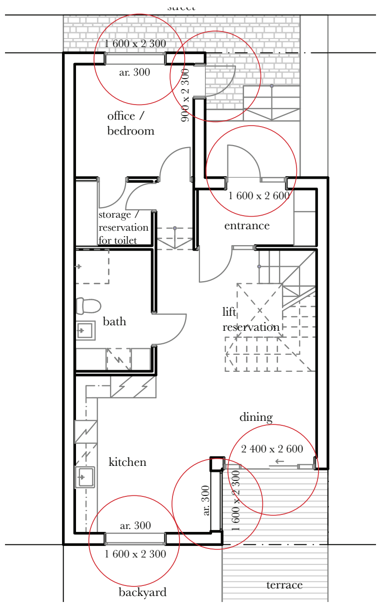
The windows and doors where modifications were made are indicated by the red circles in the attached floor plan drawings.

We can see that this modification results in distinct changes to the daylight patterns in the house. The change is evident, for example, in the 1st floor bedroom (top left corner of the house), where the area with a daylight factor below 1 % has markedly decreased. The area with a daylight afctor above 2 % has increased in the bedroom, as well as in the ground floor living and dining space.

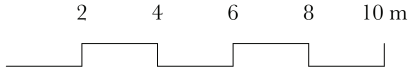
As we can see, increasing the height of the window primarily increases the depth of the illuminated area. It does not, however, affect the width of the illuminated area and does not markedly decrease the formation of dark corners on the window wall. However, increasing the depth of illumination is one of the key objectives in the daylighting of the townhouse, and thus, we could say that



1st floor 1:200



Ground floor 1:200



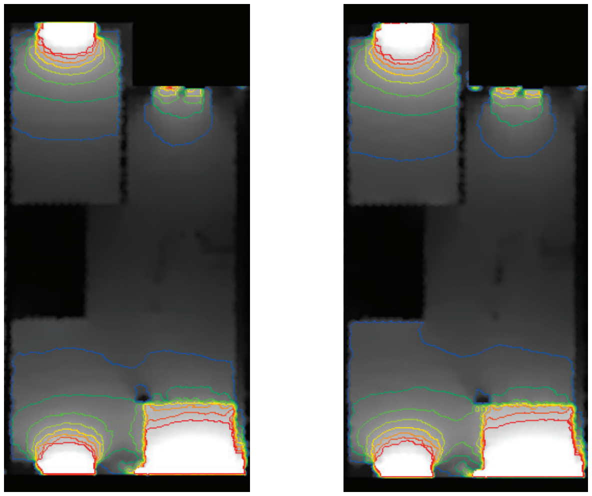
sufficient window height will be one of the main tools for improving daylight conditions.

It is interesting that increasing the height of the window produces very similar results as lifting the windows 200 mm higher without changing their height as was done in a previous experiment. However, this finding is in line with what could be assumed based on the literature: the main determinant of daylighting conditions is the height of the upper frame of the window. After all, in most cases it is the limiting factor affecting sky view and thus, daylight availability.

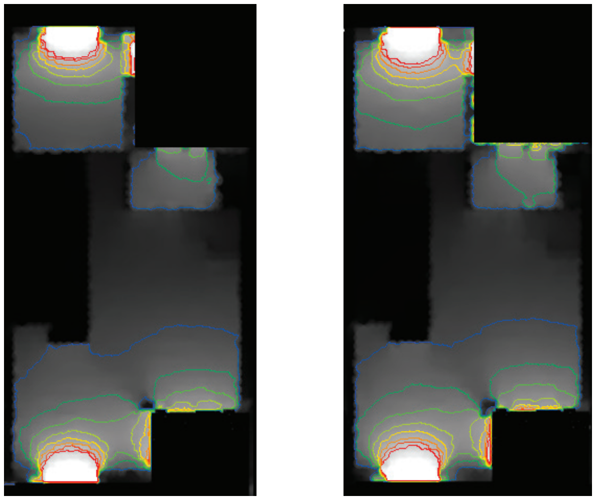
Yet we can also state that even with very high windows — in this case, reaching up to the height of the ceiling, illumination depth is still quite limited. It seems that in order to illuminate the core areas, other strategies besides side windows are in order.

However, as was discussed in earlier experiments, combined modifications may have synergistic effects. As was mentioned, an increased room height allows for freedom in fenestration design: the upper frame of the window can be located higehr up. While this thesis only includes a univariate analysis of each modification, studying the synergistic effects of modifcations could be the next stage of research on daylighting of Finnish townhouses.

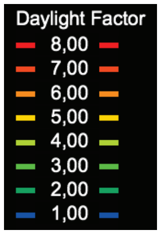
ORIGINAL MODIFIED



1st floor



Ground floor



EXPERIMENT 4:

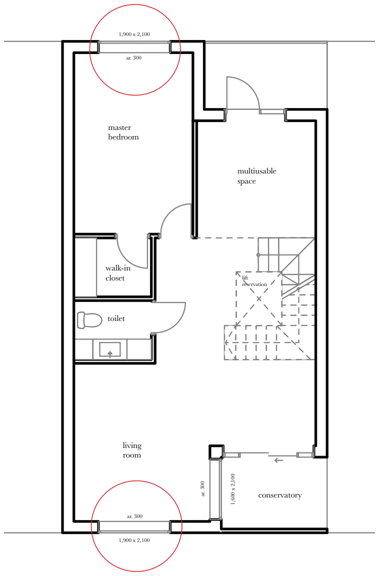
INCREASING WINDOW WIDTH

In this experiment, the width of four main windows on the ground floor and the 1st floor (two on each) was increased by 300 mm, from 1600 mm to 1900 mm. The width of the windows on the 2nd floor could not be modified as it was restricted by the roof shape.

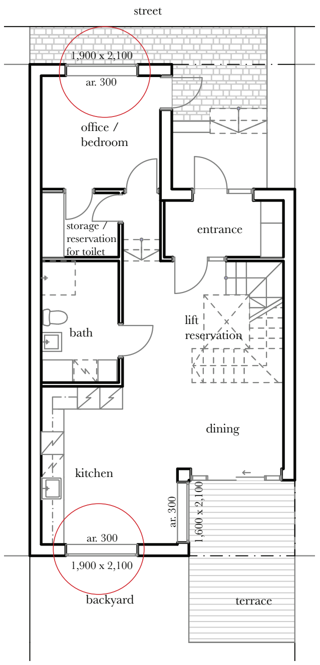
We could expect that modifying the width of a window would mostly affect the area directly infront of it. However, as we can see on the ground floor, the increased width of the window on the left side actually has a clear effect on the daylighting of the whole space (the living+dining space). Though the effect quicly becomes less significant, it is still perceivable in the areas far right of the window.

Unlike in the previous experiment on increasing window height, we can see that in both the living+dining space as well as the multiusable space on the top left on the ground floor and the master bedroom (top left on the 1st floor), the formation of dark corners on the window wall is lessened. Based on the results, it seems that contrasts in these spaces has markedly decreased. It is likely that visual comfort would be markedly improved, as the stark contrast — the very bright window and the dark corner right next to it — is eliminated.

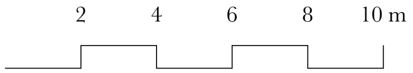
Suprisingly, increasing the width of the window seems to be quite effective at increasing illumination depth



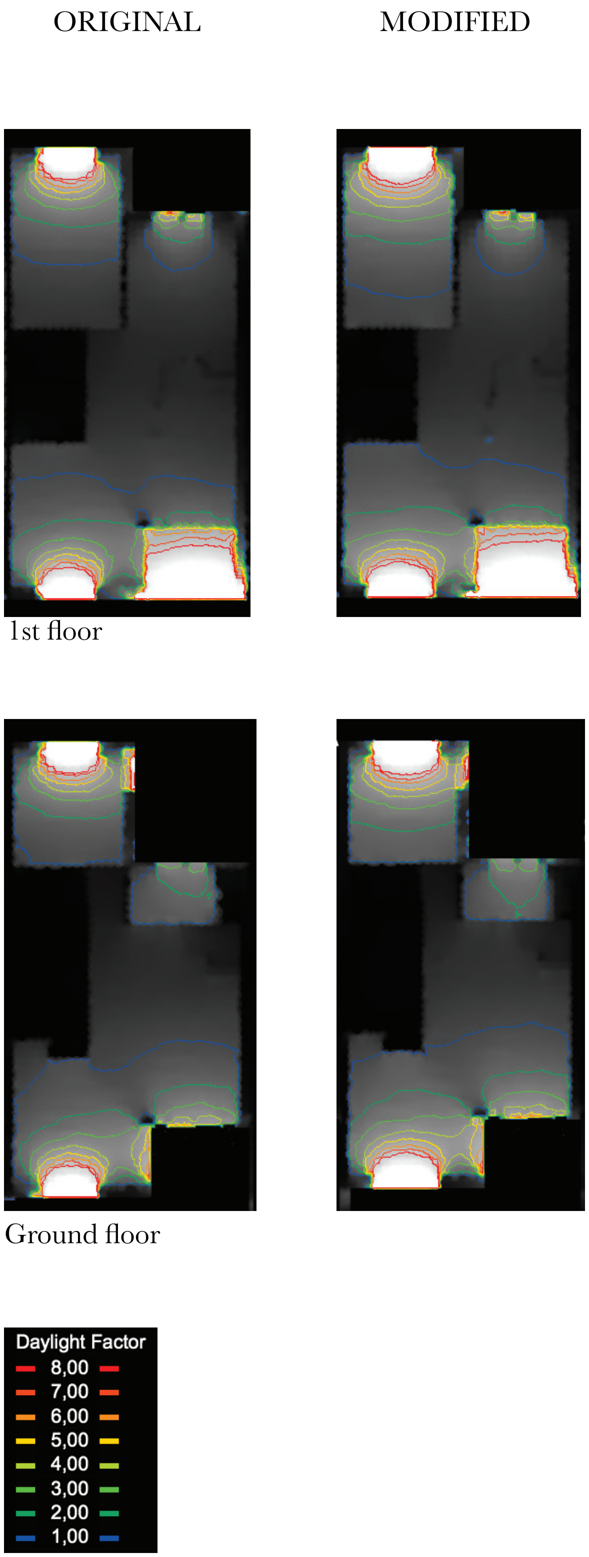
1st floor 1:200



Ground floor 1:200



of the windows as well. Based on the literature, it would have been more likely that increasing the width of the window would even the distibution of light but wouldn't do much to the illumination depth. Yet in these experiments, the increase in illumination depth was close to that of increasing the height of the window. The model was double-checked to ensure the results were indeed correct. In future research, this could be studied further.



As was the case with side windows, the 30° rule can be used to estimate the size of the area that will receive strong daylight from skylights. In this case, areas that are within a 30° angle from the skylight will be brightly lit. This results in an area that is roughly equal to the height of the space plus the width of the skylight opening[2] (Diagram 10.7.1). (Corrodi et al. 2008, p. 138.)

The best results are obtained through the use of several skylights, which offer a more even illuminance (Boubekri 2014). Ideally, the skylights would be placed at a distance equal to the room's height from one another. If the space has multiple skylights, the area lit by daylight will be much higher, as a single skylight normally only illuminates a small surface area directly below it. Depending on the glass used in the skylight, a daylight factor as high as 4 % can be obtained when the skylights cover 7—15 % of the roof surface. (Brandi 2006.) For example, the circular skylights or window wells used in Viipuri Library by Aino and Alvar Aalto, are efficient in daylighting the space while simultaneously avoiding direct sunlight and thus protecting from glare.

To further improve the function of the skylight, baffles can be placed underneath to reflect some of the light onto the ceiling surface. This can improve visual quality by decreasing contrasts between the light source and the background. In effect, it makes the ceiling a large source of indirect light. Roof design should also be considered: when placed on a sloping roof, the character of the skylight becomes more similar to that of side windows. The greater the slope, the more the efficiency of the skylight is reduced. The orientation of the roof slope also matters: on roof slopes facing south, east or west, the need for solar control strategies is higher than on north-facing ones. (Public Technology, Inc. 1996.) Disadvantages of skylights include the loss of thermal insulation, potential for excess heat gains the warmer months, and the higher cost of the roof

Image 10.7.2
Skylights are effective at illuminating spaces in the building's core.

