AARHUS SCHOOL OF ARCHITECTURE

Light, Architecture and Health a Method

Carlo Volf, MAA Ph.D.-thesis

Light, Architecture and Health – a Method
Ph.D.-thesis by Carlo Volf

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FOREWORD

This thesis is a contribution to the overall social and health debate of today. A health debate which is often characterized by the medical sciences and the medical profession, but which however, historically, has been an important part of the architectural profession as well.

Close collaboration between medical and architectural disciplines have created several good examples of healthy architecture over the years. Hippocrates, the father of medical art, giving name to the Hippocratic Oath, was actually both a doctor and an architect, healing diseases as well as preventing them. In the eyes of Hippocrates, preventing diseases first of all meant a healthy lifestyle in a healthy physical environment, putting a special emphasis on healthy architecture.

The goal of this thesis is to restore the importance of architecture and light to our general health. By studying the effect of light on the health, the thesis makes suggestions as to how the architecture may provide a better framework for health in the future.

Through this thesis, it has been amazing to see how clearly the faith in light as a preventive and curative agent manifests itself in the architecture, such as in the sanatoriums, e.g. in Alvar Aaltos Paimio Sanatorium. And equally amazing to see how the lack of faith in the restorative aspects of light – and a belief exclusively based on medical and technological treatment – manifests itself, e.g. at The State Hospital in Copenhagen, where the faith is put entirely into the hands of medical and technological treatment, in an era, here described as the antibiotic era, in which better vaccines and better medical responses to various diseases are gaining ground.

However, new knowledge about the effects of light in maintaining a good health, and preventing diseases, is increasingly challenging this point of view. The architecture may, in this respect, help and support the recovery, thus reducing the overall health care costs, and a purely medical treatment may be supplemented with knowledge of architecture and light, and their shared importance to the health and to the general well-being.

In Denmark the health care annually amounts to 8.8 % of a total GDP of approx. 1,384 billion DKK, corresponding to approx. 122 billion DKK. Today these costs mainly pass to curative medical care. However, in this context, the preventive role of architecture should not be underestimated, a role, which is interesting to investigate further. Light and architecture may complement the treatment and the prevention of diseases, in this way reducing the overall costs of health care.

Carlo Volf, Aarhus, June 2013

CREDITS

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I would like to thank my supervisors; Torben Nielsen, Jørgen Dehs and Niels Albertsen. The latter arrived relatively late in the process, however he has been an important and indispensable part of my academic advisory team. Thanks to Rob Marsh. I would like to thank Jennifer Veitch and Guy Newsham at NRC, the National Research Center in Canada, thank you for your hospitality and for your professional contributions to the thesis. Also thanks to Erhan Dikel at NRC. Thanks to the Danish equivalent of NRC, SBI, and to DTU Photonics, it is always inspiring and rewarding to meet deeply professional and engaged lighting people.

Thanks to The State Hospital, to Mogens Thrane and to the many people helping me, providing access to the roof top of the hospital during the unforgettable days and nights, winter and summer with helicopters flying over the light station. Thanks to Jacob Valling and Morten Thing for their contributions to the practical light experiments. Thanks to Keramikbutikken, for making the workshop available to me. Also thanks for several insightful conversations with interested medical people, Hans Christian Wulf, Henrik A. Kolstad, Per Nelleman and Carsten Geisler. I would also like to thank the architects, Henning Larsen Architects and Friis & Moltke Architects for a good cooperation in the application of the method at The New Herlev Hospital, as I would like to thank other interested architects, C. F. Møller, Aarhus Architects and BIG.

Thanks to The Danish Library of Natural and Health Sciences in Copenhagen. Finally, a warm thank you to all my colleagues and fellow PhD students at the Aarhus School of Architecture, thanks for the personal and academic discussions about architecture, joys and sorrows during the course of my work with this thesis.

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SUMMARY

This thesis focuses on the relationship between *light, health* and *architecture*. Light and health is an area which has in recent years undergone major changes and gained increasing attention in the architectural planning. However, it is still a relatively new area, which is why a lot of effort and work is put into defining the different health aspects of light in order to better utilize them in architecture.

Much recent research reveals new beneficial aspects of the light, while other research merely seems to confirm the ideas of a healthy architecture in the early 20th century.