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[2] The exact distance as calculated from the 30° angle would be 2/ √3 (≈ 1,15) times the height of the space + width of the window. However, the 30° rule is a rule of thumb, and therefore no exact numbers can be inferred from it.

EXPERIMENT 5:

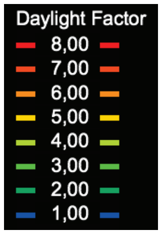
ADDING A SKYLIGHT

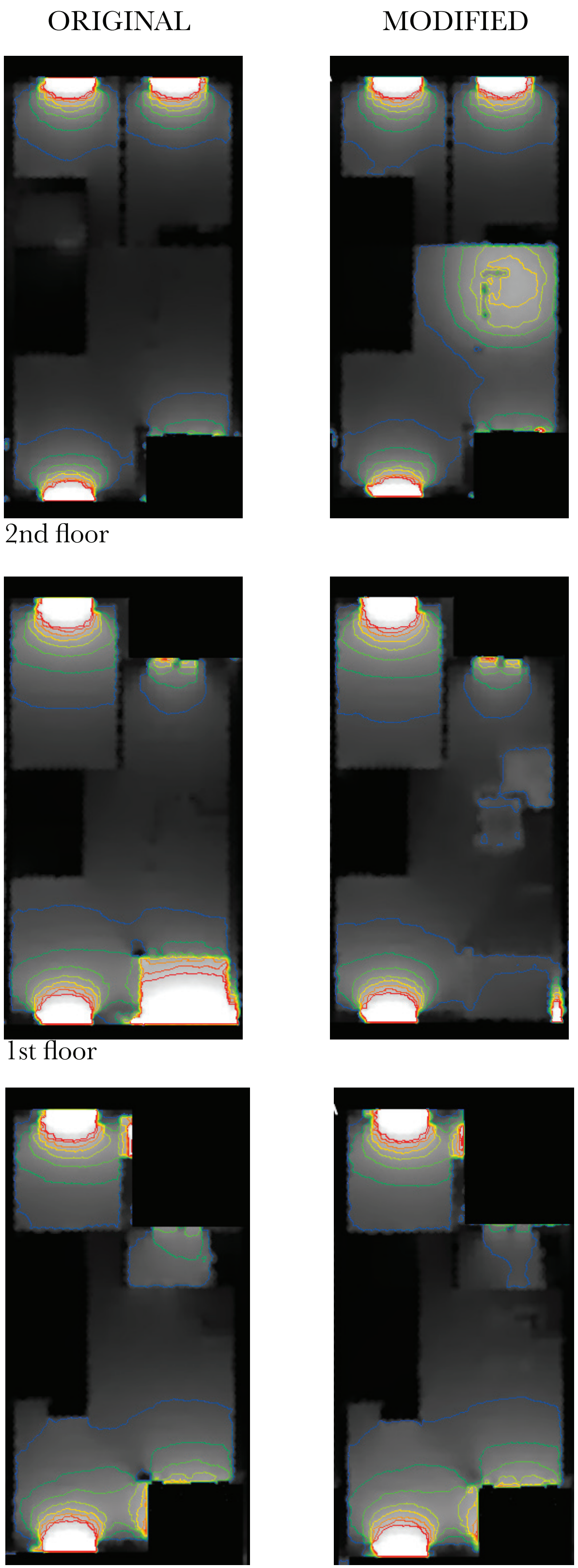
In this experiment, a skylight was added above the elevator reservation space that is adjacent to the main stair. The skylight measures 1200 x 1500 mm.

On the 2nd floor, the skylight has a dramatic effect on daylight conditions. Whereas in the original model, the middle areas of the house have a daylight factor below 1 %, with the skylight the core areas have a daylight factor above 5 %.

We can see that on the 1st floor, the skylight produces a meaningful contribution to daylight: there is a zone with a daylight factor of at least 1 % formed under the skylight, despite the fact that the stair clearly blocks some of the light. However, it seems that the skylight does not have a significant effect on daylight on the ground floor, since the daylight factor below the skylight remains under 1 %.

As we have seen, guiding light to the core of the house from side windows is very challenging, and even with increased room height or windows that reach up to ceiling level, the illumination depth is limited. As such, skylights will be an indispensable tool for illuminating the core areas of the house.





2nd floor

1st floor

Ground floor

structure. Skylights can also pose a risk of water leakage. (Public Technology, Inc. 1996.)

10.8 GLAZING MATERIALS

These days, a variety of special window glazing materials are available. Among these specialty glazing materials, there are huge differences in how they pass through light and heat (Tregenza & Wilson 2011). Special glasses can therefore be used to limit indoor illuminances or to prevent overheating, which allows much more freedom in fenestration design.

Image 10.7.3
A skylight above the staircase of a 1960s apartment building provides daylight into the stairwell.

Specialty glazing materials are typically designed to alter the luminous efficacy value, which is the ratio of visible-light transmittance to the shading coefficient. They can also be designed to transmit certain kinds of radiation while blocking others. For example, a coating can be applied to the glass to block most of the infrared spectrum while still transmitting most of the visible light, though this solution may not be advisable if passive solar heating is needed (Public Technology, Inc. 1996).

Especially on sunny facades, it may be necessary to have a glazing material that limits transmission of solar radiation in order to avoid glare. A downside of these glasses is that on cloudy days, the amount of daylight that transmitted inside may be too low. Therefore, a normal, clear glass combined with a separate sun protection may be a better option in some cases. (RT 07-10912 2008.)

Special materials can also be helpful in situations where adding fenestration would seriously risk privacy. Opaque glass, for example, penetrates light but blocks direct view from outside (Friedman & Whitwham, 2012). Glass tiles and aerogel may be offer similar advantages. Below, some examples of specialty glazing materials are explored further.

LIGHT-SCATTERING GLASS

A glass that scatters sunlight is not typically effective as glare protection on its own. It does not decrease the illuminances enough, and the result can be glare-causing radiation arriving from multiple directions. Light-scattering glasses tend to work best as large surfaces that are protected from direct sunlight. (RT 07-10912 2008, p. 10.)

PRISMATIC GLAZING

Prismatic glazing allows diffused solar radiation to enter the interior space while reflecting direct radiation back to the sky. Prismatic glazing can help achieve energy savings by filtering a greater proportion of the radiation in the summertime, when it is prone to cause overheating, and conversely, transmitting more radiation in the winter. This way, the need for cooling in the summer and heating in the winter can both be reduced. (Gago et al. 2015.) A downside of prismatic glazing is that it may cause unwanted reflections on interior surfaces. They may also require adjustments to ceiling design in order to function properly. (RT 07-10912 2008, p. 10.)

PHOTOCHROMIC GLASS

Photochromic glass is a light-sensitive glass material that functions similarly to light-sensitive sunglasses: it gets darker at a predetermined light intensity level (Public Technology, Inc. 1996).

THERMOCHROMIC GLASS

Thermochromic glass responds to temperature: it becomes translucent when the temperature reaches a predetermined level (Public Technology, Inc. 1996).

ELECTROCHROMIC GLASS

The translucence of electrochromic glass can be controlled by electricity. When a current is applied to the glass, it gets darker, and when the current is reduced, the material returns to a clear state. (Public Technology, Inc. 1996.) The WELL Building Standard™ also lists use of electrochromic glass as one way to prevent solar glare, and states that it can decrease transmissivity by over 90 % (International WELL Building Institute <https://standard.wellcertified.com/light/solar-glare-control>).

LIQUID CRYSTAL (LCD)

LCD glass also responds to an electrical current. Tints can be added to the liquid crystal films of the glass to further increase its solar control capacity. (Public Technology, Inc. 1996.)

11

OUTDOOR SPACES

This chapter takes a look at the private outdoor spaces of the townhouse. This includes the front yard and the backyard as well as balconies and terraces. Design of yard arrangements has to be done in tandem with the building design, and is a central role espcially in the case of urban townhouses, which often have rather small plots.. What is more, outdoor spaces have an interesting role in daylighting design: they offer spaces where it is much easier to reach high illuminances than in indoor spaces. For the occupants, they can offer places to enjoy bright light in a way that is not possible indoors.

Townhouse sites are typically small and as a result, have limited outdoor spaces. According to Jalkanen et al. (2012, p. 50), the minimum depth of a townhouse site is 15 meters and 25—30 meters if there are outdoor buildings on the site. In some cases, the site and yard plan may be limited by accessibility regulations: since townhouses are typically located close to the edge of the street, it can be difficult to arrange an accessible entrance. Lifting the ground floor up from the street level in order to increase privacy makes the situation even more challenging. (Jalkanen et al. 2012.) In some cases, an accessible entrance is easier to arrange through the backyard, which affects the site plan.

11.1 BALCONIES AND TERRACES

Patios, glazed terraces and balconies offer a way to spend time outdoors also in cooler weather while going about one's chores and daily activities. On balconies, it is possible to achieve a higher daylight factor than in indoor rooms, which makes exposure to daylight easier, especially in the winter months. At the same time, outdoor spaces can act as an extension of interior spaces and connect them to the outside world.

When designing balconies, the architect needs to be aware that similarly to long eaves in front of windows, they have a shading effect and can make the house darker (Littlefair 2011) (see diagram 11.1). If wishing to avoid this shading effect, the balconies should not be placed in front of or above the main windows (Corrodi et al. 2008). Especially large balconies, which are common in new buildings, can be problematic in terms of daylighting. On the other, balconies can act as natural sun shaders, blocking the bright and hot sun of the midday, while letting in the sunlight coming from a lower angle in the morning or evening as well as during the winter (Corrodi et al. 2008). This can be useful especially when the risk of overheating is significant.

Friedman and Whitwham (2012) also point out that glazed balconies and terraces around the house further decrease availability of daylight inside. They recommend that glazing used to increase privacy is minimized in townhouses, which have limited space for fenestration space due to their narrow facades (Friedman & Whitwham 2012). According to Corrodi et al. (2008, p. 143), glazing can, in some cases, decrease the amount of daylight inside by as much as 30—45 %. It should be noted though that in Finland, glazing increases the usable season of outdoor spaces and can therefore offer more total exposure to daylight for the inhabitants.

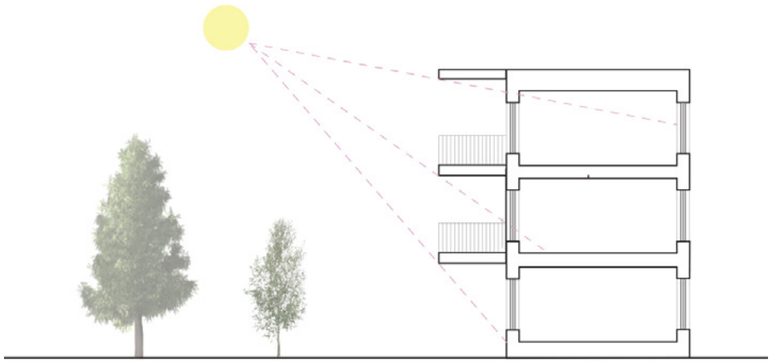


Diagram 11.1
Balconies placed in front of or above windows can a have significant effect on interior spaces.

Adding a small interior space and a fireplace or partially covering the terrace areas increases its usability. A roof terrace may even replace the backyard in dense, urban areas where privacy can sometimes be hard to ensure. It also provides better views compared to a ground-level yard. However, it should be noted that in Finland, at least one of the dwelling's private outdoor spaces should be accessible. (Jalkanen et al. 2012, p. 23.)

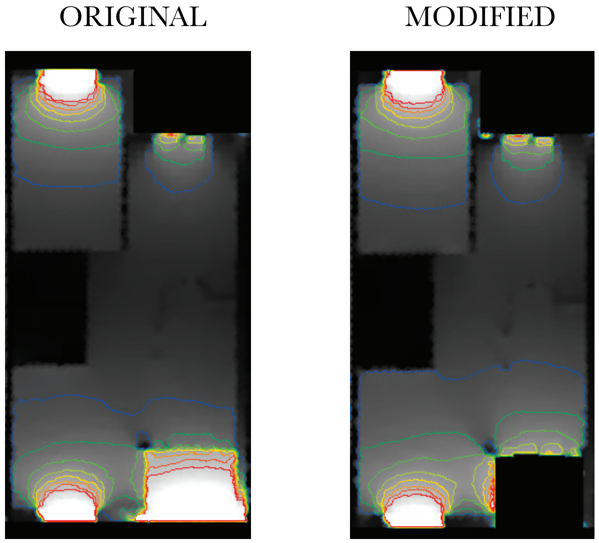
11.2 YARDS AND GARDENS

Daylight is important in the garden. It creates pleasant views, makes pastime in the garden more enjoyable, enhances growth of plants and melts ice and snow. Littlefair (2011) recommends that at least half of the garden should get two hours of sunlight on March 21st. It is important to examine the sunniness of different parts of the garden, and place different outdoor functions accordingly. (Littlefair 2011.) Naturally, most sunlight comes from the south. If the garden is used mostly in the afternoon or evening hours, the most opportune direction would be west (Lappalainen 2010), in order to enjoy the evening sun.

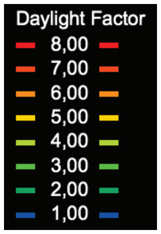
All daylighting solutions in the yard should also be considered in terms of their effect on privacy. Privacy is important not only in the house, but in the yard areas as well: in The New Finnish Dream Home study (Huttunen et

EXPERIMENT 6:

REMOVING BALCONY GLAZING



1st floor



In this experiment, the effect of removing the glazing from the balcony was studied. In the original model, the balcony had clear glazing with 78 % opacity (same as windows, and the highest opacity level in the VELUX Daylight Visualizer). Because the balcony now has no outer wall, the daylight factors for the balcony area are no longer calculated as the software sees it as outdoor space.

We can see that removing the glazing significantly increases daylight in the spaces behind the balcony. Areas right by the balcony now receive significantly higher daylight factors: 3—6 % instead of 2—3 %. The area with a daylight factor above 2 % is clearly increased, as is the area with a daylight factor above 1 %. Based on the results, it seems that the end of the house — the living room — enjoys much improved daylighting conditions as result of the removal of the glazing. Whereas in the original situation, the back areas of the space had a daylight factor below 1 %, now the entire space has a daylight factor above 1 %.

However, contrasts in the space are not necssarily diminished since the brightness next to the windows is also clearly increased. Thus, it is difficult to say if the change results in improved visual comfort or what the effect on experienced brightness is. A significant downside of removing the glazing is that the usable season of the balcony is radically shortened. As we can see in the analysis picture of the original situation, the balcony enjoys high levels of daylight for most of the year. Thus, it provides spaces where occupants can be exposed to bright light without going outside. Therefore, it seems that the benefits of having a glazed balcony may outweigh the benefits achieved by removing the glazing. Nevertheless, it would better to not place the glazed balcony in front of spaces that benefit from high levels of daylight, like the living room. While it may be desired to have access to the balcony from the living room, it could be placed adjacent to it but not in front of its windows.

al. 2016a, p. 7), over 80% felt that it was important or very important that passers-by do not have a view to the private yard areas. Ultimately, the goal should be to balance privacy and daylighting needs, as the two can sometimes be contradicting. For example, fences around the yard do increase privacy but also considerably darken the area, especially in small yards where the shades take up a large proportion of the surface area.

11.2.1 FRONT YARD

While townhouses are typically placed right next to or close to the edge of the site, they can have a small front yard, which increases privacy on the ground floor. The front yard zone can act as a transitional zone between public and private space (Manninen & Holopainen 2006, p. 32), connect the dwelling to its surroundings, and serve as a place for social encounters (Straver Nevalainen 2006). It also protects privacy of ground floor interior spaces (Jalkanen et al. 2012, p. 23). If parking is located on site, the depth of the front yard will be increased (Ellilä 2014, p. 60).

From a daylighting perspective, having even a small front yard is advantageous for at least two reason. Firstly, it pushes the building slightly back from the edge of the of the site and further away from opposing buildings. This can increase the distance between the buildings and thereby decrease their shading effect on interior spaces. However, it is likely that the distance to the closest building on the backyard side decreases as a result — therefore, the location on the building should be adjusted according to which facade would most benefit from increased empty space in front of it. Regardless, another benefit of the small front yard is that it since it opens to the opposite direction than the backyard, it increases the proportion of time that at least some part of the dwelling's outdoor spaces is exposed to direct sunlight.

Huttunen et al. (2016a) divide townhouse front yards into three types: no front yard, inset front yard and offset front yard (see diagram 11.2.1). The inset type refers to a front yard that is inset into the building, creating a private or semi-private space, while allowing the house to be built directly to the edge of the plot. The offset type is a typical front yard, where the building is moved further away from the edge of the plot. In addition to these, Huttunen et al. (2016a) identified two additional, alternative solutions: an inner yard, where both the front yard and the back yard are moved into the mass of the building, and a (roof)terrace. (Huttunen et al. 2016a.)

The first type, no front yard, produces dense street space and leaves the facade row of townhouses unbroken (Huttunen et al. 2016a, p. 43). This means that the distance between buildings is limited to the width the of the street, which can increase the shading effect of opposing buildings. Simultaneously, the space available for the back yard on the plot is increased. Since the backyard side is typically a more optimal direction for main windows because of its higher degree of privacy, maximizing the empty space in front of the yard-side facade — which usually means minimizing the front yard — can be advantageous for fenestration goals.

In the case of the inset type, the front yard can either be a small inset space sunk into the building mass, or, more commonly, be as wide as the facade. The inset increases privacy at the entrance and also provides shelter from rain. A variation of the inset type is a solution where a garage or carport is embedded into the building. Both of these can also be used for other purposes, such as play area or bicycle storage. Another solution is to leave the ground floor entirely open as outdoor space — however, in this case the level of privacy in the backyard is reduced and noise more readily travels from the street to the backyard. (Huttunen et al. 2016a, p. 44—47.) Each of these variations have their own effect on the houses' daylighting. In general, windows opening into the inset will be considerably shaded by the above floors. With the minimum inset model, there's the upside that the spaces next to the inset can have windows opening to multiple directions: to the street and to the inset. Privacy will obviously be compromised with a window opening toward the entrance — however, a space such as an office may even benefit from a view toward the entrance.

The offset type comprises of front yard zones of various sizes. The front yard zone in front or the house can range from really narrow up to the depth or a parking space. The front yard can also extend into the building mass. (Huttunen et al. 2016a, p. 48—51.) In contrast to the first type (no front yard) the distance between buildings on opposite sides of the street is increased and thus windows on the street side will receive more daylight. As already mentioned, the downside in most cases is that at the same time, space on the backyard side is decreased as a result. If main windows are placed on the backyard side, it is generally best to minimize the portion of the plot devoted to the front yard as far as privacy needs permit.

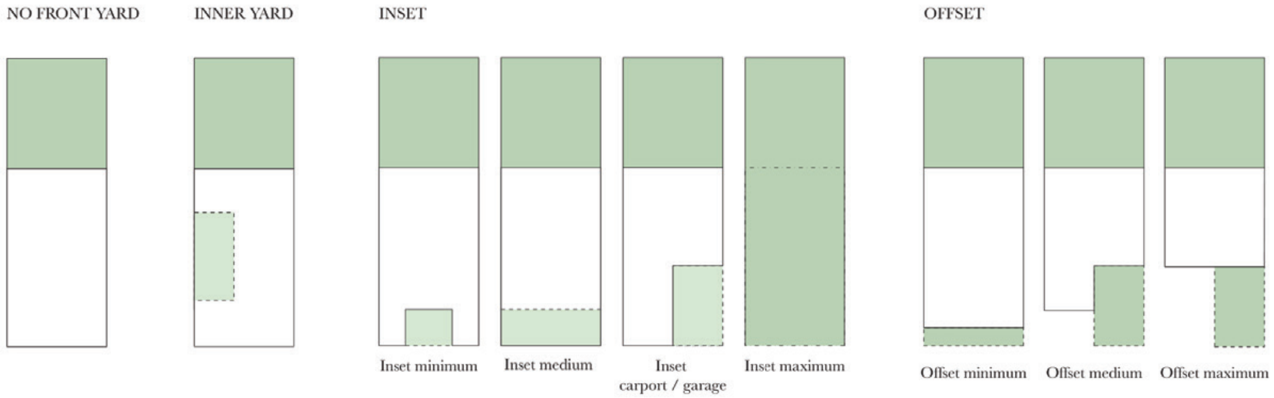


Diagram 11.2.1
Types of front yard discussed in the New Finnish Dream Home study (Huttunen et al. 2015)
Based on: Huttunen et al. 2015

According to Hasu (2010, p. 161), a distance of 5,5 meters between the front facade and the street could be regarded as a minimum for visual and functional needs. Especially if parking and bicycle storage if located on the front yard, this will more or less take up the entire space. Snow in the winter is also a key concern in the design of the front yard: there must be space for plowed snow, and the car should be parked so that snow falling from the roof won't fall on the car, as it could break the windshield. (Hasu 2010, p. 161—162.)

11.2.2 BACKYARD

Normally, the backyard of the townhouse is located behind building, shielded from outsider's gazes (Jalkanen et al. 2012, p. 23). In urban areas, a ground-level garden may also be replaced by terraces. The nature of the backyard depends on the arrangement of the block: if two townhouse rows are located opposite to each other so that their backyards are facing each other, the yards will have significantly more privacy. In these cases, it is common to have a path between the rows leading to the backyards (Ellilä 2014). In terms of daylighting, a block solution like this may be advantageous as the yards are likely to be less shaded because the nearest buildings are further away.

In a straight townhouse row, the privacy of backyards is vulnerable since neighbouring yards often have views to each other. The situation can be improved by arranging the townhouses in a zig-zag line, which blocks some of the views (Väliniemi et al. 2009). Many of the townhouses that have been built in Helsinki have their backyards open to a park (Ellilä 2014, p. 57). Naturally, they are also more likely to receive more daylight compared to, for example, townhouses whose yards are surrounded by high apartment buildings.

An interesting case is a yard that runs throughout the site, which creates a direct connection between the street and the yard. The arrangement does, however, result in both the dwelling and the yard being very narrow. (Ellilä 2014, p. 118.) Very narrow townhouses are generally difficult from a daylighting perspective, but in this case the situation may be different if windows can be placed on the yard-facing side wall. This depends, however, on the site's width and the distance between buildings: if the distance is less than eight meters, windows are usually not allowed according to the Finnish building regulations. However, if windows can be opened to the yard, it can offer pleasant views. Furthermore, views from the street to the house can then be avoided (Ellilä 2014, p. 118).

Ellilä (2014) also presents another interesting alternative: a yard in the middle of the house, which has been divided into two parts. In this scenario, the yard is an active part of daily living (Ellilä 2014, p. 118). What's more, as the house is divided in two, the daylighting challenges created by the deep building frame are alleviated. The yard itself enjoys increased privacy but is likely to be darker since it is shaded by the building masses on both sides.

Backyards of townhouses may also have outbuildings, such as an outdoor storage, guest house or sauna. The effect of the outbuilding on shading of the yard area should be considered when working on the site plan. Especially on south-facing yards, the effect of the outbuilding can be significant.

11.2.3 SHARED OUTDOOR SPACES

Most of the townhouse projects built in Finland do not have shared outdoor spaces, but there are some exceptions to this. In Kalasatama, for example, townhouses have been combined with apartment buildings in a mixed-typology blocks, which makes arrangement of shared spaces, such as play areas, easier. (Ellilä 2014.) The backyards of townhouses that are located close to apartment buildings are, however, at disadvantage in terms of daylighting, as was already mentioned in Chapter 7. Placing the townhouses in the southernmost part of the block and arranging the yard areas so that shading elements on the south side are minimized is another way to increase daylight availability for the townhouses' backyards in mixed-typology blocks.