The point of departure of this thesis is based on historical sources. Through a literature study, the thesis unfolds what can be described as *forgotten knowledge*. Subsequently, the thesis reviews recent and evidence-based knowledge on *light and health*. Here, the influence of light on health is conceptualized, also relating the role of architecture to various diseases.

This is followed by field studies of modernist buildings, all based on health aspects. The original intentions are described and subsequently evaluated with contemporary eyes based on the knowledge obtained through the literature study.

The overall lesson to be learned, is that a strategy of unilateral exposure to sunlight often fails, simply because it over-emphasizes the sunlight. Instead a balance between *exposure to* sunlight and *protection from* sunlight is suggested.

This balance is investigated through two practical light experiments. In the first experiment glass is examined, seen from a health perspective. Here the thesis presents a new concept, *the unhealthiness factor* of glass. The second experiment seeks to find a balance between exposure to and protection from the sun, based on studies of the geographical orientation, the weather and the circadian rhythm during the day and year. This is done through a setup of eight scale models in controlled test and control trials comparing and representing *differences in light* over time and place.

For this purpose the thesis develops a new method of representation, *simultaneous-time-lapse-photography*, depicting differences in light over time and space, according to E, S, W and N, also depicting the differences in the light respectively at summer solstice, equinox and winter solstice.

Based on the light experiments, the thesis introduces an overall architectural strategy for healthier light in buildings, a strategy which responds to the asymmetrical light of the sun. It does this by, in itself, being asymmetrical.

Thereby the thesis restores the importance of the geographical orientation, that is, the aspect of morning sun, evening sun, summer sun and winter sun and the fundamental importance of light for temporality, place and body.

The thesis emphasizes the importance of two factors, when we talk about light, architecture and health, namely the differences in light during the day and the clear, low-iron glass. Two factors, which in a healthy and sustainable architecture seem to go hand in hand.

In the thesis, a new method to better cater for a healthier planning of light in the architecture is developed. A method which can complement existing methods, such as the daylight factor, its greatest weakness being that it overlooks both time and place, only working from the concept of *a cloudy sky*.

The conclusion of the dissertation is that it is possible to plan a healthier daylight – if the architecture is planned deliberately both according to E, S, W and N, and according to the circadian rhythm of the body. Architecturally, this is suggested done by differentiating the architecture according to the asymmetrical light of the sun. Be it in the form of an asymmetric planning of building forms, facades, apertures or artificial lighting.

0 INTRODUCTION: FROM HELIOTHERAPY TO HELIOPHOBIA

0. INTRODUCTION: FROM HELIOTHERAPY TO HELIOPHOBIA

Our relationship to the sun in many ways is a very complex and contradictory relationship. On the one hand, we consider the sunlight a prerequisite for our general well-being and our very existence on earth. On the other hand, we fear the rays of the sun and lubricate ourselves and our children in protective sunscreen. A paradox not made less by the fact that, as we expose ourselves less to the rays of the sun and spend more time inside[1], we actually concern ourselves more with protection against the rays from the sun.

In recent years, an increased awareness of the advantages of utilizing and optimizing the daylight in buildings, and daylight has become an important factor in the effort to create a more sustainable architecture. However, in these efforts to optimize daylight and achieve high daylight factors, there often seems to be a discrepancy between energy and health related factors. More daylight does not necessarily mean better health. It depends on several factors, such as time and place. Healthwise, light in the morning is not the same as light in the evening, and there is a body of evidence suggesting, that instead of *optimizing* the daylight, it is about *balancing* the daylight, balancing light and darkness during the day and the night. Therefore, this dissertation complements the daylight factor by studying the light of the sun and the geographical orientation, together with the Danish weather, in an effort to create a more sustainable method which better takes into account the health aspects of light.

The thesis is divided into two parts: a *theoretical part* and a *practical part*. The theoretical part starts with a clarification of the concept *light and health,* as well as a clarification of the historical role, which light has played as a health agent in the treatment and the prevention of several diseases. Changes in knowledge and behavior are put into perspective, changes which evoke different requirements both for the physical environment and for the architecture through the past centuries.

The next section, *light and disease*, is more specific about the diseases challenging us today. Challenges, which may not only be solved medically, but also by using light as a non-medical form of treatment.