11.3 VEGETATION

Vegetation is the best way to distribute sunlight in outdoor spaces. Vegetation offers shading from both sunlight and skylight. The appropriate density of the foliage depends on the climate: the closer the location is to the Equator, the denser it should be. An advantage of deciduous trees is that they drop their leaves in the winter, and thus, their shading effect adapts to the seasons. (Tregenza & Wilson 2011, p. 88.) Trees that have dropped their leaves penetrate 70—80 % of the sun's radiation (Lappalainen 2010), while leaved trees only penetrate 10—20 % (Peltonen 2002). Lower trees make it possible to have views of the foliage instead of the trunks (Tregenza & Wilson 2011, p. 88).

Shading offered by vegetation is more incoherent and pleasant than the solid shadow of a building. Yet the shadows cast by plants should be considered when making the garden plan. It is recommendable to have at least some spots shaded by a tree, but to also ensure some areas are still exposed to direct sunlight. Vegetation can also be used to block views and increase privacy. Dense vegetation chosen for this purpose can, however, make the garden substantially darker, which should be taken into account when examining the sunniness of the garden areas. (Littlefair 2011.)

11.4 PARKING ARRANGEMENTS

The easiest way to arrange parking in townhouses is on the street, or alternatively on the plot either integrated into the building or on the front yard (Pulkkinen 2011). In downtown areas, parking is usually located underground (Jalkanen et al. 2012, p. 23). This is often desirable from an urban design perspective (Ullrich 2014, p. 103), and it is convenient from daylighting perspective since the parking solution does not interfere with daylighting of the house — there are neither cars or car shelters shading the windows nor an integrated garage taking up facade space. Underground parking may, however, be financially impossible for many projects (Ullrich 2014, p. 103).

Parking can also be assigned to a separate, centralized parking facility or parking area that is not underground (Jalkanen et al. 2012, p. 23). From an urban planning perspective, however, it may be preferable to avoid formation of large parking areas. Furthermore, centralized parking is not particularly well suited for independently owned townhouses, as it would require separate contracts and extra arrangements. This is why in suburban areas, parking is usually placed in a garage that is integrated into the house, though this solution is prone to create unpleasant walking environments. Other solutions include a car shelter in front of the house or between neighbouring houses. (Jalkanen et al. 2012, p. 23.) Guest and customer parking is usually best arranged on the street (Ellilä 2014, p. 60).

Garages that are integrated to the house take up a large proportion of the narrow facade, which is disadvantageous for daylight if there are other spaces on the same floor. In cases where the garage is located half a storey below ground level, this is less of a concern. A separate garage or car shelter, on the other hand, has a shading effect and also impairs views. A simple, unsheltered parking space on site has less of an effect on daylighting, though if located very close to the facade the car may, to a degree, reduce daylight and impair views on the ground floor. Having parking on the street in front of the house minimizes shading the effect of decentralized parking since the car is further away from the facade and there are no additional structures like there are in the case the case of a car shelter or garage.

12

DAYLIGHTING SYSTEMS & FURTHER STRATEGIES

This chapter covers the final, most detail-level of daylighting design. It discusses choice of surface materials as well as daylighting systems. These are systems that are, in a way, the ”next level” of daylighting; ways to improve daylight conditions beyond what is possible by basic design solutions. This systems will be useful especially in situations where the starting point in the daylighting design is challenging and there are many factors that limit daylight availability. Therefore, they may be valuable in the design of Finnish townhouses, which have challenges posed by the typology as well as the geographical location and climate. There is a very large variety of solutions that could be included in daylighting systems. Therefore, this chapter focuses on some of the most commmon ones and the ones that could be useful in the design of Finnish townhouses.

In many cases, the basic daylighting solutions — for example, simple side windows — benefit or even require additional measures to either optimize their efficacy or to protect from excess illumination or overheating. Indeed, the main failure of daylighting systems is faulty design or installation of control systems (Public Technology, Inc. 1996.)

Daylighting systems cannot be used in place careful design (Boubekri 2014, p. 62). They can, however, fulfil or support in achieving goals that couldn’t be achieved with only a regular window, such as:

- Guiding light deeper into the space.
- Increasing the amount usable of daylight available in cloudy climates.
- Increasing the amount of usable daylight available in sunny climates, where it is necessary to control the light.
- Increasing the amount of daylight available in windows that have a blocked sky view because of an exterior obstruction
- Guiding natural light into windowless spaces. (Johnsen & Watkins 2010.)

Daylighting systems can be used to improve daylighting provided by a regular window, or to add control. A common aim in using daylighting systems is sun protection (Johnsen & Watkins 2010). This is important especially in rooms with large windows or skylights, or if the uses of the room require limiting glare, direct sunlight and illuminances in the field of vision. It should be noted that some sun shading systems can affect indoor temperature and cooling needs, energy consumption and acoustics. (RT 07-10912 2008, p. 7.)

Sun shades have two main purposes: glare protection and shading. Glare is related to visual effects and limiting contrasts within the view of vision, while shading mainly deals with prevention of overheating. Glare protection has to take into account direct sunlight, skylight and reflected sunlight, which is why systems intended for shading are not always effective against glare. (Johnsen & Watkin 2010.) When designing daylighting systems, the designer needs to be aware that some fixed shading systems can decrease availability of daylight on darker days as well (Corrodi et al. 2008). Other things to consider are reliability — meaning how certain can we be that the system will work as intended when needed — durability and ease of use (RT 07-10912 2008, p. 8).

Sun protection systems can either block direct sunlight while penetrating ambient light, or just prevent direct sunlight above eye level (Johnsen & Watkin 2010). About half of the energy in sun's radiation is within the realm of visible light, so visible light is also capable of causing overheating on its own when it is absorbed into the building. Therefore, shading systems outside the window tend to be more effective at preventing overheating. (RT 07-10912 2008..)

According to some research, people value sunlight more when they can freely choose whether to stay in sunlight or move to a shaded area (Littlefair 2011). Blinds and curtains offer the inhabitants easy ways to control the lighting at a relatively low cost. Blinds are used for sun protection and shading especially in south-facing windows (Galasiu & Veitch 2006.) They can also be used to block direct view from outside and thus increase privacy.

The goal of the use of these systems is to maximize availability of daylight inside while optimizing the quality of light for the occupants. It is important to control illumination levels as well as the direction and distribution in the use of daylight. (Gago & al. 2015.) For example, traditional, lateral windows may produce unequal distribution of light, and daylighting systems can be used to balance this distribution and create a more uniform lighting. Some commonly used daylighting systems are presented below. This is not a comprehensive overview of the numerous systems that are available; instead, the aim with this chapter was to choose commonly used daylighting systems that would be likely to be relevant in the case of daylighting of Finnish townhouses. Before actual daylighting systems, we will take a look into another daylighting strategy: the choice of surface materials.

12.1 SURFACE MATERIALS

Reflectance of surface materials can be measured, and through well-chosen materials, it is possible to achieve a better-balanced luminance distribution and protect against glare (Bellia et al. 2011, p. 1985). Reflective surfaces can enhance the illuminance of the interior space. In each space — outdoors or indoors — the amount of light reflected depends on the amount of light flowing in and the surface area of bounding elements, as well as their reflectance. Especially in narrow streets, the reflectance of facade surfaces greatly influences brightness of interior spaces. (Tregenza & Wilson 2011.) Reflectance of surrounding surfaces can improve the daylight factor of interior spaces by as much as 10—20 % (Corrodi et al. 2008, p. 145). The magnitude of the effect depends primarily on the density of the area (Boubekri 2014, p. 59).

Similarly, the reflectance of interior surfaces can improve illuminance in the center of the room by 10—20 %. Interior reflection can be used to guide light deeper into the space and to even out contrasts. Avoiding forms that block the flow of light indoors maximizes the benefits of interior reflectance. Light reflected to the ceiling from the floor or from the ground outside can change the daylighting of the space considerably. Wide windowsills can also be used to reflect light to the ceiling. (Corrodi et al. 2008.)

Reflectance of materials can also be used to improve distribution of light in space. As the light is reflected from a number of surfaces, it becomes increasingly non-directional and thereby causes less shadows. This in turn improves visual comfort. (Public Technology, Inc. 1996.)

To utilize and control reflection from surfaces, the architect needs to be aware of the large differences in reflectance between surface. For example, a white plaster wall reflects 85 % of the light, while red brick only reflects 25 % (Corrodi et al. 2008, p. 136). In general, lighter shades reflect more light than darker ones, which tend to absorb it (Peltonen 2002). Dark surface materials, especially around the windows, may create large contrasts within the space and pose a risk of glare. Matte surfaces are preferable to mirroring ones, as they support a more even distribution of light. (Corrodi et al. 2008, p. 178.) Surfaces that reflect light can also be utilized to protect from excessive sunshine: these surfaces can reflect light back to the direction it came from — toward the sky — and thus are effective in protecting from excess light and overheating (Köster 2004).

The reflectance of interior surfaces should be lowest at the floor level and increase toward the ceiling. Corrodi et al. (2008, p. 178) recommend choosing materials with the following reflectances:

- 20—40 % for the floor
- 50—70 % for the interior walls
- 80 % for the ceiling
- 25—45 % for furniture.

Public Technology, Inc (1996) also gives recommendations for surface reflectance values, which are quite close to those proposed by Corrodi et al., further confirming accuracy of these values. Transparent materials can also be used inside to increase flow of light within the space.

While interior windows and other transparent surfaces do not make interior illuminance considerably higher, but they can make it more even. Partly transparent surfaces penetrate light and create an ambient lighting in the space (Corrodi et al. 2008.)

12.2 LIGHT SHELF

The shelf is a natural lighting system used in conjunction with side windows. It is installed into the window, between the windowsill and the top of the frame, effectively dividing the window in two. This way, light will be reflected to the ceiling from the top surface of the shelf, lightening the back of the room (See diagram 12.2). (Boubekri 2014, p. 63—65.) This will make the light distribution in the room more even (Public Technology, Inc. 1996). Simultaneously, the shelf protects from glare and can act as a sun protector (Boubekri 2014, p. 63). However, the light shelf is only effective during the season when where light falls directly on them. Furthermore, as it decreases illumination levels, it may not be well-suited for rooms facing north, where the illumination level is often already comprised (Gago et al. 2015.) Because of these factors, light shelves may not be ideal for Finnish conditions. (RT 07-10912 2008, p. 9.)

Standard light shelves can be expected to produce an even daylight illumination to the area within a distance from the window that is equal to 2,5 times the height of the top of the window measured from floor level. However, there are advanced versions that can produce an even illumination to a considerably larger area, within a distance that is equal to up to 4 times the height of the top of the window opening. In addition, tracking systems can be implemented to optimize the function of the light shelf to changing conditions. Compared to passive systems, the advantage of tracking is a more uniform efficiency and light distribution pattern, but there is also higher potential for problems and higher maintenance costs. (Public Technology, Inc. 1996.)

Because light shelves work by reflecting light upwards, the shape of the ceiling plays a key role on the light shelf's efficacy. According to some analyses, the best results are achieved when the ceiling is curved at both the front and the rear. Similarly, the geometry of the shelf itself affects its function, and it seems that a curved, beveled shape works best here as well. However, light shelves have a profound effect on both architectural and structural design. Furthermore, they require a rather high ceiling to function optimally. They also have to be specifically designed for each window orientation, spatial configuration and geographical location. Therefore, the use of light shelves should be considered quite early on in the design process. (Gago et al. 2015.)

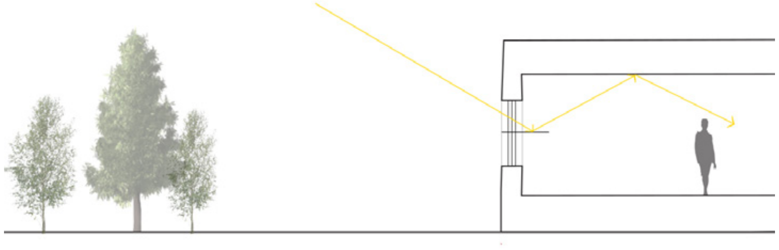


Diagram 12.2
The light shelf reflects light to the ceiling and deeper into the space.

12.3 CURTAINS AND BLINDS

Screen-like curtains can be used to dampen and possibly scatter sunlight. They do not completely block direct sunlight, and the penetration of the fabric or material can be chosen to fit the needs so that thermal protection efficacy is ensured. Curtains can be effective in glare protection on large surface areas. They can also be visually subtle, especially if all windows are covered with similar curtains. Another advantage of curtains is that they can be used and adjusted according to varying needs. (RT 07-10912 2008, p. 9.)

Blinds include different styles of systems that consist of numerous vertical, horizontal or sloping slats. Similar to a light shelf, they capture sunlight at the front part of the room and reflect it deeper into the space. Thus, they are effective at reducing contrasts within the space by reducing illumination levels in front of the window and increasing levels at the rear areas of the room. The resulting glare and visibility conditions are influenced by the shape, size and angle of the implemented blind system. The blind configuration also plays affects the way the system transmits, absorbs and reflects light. The solar angle also influences the optical and thermal properties of the device. (Gago et al. 2015.) Therefore, the opening direction of the window should always be taken into account when choosing or designing the blinds. The colour of the slats also affects the blind's function — light-shaded slats increase ambient light in the room, while mirroring surfaces may cause reflections on interior surfaces. Architects should keep in mind that having a light and airy aesthetic as the key objective of the design of the blinds system may lead to inadequate shading. Relative dimensions of the blinds are the key factor for their shading effect. An advantage of adjustable blinds is that the dimensioning is less critical than with fixed structures. (RT 07-10912 2008.)

A possible downside of manually controlled blinds is that they do not necessarily correctly comply to visual and thermal requirements. This can be solved by using automated blinds, which adjust to optimize the balance between protection from overheating and the correct amount of daylight. (Gago et al. 2015.) Another disadvantage of blinds is that they are not as effective at preventing overheating as shading outside the facade (RT 07-10912 2008) since they don't prevent thermal radiation getting absorbed into the interior space. Furthermore, they tend to darken the space considerably, which is why many innovative solutions have been developed to protect from bright light close to the window while guiding light deeper into the space (Johnsen & Watkins 2010). For example, surface materials that reflect light back to the sky offer glare protection without blocking the view. They are particularly helpful around working spaces, where glare can cause significant discomfort and trouble, especially when working on a computer. (Köster 2004.)

12.4 ANIDOLIC CEILING

Anidolic ceiling systems direct light deeper into rooms through non-imaging mirrors, light guides and lenses. The word “anidolic” means “without and image” and refers to the fact that the optical components used in anidolic ceilings do not direct light to converge to a focal point to form an image.

An anidolic ceiling can be used to increase the amount of daylight inside the building and to improve the building’s energy efficiency (Wittkopf et al. 2006). Anidolic ceilings can increase the daylight factor measured in the back of the room by 170 % under overcast conditions. This increase in daylight factor could reduce electrical energy consumption by a third. The visual comfort in spaces with an anidolic ceiling seems to also be increased (Courret et al. 1998.) Care is needed in the design of the anidolic ceiling, however, in order to accurately control the solar angles and thereby prevent glare and undesired reflections (Gago et al. 2015).

12.5 MIRRORS AND HOLOGRAMS

Mirrors and holograms or Holographic Optical Elements (HOEs) are used to redirect daylight and to thus improve penetration and distribution of light inside buildings. Like other side-lighting systems, they can be used to achieve energy savings and improve user comfort. Holograms are effective at separating the majority of visible light from infrared radiation, which can be useful when wishing to modify the heat load caused by solar radiation. Weaknesses of holograms include their relatively high cost and reduced transparency in an environment. Similarly, other systems used to reflect back sunlight can reduce the light transmitted inside and therefore increase the need for artificial lighting. (Gago et al. 2015.)

12.6 LIGHT PIPES

Light pipes can either simply transfer light from an external source, or the pipes can be a continuous light source themselves. Light pipes are commonly used in conjunction with light concentrating strategies or heliostats as high-intensity light sources. The light pipes are highly usable in cases where security requirements or a challenging environment limit other daylighting strategies. (Public Technology, Inc. 1996.)

12.7 TRELLISES

A canopy-like trellis can be an effective way to modify thermal radiation. They can be used, for example, in spaces with a transparent roof material. A trellis can be composed of one set of parallel slats or of multiple sets of parallel slats crossing over each other. Like blinds, the dimensions and configuration of the trellis slats should be designed according to context. Factors to consider include the case-specific solar conditions and shading needs as well as the “stripes” in the field of vision the trellis can cause. It is also important to note that a trellis will not offer shading when the sun shines from a low angle. (RT 07-10912 2008, p. 8.)

12.8 MONITORING AND TRACKING SYSTEMS

As already mentioned, monitoring or tracking systems can be used in conjunction with other daylighting systems, such as the light shelf, venetian blinds or smart windows. These systems allow implemented systems to respond to changing weather conditions and daylight levels. Thus, they can reduce the need for artificial lighting and result in reduced lighting and cooling energy consumption (Public Technology, Inc. 1996.)

13

DISCUSSION & CONCLUSIONS

Because of its narrow facades and deep building frame, the townhouse is a challenging typology in terms of daylighting. Especially in Finland, where outdoor illuminance levels are low for a large proportion of the year, architectural design solutions play an important role in determining whether the Finnish townhouse will have sufficient amounts of daylight. Since townhouses are often individually designed, the architect often has some freedom and good opportunities to influence the outcome. The townhouse is also a typology that lends itself to many kinds of interpretations, thereby making it possible to modify the design to better advance daylighting goals. With conscious and careful design, the lighting conditions in Finnish townhouses can be optimized, which can help support the health and enjoyment of the occupants.

Because of the deep building frame, the primary challenges in the daylighting of townhouses are increasing the depth of the illuminated area and guiding light to the core of the house. Large contrasts — high illuminances in areas close to the windows and dark areas in the core of the house — will result in an unpleasant lighting environment and reduced visual quality. Based on the experiments, it seems that increasing room height is an effective tool for increasing the illumination depth provided by the windows. Another key factor is the height of the window. However, as we saw in the experiments, lifting the windows up without changing their height seems to be almost equally effective at improving daylight conditions as increasing the height of the window an equal amount.

While lifting the upper frame of the windows and increasing room height both significantly increase illumination depth of side windows, based on the experiments, their effectiveness is limited. It seems that in order to illuminate the core areas of relatively deep townhouses, other strategies besides side windows are needed. One way to guide light to areas difficult to reach by side windows is to use skylights. Skylights are a particularly efficient tools in cloudy climates like Finland, as in cloudy climates, the sky is brightest at zenith, directly above. Placing a skylight will allow the areas directly under it to enjoy plentiful daylight, and effectively decreases contrasts between areas close to the facades and at the core. By adding a light well — making a void in the building underneath the skylight — we can also guide light to the core areas on lower floors. However, at least in the experiments in this thesis, it seemed that the effect of the skylight was mostly limited to just one storey below: two stories down, the skylight did not make a meaningful difference to the daylight conditions. Perhaps the results would have been different if the skylight had been larger — that is something that could be researched further in the future.

Other strategies for directing light into the core areas of the house could include multi-storey high spaces the end of the house, fitted with high windows. For privacy reasons, the best place for such a high space would be the backyard side in order to not have a very open views from the street into the house. Furthermore, the spaces that would most benefit from the airiness and brightness of a two-storey space are spaces where people spend a lot of time — in most cases, the living room, which is likely to be located on the backyard side. What's more, a multi-storey high space on the ground floor could be a way solve the contradiction between wanting to locate the living and dining spaces on the ground floor for functional reasons while also wanting them to have plentiful daylight, which would normally be better available on the upper stories.

It is also important to study the dimensions of the townhouse in order to assess how deep the frame could be without rendering the core areas too dark: depending on the other daylighting strategies implemented, it may be necessary to limit the depth of the house. Extremely narrow and deep versions of townhouses are in general not ideal for Finnish conditions in terms of daylighting. Even more important than the absolute depth is the ratio of depth to width and to room height. Increased room height and wide facades with more window surface will increase the penetration of daylight into the core of the house, which then allows a deeper building frame. In addition to determining the distances between buildings, the no-sky line can also be used to illustrate the effect that modifying frame depth and room height have on sky view in the space.

Openness of the floor plan also affects the flow of light and how it can travel to the core of the building. Townhouses are structurally well-suited for open plans, as the side walls can usually carry the loads of the narrow building without the need for additional load-bearing elements. Especially on the ground floor, which is in the most vulnerable position in terms of daylighting, it is essential to consider how the spatial arrangement affects the lighting of the space. In order to optimize the flexibility and adaptability of the townhouse, auxiliary spaces such as toilets and bathrooms are often grouped into one zone. This strategy is also helpful in daylighting because it can help minimize the darkening effect of auxiliary spaces.

All placement options of auxiliary spaces have their pros and cons. Firstly, a longitudinal side zone takes up little facade space but can be problematic as the remaining spaces are likely to become quite narrow and thereby difficult to daylight. Secondly, placing auxiliary spaces in one end or corner of the house is often favorable in the sense that it makes it easier to convert the townhouse into several apartments later on, increasing the potential lifespan of the building. However, the end or corner zone typically and takes up a significant proportion of one main facade and can make it difficult or impossible to receive light from two directions. The remaining space will be deep, and the middle areas of the house are prone to be dark. Finally, a middle zone solution parallel to the facades leaves the facades free but makes it impossible to receive light from two directions.

Another challenge in the daylighting of townhouses is created by the narrow facades. They are challenging in terms of daylighting as they limit fenestration space and typically only allow light in from the two opposing facades that are often far away from one another. These conditions can be improved by choosing a more complicated facade form: zig-zagging and other more complicated forms in the townhouse block or in the shape of the individual building will make it possible to receive light from more than two directions. At the same time, there is more facade surface available for fenestration.

The optimal orientation of the building's facades is a heavily debated question, and both east-west and south-north orientations have their proponents. For Northern locations like Finland, having a facade facing south is often recommended because it allows for better utilization of passive heating. At the same time, it increases exposure to sunlight during the wintertime, when the sun mainly shines from the south. On the other hand, a benefit of east-west orientation of facades is that rows of buildings can be located closer to each other without excessively shading one another. However, there is the disadvantage that sunlight from east and west arrives mostly at a low angle and is prone to cause glare. In many cases, the orientation of the townhouse's facades is defined by the street line, so the orientation of facades is often already determined at the masterplanning stage.

Especially in a country like Finland, where outdoor illuminances are very low during the winter months, a high enough window surface area is required to reach a good indoor illuminance level. Recommendations for window-wall ratio vary widely between sources, ranging between 20 % and 60 %, and depends on the use of the space. A high window surface area increases the need for protection from overheating. The risk of overheating and glare depends on the opening direction of the window: a north orientation poses a low risk, whereas south-facing windows generally require some control strategies. East and west orientation can also be challenging because they receive light from a low angle, meaning that it is difficult to control and prone to cause issues.

Strategic placement of shading elements such as balconies is one way to control sunlight penetration into the interior space. Glare risk can be diminished by hiding the light source from the field of vision — for example, having a window behind a corner or guiding in light through the sides of a bay window. Furthermore, aiming for even indoor illumination and avoiding stark contrasts is crucial for managing glare risk. One of the best ways to even out contrasts is through employing several light sources. One light source can be a window and the other can be electric lighting, reflective surfaces or another window opening to another direction. Having windows open in at least two directions will also significantly increase the size of the well-lit area. This is most efficient if the windows are on opposing walls, like the two facades of the townhouse.

The shape and location of a window should be determined according to daylighting goals. The most efficient illumination is provided by windows higher up in the wall: they efficiently increase the sky view in the space and guide light deeper than windows lower down in the wall. Having the upper frame of the window close to the ceiling — ideally, meeting the ceiling without a frame — will illuminate the ceiling more effectively and allow light to be reflected from it into the back of the room.

In terms of horizontal location, a window in the center of the wall provides a more even illumination than one in the corner. However, corner windows can be more efficient at illuminating the rear areas of the space. The shape of the window also plays a role: a wider window provides a more even illumination throughout the day, whereas lighting from vertically shaped windows will vary more with the movement of the sun. However, a remarkable advantage of vertical windows is their capacity to let light in deep into the space, which is why they can be especially valuable in deep-framed buildings like townhouses.