In the section *architecture and health*, various diseases are described, as well as their subsequent influence on a healthier architecture through the 19th and 20th centuries. An architecture, further elaborated through historical examples from the UK and Scandinavia, each followed up until today to draw

1 Gunnarsen L, Afshari A. *Sundhedseffekter af partikelforurening i indeluften*. According to Danish Building Research Institute, in DK approx. 90% of our time is spent in the indoor environment. SBI, 2009.

an outline of how a healthier architecture may look in the future. An outline, which calls for a break with *the symmetry of daylight*, and a showdown with the concept of *a cloudy sky*. As well as a showdown with the daylight factor, which does not take into account the direct light of the sun.

Larger context of the thesis

Today, Denmark is investing 40 billion DKK in new and larger hospitals. In the planning of these hospitals, the Medical Council came up with a wish list, and on this list the following wish is notable:

A good environment with natural light and noise reduction reduces the risk of errors and benefits the health of the patients. This basic fact should inspire the design of hospitals when it comes to the architecture[2].

Natural light is hence recognized as an important prerequisite for a better working environment and better health, which is not completely random, since light, and the impact of light on a variety of diseases, in recent years has been scientifically identified.

However, at the same time, the Danish Climate Commission is expecting Denmark to become independent of fossil fuels by 2050, meaning, that in the course of 2020, the ever-increasing energy consumption is, for the first time ever, expected to decrease significantly. An energy consumption which today accounts for 80% of the total energy spent in the estimated lifetime of a building. In this context, daylight becomes an important factor in the zero-energy strategy and glass architecture becomes a key concept in the efforts to reduce the energy consumption for artificial lighting. From an energy point of view, it is assumed, that increased *daylight factors*[3] may reduce the energy consumption, while also creating a better and a healthier indoor environment.

In this context, glass is often considered a "quick fix", providing both a healthy and a sustainable architecture. Therefore more and more glass architecture is build today. The fascination of glass as a building block is reinforced by the fact, that glass is not only becoming cheaper to manufacture, but also to maintain. Glass is no longer a weak point in the envelope of the building, as both solar gain (G-value) and heat loss (U-value) can be controlled by the means of solar protective glass and insulating glass units, such as thermal glazing and vacuum glazing.

2 Ugeskrift for Læger 2012;174(26):1791.

3 Johnsen K, Christoffersen J. *Dagslys i rum og bygninger.* SBI 219, p. 51. 2008. The daylight factor tells how much light there is indoors, compared to outdors, when measured under a cloudy sky. E.g. 200 lux, measured at 10.000 lux outside, equals a Df of 2%.

Against this background, it is no coincidence that glass constitutes a large part of the building facades today – in Denmark it is estimated, that there are approx. 3.5 million buildings, using a total of approx. 60 million m^2 glass. Technologically and energywise, this development has brought great progress. However, this development may prove to be less fortunate light and health-wise. Today, a very close correlation between light and energy exists, and with glass as an improved building-envelope, and highly insulated buildings, overheating from the sun quickly becomes a problem when the glass area is simultaneously increased. In this way, requirements for more daylight often mean that we have to protect ourselves against the sunlight and the heat loss in another way, using high-tech processes, such as coated glass and solar protective glass, all of which reduce the quality of the natural daylight.

So, to return to the wish list, if we want natural daylight in the architecture, we can´t base the architecture on glass alone, just as we may have to recognize that the fascination of glass can no longer be the same as it was in the early Modernism – in the 1920s – simply because the glass is no longer the same.

Last but not least, there is another important reason to break with Modernism´s mantra of light and openness. Seen from a health perspective, scientific evidence[4] suggests that light in itself may not be only healthy and that more light does not equal more well-being. Apparently light is only half of the story, and more and more research seems to document that *both* light *and* darkness has a positive impact on the health. Instead we may consider light and darkness as something cyclical – as factors which support the body and its cyclic rhythm differently during the day, from concentration to recreation, from activity to rest. All in all, good lighting seems to be a more complex – and important – ingredient in the concept *healing architecture*.