Balconies are an interesting case in terms of daylighting in Finnish conditions. Glazing of the balcony clearly decreases daylight in the spaces behind the balcony. However, balconies themselves usually receive much higher levels of daylight than normal interior spaces and thereby offer spaces where the occupants of the house can be exposed to bright light without going outside. Glazing of the balcony significantly increases its usable season in the Finnish climate. Based on the findings in this thesis, it seems that the benefits of having a glazed balcony may outweigh the disadvantages of the glazing. Nevertheless, because of the darkening effect the glazed balcony has, it is recommendable to not place the balcony in front of or above spaces that need high levels of daylight, such as the living room.

As townhouses are a typology of urban settings and are typically located in relatively dense areas, surroundings also play a key role in determining daylight conditions in the townhouse. Distance between buildings is a key component — its effect can be easily studied using a strategy like the no-sky-line, which demonstrates how the opposing building affects the sky view in the interior space. The visibility of sky in the space is a good proxy for adequate daylighting: generally, the areas in the space that have a view of the sky will receive adequate amounts of daylight. In contrast, in areas where view of the sky is blocked, daylight is also typically insufficient.

Townhouses may be combined with apartment buildings in mixed-typology blocks, and in these cases, it is essential to carefully consider daylight availability in both indoor and outdoor areas. High-rise buildings located within a close proximity will make it significantly harder to guide light into the townhouses. In mixed-typology blocks, the townhouses' limited outdoor areas are also at an increased risk of darkness. In terms of daylighting, it is recommendable that the tallest buildings are placed on the north side and lowest on the south side. The darkening effect of surrounding buildings can be alleviated by choosing lighter facade colors. Vegetation should also be designed mindfully. Deciduous trees are advantageous in that they drop their leaves during the winter when daylight is limited but provide shade at summertime.

Yard arrangements of the townhouse should be designed in coordination with the daylighting strategy. Modifying yard dimensions and the location of the house on the site can be a way to manage distances between buildings. Light exposure of outdoor spaces should also be considered during the design process. Ideally, the areas where people spend a lot of time should receive afternoon sun and therefore, be orientated toward south or west. Choice of parking arrangements will have a strong impact on the daylighting of interior spaces: integrated garages will take up facade space, whereas a shelter structure close to the facade will cause shading and impair views. Centralized or underground parking solutions are ideal in terms of daylighting but may not be a viable option in many cases due to high cost or urban design goals.

The need to conserve energy and increase the sustainability of buildings over the course of their life also underlines the importance of utilizing natural light. Daylight is a free and sustainable light source. Designing buildings to make use of daylight can decrease energy consumption by lowering the need for artificial lighting, which makes up a remarkable proportion of global electricity consumption.

However, no matter how well architectural solutions are optimized, it remains a fact that for a large part of the year, daylight is too scarce in Finland to provide a meaningful and sufficient light source. The fact that daylight cannot provide adequate lighting throughout the year means that the role of artificial light will be significant and should not be overlooked in the design process. Therefore, research on how artificial light could be used to compensate for the lack of daylight and to create health-supporting lighting conditions in Finnish dwellings would be important and useful for designers.

This thesis included a univariate analysis of the effects that design solutions have on daylight conditions of the townhouse. This provided valuable insights into how each design decision alters daylight. However, as discussed in the experiments, many of the studied strategies could have synergistic effects when combined together. These synergistic effects could a subject for future research. At the same time, future research could be used to verify the results obtained in this thesis. A vulnerability of these experiments is that they were made using only one software and are therefore subject to all the possible errors in the software. Therefore, doing similar experiments with a different software and comparing them to these results would be beneficial. However, even with the data gained in this research provides us with a better understanding of daylight conditions of the townhouse. As we saw in the daylight simulations, daylight conditions in the townhouse are vulnerable because of the typology's characteristic deep frame and are further compromised by the Finnish climate. Yet we also saw that through manipulation of key design solutions, such as room height and fenestration, we can markedly improve daylight conditions of the Finnish townhouse. The changes required to improve daylighting are not complicated and not necessarily even expensive, but they require knowledge and awareness from the architect.

The townhouse typology is still relatively rare in Finland. However, the typology has received an increasing amount of interest in the recent years and it seems likely that townhouses will become more common in Finland in the future. It is therefore crucial that the importance of daylighting in the Finnish context is understood and taken into account so that the townhouses that will be designed and built can provide pleasant dwellings with adequate daylight. At the moment, there is relatively little Finnish literature on natural lighting, and comparatively few regulations or guidelines about the subject. In other countries, the importance of natural lighting has already been better acknowledged: for example, in the Estonian 2008 standard, detailed instructions about the use of daylight in housing are given. Similar instructions for designers or requirements for constructions would also be beneficial in Finland in order to ensure the quality of daylighting in the building stock.

New discoveries about light's effects on human health call for more attention to the issue in the design of our living environments. As recent advances in the science of light's effects on health have shown, light exposure has a powerful impact on many aspects of health. Light can influence mental and physical health, disease risk, sleep quality, alertness and cognitive performance as well as provide enjoyment and pleasure. Insufficient exposure to bright light during the day is a common issue in industrialized countries. As home is a place where people spend a large proportion of time, the lighting conditions of the dwelling will play a central role in the individual's light exposure patterns. Especially in a country like Finland, where daylight is scarce for a large proportion of the year, it is of central importance that architects and designers acknowledge and understand their role in the creation of lighting conditions of people's living environments.

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APPENDIX A

THE TEST HOUSE

To test and illustrate the effects that design solutions have on daylighting in the Finnish townhouse, this thesis includes a simplified townhouse design. This test house serves as an experimentation tool: it is modified according to the ideas and theories presented in the text, after which a daylight analysis is performed to see how the design change affected daylight conditions in the house.

DESIGN PRINCIPLES

There were two important principles guiding the design of the test house. Firstly, in terms of key design solutions, the test house aims to represent a fairly typical Finnish townhouse. This is important because in order to provide data that would be relevant in the design of future Finnish townhouses, the test house has to resemble a house that could actually be built. To align the design with Finnish ideas about townhouses, the key design solutions were guided by an analysis of the existing literature and material on Finnish townhouses. The idea in the analysis of existing resources on Finnish townhouses was to find common denominators and principles. The *Habitat Components — Townhouse* study conducted in Aalto University was a particularly influential resource when laying out key design solutions, for it aimed to define what the townhouse in a Finnish context is and included plenty of pioneering material on multiple aspect of the subject. The analysis influenced, for example, decisions such as dimensions, number of stories and yard arrangements of the test house. The basic design solutions of the test house also aim to be aligned with today's Finnish housing design practices.

The second important goal in the design process was to include a variety of different daylighting settings. This is why the house includes insets, canopies, terraces and both glazed and unglazed balconies. This way, some parts of the facades have shading elements in front of them while some do not. Along the same vein, some spaces receive light directly from a window while some receive light through a balcony. In addition, there are spaces that can receive light from multiple directions while some only receive it from one side only. There are spaces of different heights, and there is the highest floor which has a different ceiling shape and different kinds of windows.

As flexibility and adaptability arouse as important, repeating themes in the Finnish townhouse literature, the test house also attempts to offer something when it comes to these issues. After all, the goal with the test house is to provide data that would guide the design of desirable, functionally sustainable Finnish townhouses, which is why its design was conducted with flexibility and adaptability in mind. An aspect related to the issue of flexibility is the traditional role of townhouses as buildings with two functions: living and commercial space on the ground floor, which was also repeatedly mentioned in the literature. For these reasons, the test house includes a space on the ground floor on the street side that has a higher ceiling and can easily be converted into commercial or office space. The floor level on this space is at street level, 500 mm below the rest of the ground floor. This space has its own entrance from the same path leading up to the main front door, but it also has an interior connection to the rest of the ground floor. If needed, the street side window could be converted to a door to arrange a more public entrance to the space. In addition, the space has an adjoining storage space that is adjacent to the vertical line of bathrooms and toilets and could thus be converted into a toilet if the space were to be used as an independent unit.

Furthermore, to respond to flexibility needs even better, the test house was designed so that it could be later divided into multiple apartments. The stair is placed in the middle of the frame next to one longitudinal side, which allows the house to have windowed spaces on both sides of the stair. Next to the stair there is a reservation for an elevator. This is necessary in case the townhouse is divided into apartments, but also increases its usability as a single dwelling: having the possibility to install an elevator will allow the occupant to keep living in their home and using all its stories even if they become unable to climb stairs. If there is no need for the elevator, the space could be used as a light well as is demonstrated in one of the experiments.

Along the same vein, to comply with accessibility recommendations, the ground floor has the essentials for living: the kitchen, the bathroom and space for sleeping. In the presented floor plan, there are two tables on the ground floor — one in the dining space and one in the kitchen for breakfast and snacks — but to convert the ground floor to a so-called survival floor, the dining table could be moved to the kitchen and the freed space in the dining room could be used for sleeping.

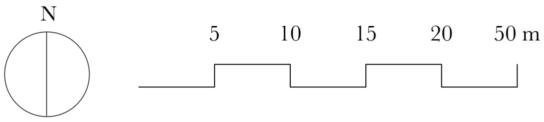
THE SURROUNDINGS

The test house model also includes the house's surroundings. The surroundings are imaginary; the goal is to test the effect of typical townhouse settings. The test house is a part of a townhouse row consisting of 3-storey townhouses. In the row there are four houses, as grouping the townhouses in this manner was mentioned in the literature as a viable solution in a Finnish context, both to create a more varied block solution and to arrange an accessible entrance through the backyard side (Jalkanen et al. 2012, p. 24, 28). The number of houses in the row was determined so that the accessible route to backyard entrance would fulfil accessibility requirements (50 m). The townhouses in the same row with the test house have the same outer shape as the test house.

There is a 1 m wide front yard zone in front of the front-most outer wall of the multi-usable office / bedroom / commercial space. The main entrance is inset and thus, there is a 4,6 m front yard zone between the entrance and the street, which increases privacy at the entrance. To further increase privacy at the entrance, there is an elevation difference of 500 mm between the street and the ground floor. There is an accessible route to the entrance

Site plan 1:500

The test house is indicated by the red dashed line.



at both ends of the townhouse row via the backyard, arranged with a ramp with a 5 % incline. The ground is mostly flat, but the backyards are elevated to the same level as the ground floor, 500 mm above street level. In addition, there are minor elevation differences between sidewalks and driving lanes as there would be in a real block.

On either side of this townhouse row there is a townhouse row with four townhouses, with a backyard zone in between on one side and a street on the other side. The townhouses in the opposing rows are modelled in a more simplified way: they are solid rectangular boxes with outer dimensions of 7,0 x 11,4 m (width x depth).

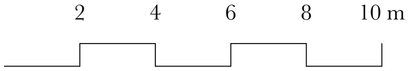
Each house has a backyard measuring 7,0 x 9,0 m, with some additional space in the inset terrace area. There are 1,2 m high stone fences between the backyards. Between two opposing backyard zones, there is a 1,5 m wide path leading to the backyards that also serves as the accessible route to the houses from the ramps at either end or the townhouse row.

The width of the street between rows is 13,5 m, with two 2,0 m wide walking and bicycles lanes and two 2,0 m wide parking zones. The street has two driving lanes each 2,75 m wide, which is 5,5 in total — the standard width for residential street according to Helsinki City street planning guidelines (Helsingin Kaupunki 2014). Parking is in the street in front of the houses.

Facade colors were chosen so that there would be a closely corresponding surface material option in the software used for the daylight analyses. All the houses have wooden

North elevation (street side) 1:200

South elevation (backyard side) 1:200



façades painted in different light-shade colors or with an unpainted wood surface, as shown in the elevations. The ground floor multi-usable, potential commercial spaces have a different surface: they all have brick facades in light grey-brown shades. This differentiates the potential commercial spaces from the rest of the house and serves as a unifying factor between the otherwise differently colored houses.

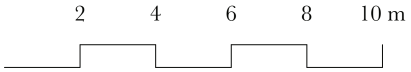
THE HOUSE

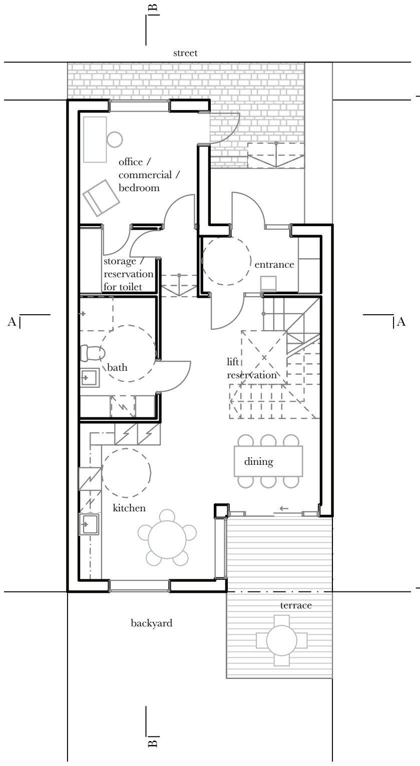
The test house model is a three-storey high townhouse with a façade width of 7,0 m. The depth of the house ranges from 7,7 m to 13,0. This variation in frame depth was created both for functional reasons and to include a wider variety of daylighting settings.

The house is located on a site measuring 7,0 x 23,6 m. The dimensions were based on the analysis of available material on Finnish townhouses: many written sources on Finnish townhouses mentioned similar dimensions being quite average (e.g. Ullrich 2014, Jalkanen et al. 2012). The New Finnish Dream Home study's example townhouse designs also had similar dimensions.

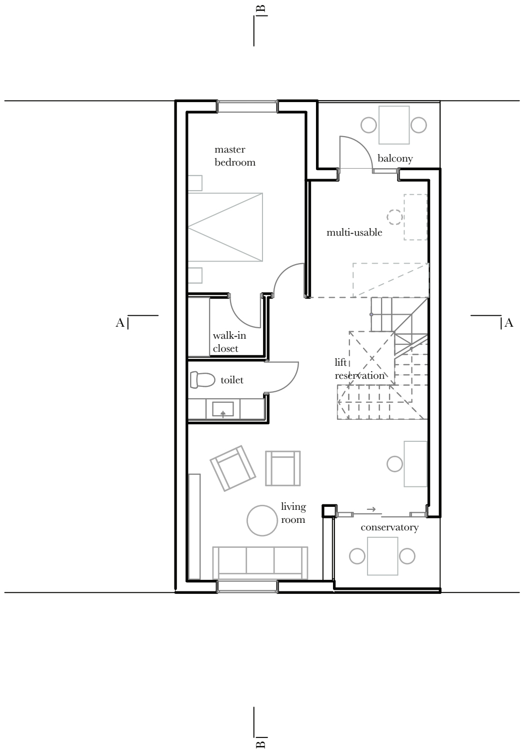
The house has a storey height of 3,0 m and ceiling height of 2,6 m, which is the standard height in today's Finnish housing production. As already mentioned, an exception to this is the front room that could be converted to commercial or office space, which has a ceiling height of 3,0 m. This is achieved by lowering the floor level of the

Section A-A' 1:200

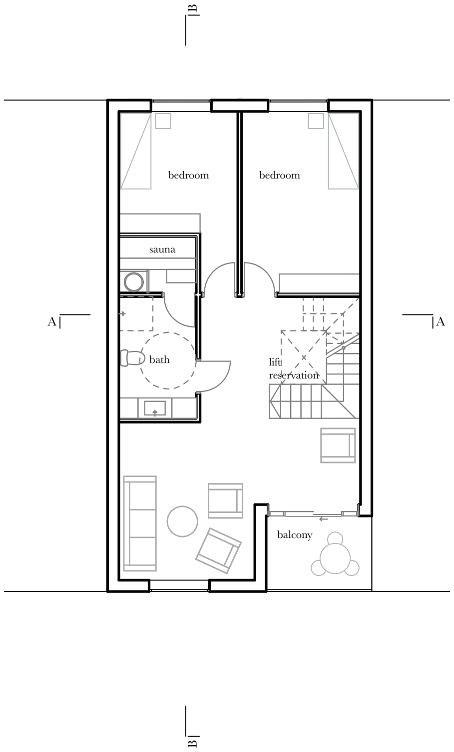




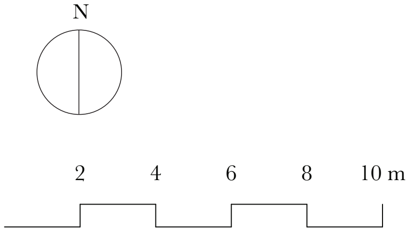
Ground floor 1:200



1st floor 1:200



2nd floor 1:200

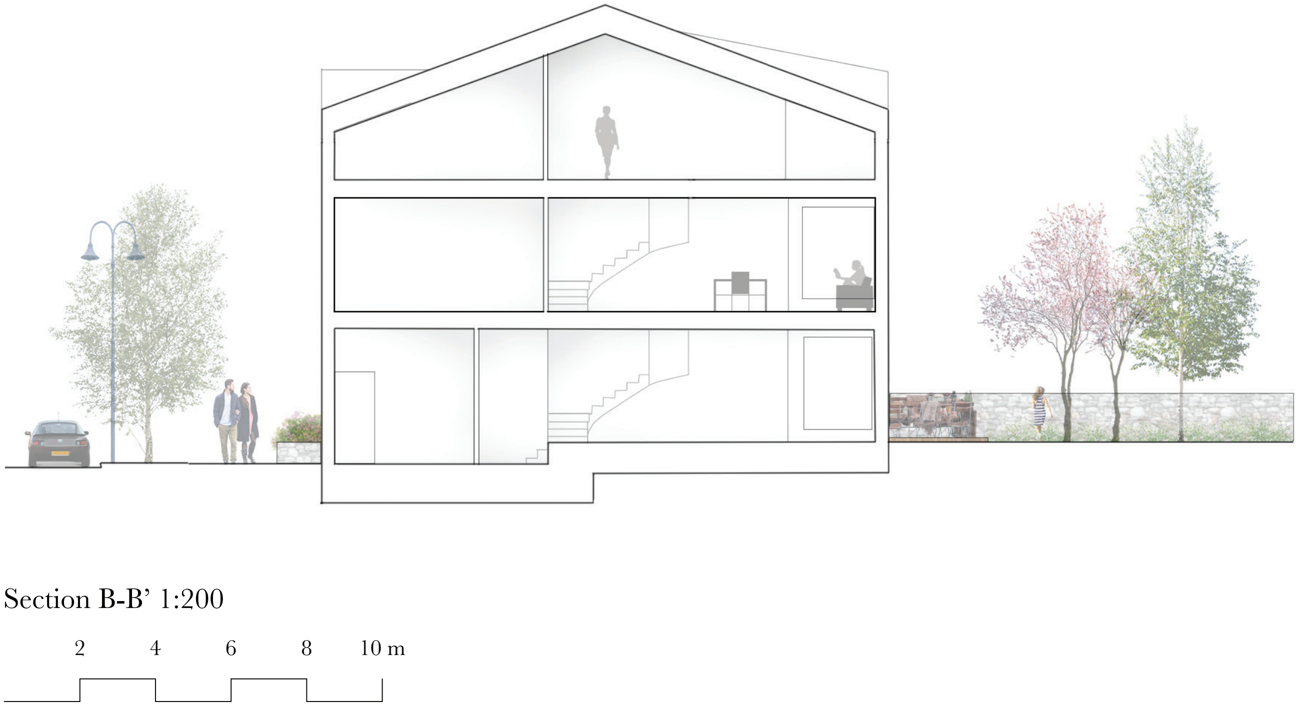


space to the same level as the street, 500 mm below the rest of the ground floor.

The stair and auxiliary spaces are located in the center of the house. The space above the stair is completely open. Adjacent to the stair is a space that serves as a reservation for an elevator. In the starting point model, this space is also open throughout the floors. In one of the experiments, the effect of placing a skylight above this space was tested.

DAYLIGHT ANALYSIS

All daylighting analyses were carried out using a software called Velux Daylight Visualizer. In order to do this, a 3D model was imported to the program. After importing the model, it is possible to choose the correct geographical location. The location used for all of the analyses is Helsinki, Finland (for which the software uses rounded coordinate values of 60° 10’ N, 25° E), primarily because it was the only Finnish location available in the software. It is, however, also the city where a large proportion of the planned or already built Finnish townhouses are located. Because the Finnish climate is mostly cloudy, the CIE Overcast sky was used for all calculations.



Section B-B’ 1:200

The visual material presents the colors used in facades and other surfaces. In the Velux Daylight Visualizer, the materials from an imported model are given a corresponding material in Velux Daylight Visualizer. For all surface materials, it was possible to choose a closely corresponding option with similar color and roughness, the two most important factors for lighting. All interior walls were assigned a white, matte surface, while floors and stairs have a light wooden surface.

A furnishing plan is presented in the material in this appendix, but furnishing was omitted from the daylight analysis, primarily because the focus in this thesis is on the major architectural solutions. Furthermore, including furniture in the analysis would affect the shape of the zones illustrating the areas with a specific daylight factor or illuminance level, and make it harder to distinguish the effects of architectural solutions. Lastly, furnishing solutions are likely to be highly variable depending on the occupant, and often not determined by the architect. Fixed elements, including kitchen cabinets and bathroom fixtures, were included in the daylight analysis model. The kitchen cabinets are white, while the refrigerator and freezer, the oven and the sink have a chrome surface.

Vegetation was also presented in the visual material of the test house in order to give a better idea about what the idea in the design is and what the outcome could actually be like. However, vegetation was also omitted from the daylight calculations, because highly complex objects such as trees would have made the model very heavy and analyses intolerably slow to carry out. What's more, as was the case with furnishing, it is best to keep the model simple in order to focus in on the effects of architectural solutions without too many other confounding factors.

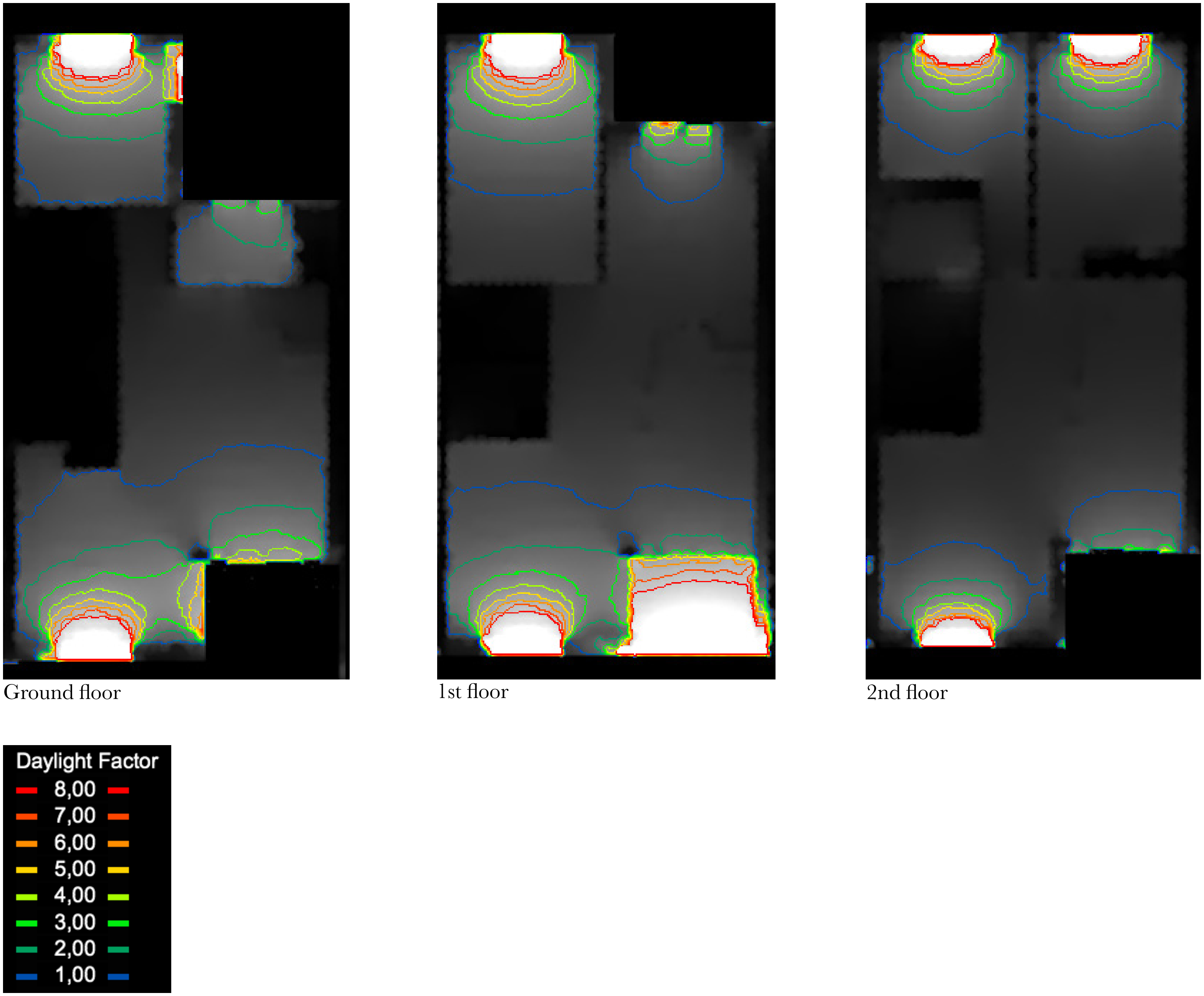
In all analyses the cut height of the plan is 1,0 m above the current floor's level. Unless otherwise stated, the analyses in the experiments are all made for March 21 noon. This is the spring equinox and represents the average daylight conditions between summer and winter. In Velux Daylight Visualizer, daylight factor analysis is only available for 21 March. However, in this appendix, an illuminance analysis of all seasons is included. This covers both the summer and the winter solstice, as well as the spring equinox (which is comparable to fall equinox on 21 September).

As we can see form the illuminance analyses, the variation in daylight conditions between seasons are significant. In the winter, indoor illuminance levels are really low even at noon. During winter months, daylight will not provide much usable light at all.

In the summer, in contrast, daylight is an abundant light source: in large areas, the lux levels reach 250 or more — close to the value of 300, which is correlated with user experience of sufficient lighting. However, as the outdoor illuminances are also very high in the summer, it is likely that the high illuminance values don't fully translate to improved user experience of brightness, as the contrast between outdoor and indoor illuminance remains quite high. In future research, it would be helpful to acquire data about daylight factors throughout the seasons.

DAYLIGHT FACTORS ON 21 MARCH, SPRING EQUINOX

12.00 (NOON)

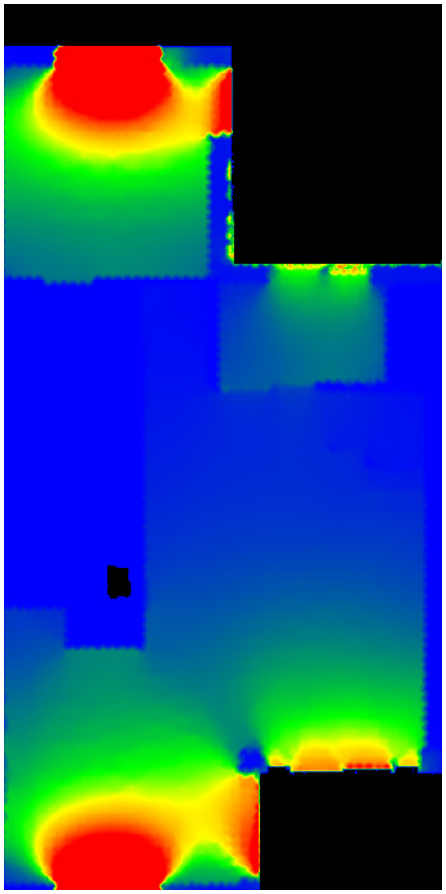


Ground floor

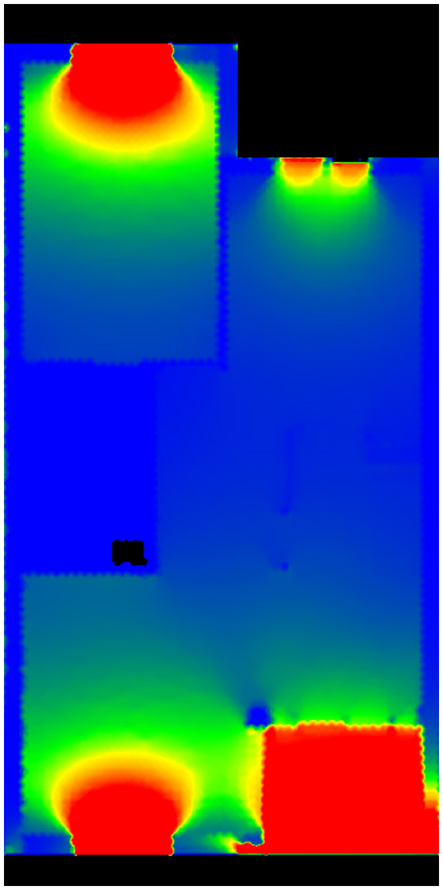
1st floor

2nd floor

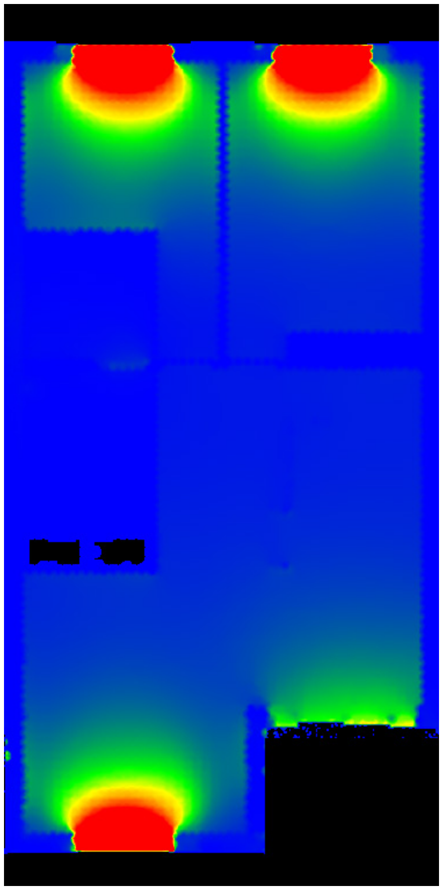
ILLUMINANCES ON 21 JUNE, SUMMER SOLSTICE
12.00 (NOON)



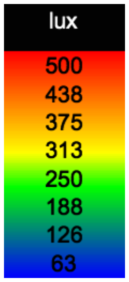
Ground floor



1st floor

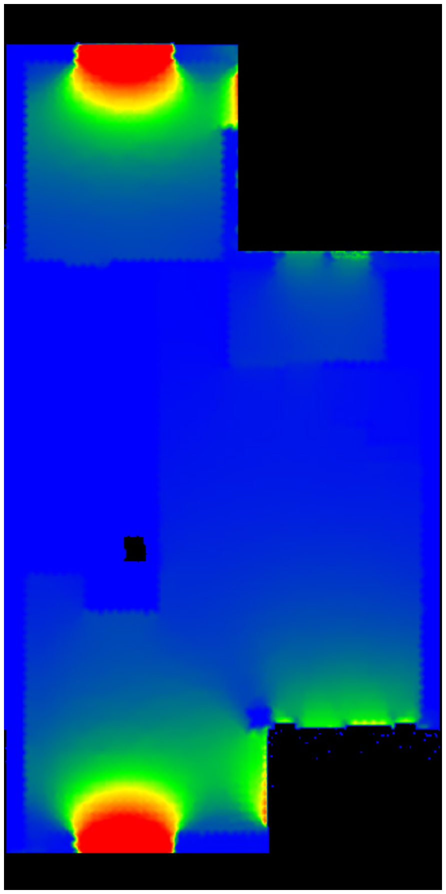


2nd floor

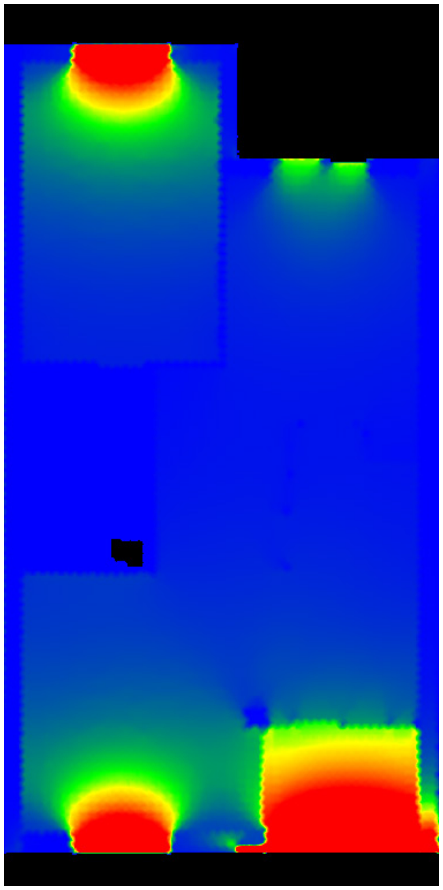


ILLUMINANCES ON 21 MARCH, SPRING EQUINOX

12.00 (NOON)

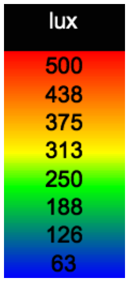


Ground floor



1st floor

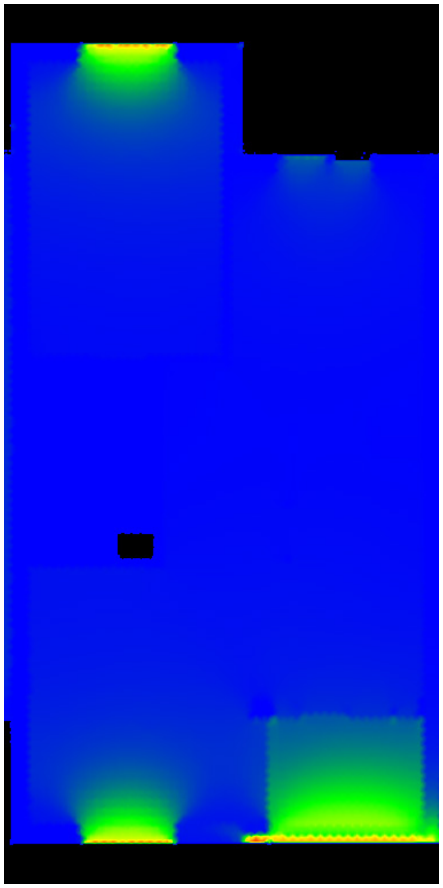
2nd floor



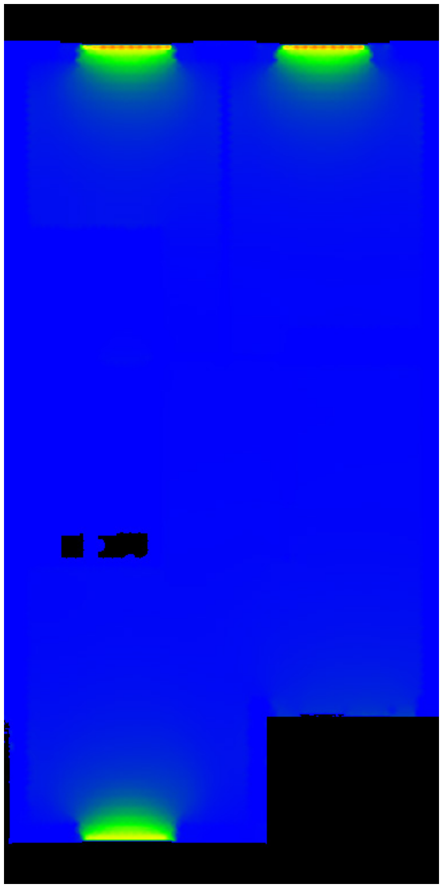
ILLUMINANCES ON 21 DECEMBER, WINTER SOLSTICE

12.00 (NOON)

Ground floor



1st floor



2nd floor