During the planning of the new hospitals in Denmark, *Healing Architecture*[5] was published, summarizing evidence-based knowledge of the physical framework and its influence on our well-being at hospitals, from various parts of the world during the period from 1958 to 2008. In this publication light is the factor which, overall, reaps most recognition, and several studies[6] show that daylight and windows are the elements most frequently mentioned, when it comes to human well-being at hospitals. Light also seems to have a positive effect on several health conditions such as; pain, the circadian rhythm, stress, depression, length of hospitalization, mood and satisfaction.

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4 Lockley Steven W, Foster Russel G. *Sleep – a very short introduction.* Oxford University Press, 2012.
5 Frandsen AK, et al. SBI. 2009.
6 Shepley MM. *Predesign and postoccupancy analysis of staff behavior in a neonatal intensive care unit.* Children's Health Care, 2002; Lawson B, Phiri M. *The architectural healthcare environment and its effect on patient health outcomes.*NHS Estates, 2003; Leather P, Beale D, Santos A, Watts J, Lee L. *Outcomes of environmental appraisal of different hospital waiting areas.* Environment & Behavior, 2003; Macnaughton J, Collins P, Coleman S, Kellett P, Purves G, Suokas A, et al. *Designing for health: Architecture, art and design at The James Cook University Hospital.* Department of Health, 2005; Mroczek, Mikitarian, Vieria & Rotrius. *Hospital design and staff perceptions.* The Health Care Manager, 24(3) 233, 2005.

Other studies[7] show that the orientation towards the four cardinal points N, S, E and W, is of importance at hospitals. The geographical orientation determines where and when the sunlight enters a building, and *where* and *when* it is prevented from entering a building, just as the geographical orientation affects the light in the morning and the darkness in the evening, which again, according to studies[8], seem to be important for the quality of sleep and the overall health at hospitals[9].

But how do we obtain a healthier balance between light and darkness? And how do we plan the light and the architecture in a healthier way, according to the geographical orientation? These are basic and complex questions, which this thesis seeks to answer by studying the geographical orientation and its importance to both light and health.

Research questions

The thesis is based on the assumption that we thrive in natural daylight. An assumption which is, moreover, justified through light experiments and literature studies. By making this basic assumption, the thesis develops a new method in the planning of a healthier light in architecture. The overall research questions are:

How does light support the general health?

How can a healthier light be planned architecturally?

The research project is based on the natural daylight[10] and seeks to create a method for planning both the daylight and the artificial lighting, taking into account evidence-based knowledge about light and health. By taking its starting point in the direct sunlight and the geographical orientation, the thesis seeks to develop a new method which better meets health concerns.

Today, light is often *added* to the architecture, in the form of measureable lux and daylight factors, and instead of *being part of* the architectural form[11], light is often dislocated. As a result, both daylight and artificial lighting is often reduced to a matter of planning the light, so that there is enough lux.

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7 Beauchemin KM, Hays P. *Sunny hospital rooms expedite recovery from severe and refractory depressions*. J. Affect Disord. 1996 Sep 9;40(1-2):49-51; Latham Jackson JM. *Morning versus Evening Light Treatment of Patients With Winter Depression*. Journal of American Medical Association, 1998; Benedetti F, Colombo C, Barbini B, Campori E, Smeraldi E. *Morning sunlight reduces length of hospitalization in bipolar depression*. J. Affect Disord. 2001 Feb;62(3):221-3.

8 Cureton-Lane & Fontaine. *Sleep in the pediatric intensive care unit: an empirical investigation*. American Journal of Critical Care, 1997; Vinzio, Ruellan, Perrin, Schlienger & Goichot. *Actigraphic assessment of the circadian rest–activity rhythm in elderly patients hospitalized in an acute care unit. Psychiatry and Clinical Neurosciences,* 2003.

9 Slevin, Farrington, Duffy, Daly, Murphy. *Altering the Intensive Care Unit and measuring infants responses*. 2000.

10 Corresponding to the light, achieved through the clear, low-iron glass, such as *diamond glass.*

11 Steemers K, Steane MA. *Environmental diversity in architecture*. Kapitel 11. Routledge, 2004.

In this respect, an additional research question is:

Can the artificial lighting – and the interplay between natural and artificial lighting – be enhanced and better integrated in the architecture?

This issue is dealt with at the end of the thesis, referring to the practical light experiments, where artificial lighting is introduced for the first time.

Definition of the problem area

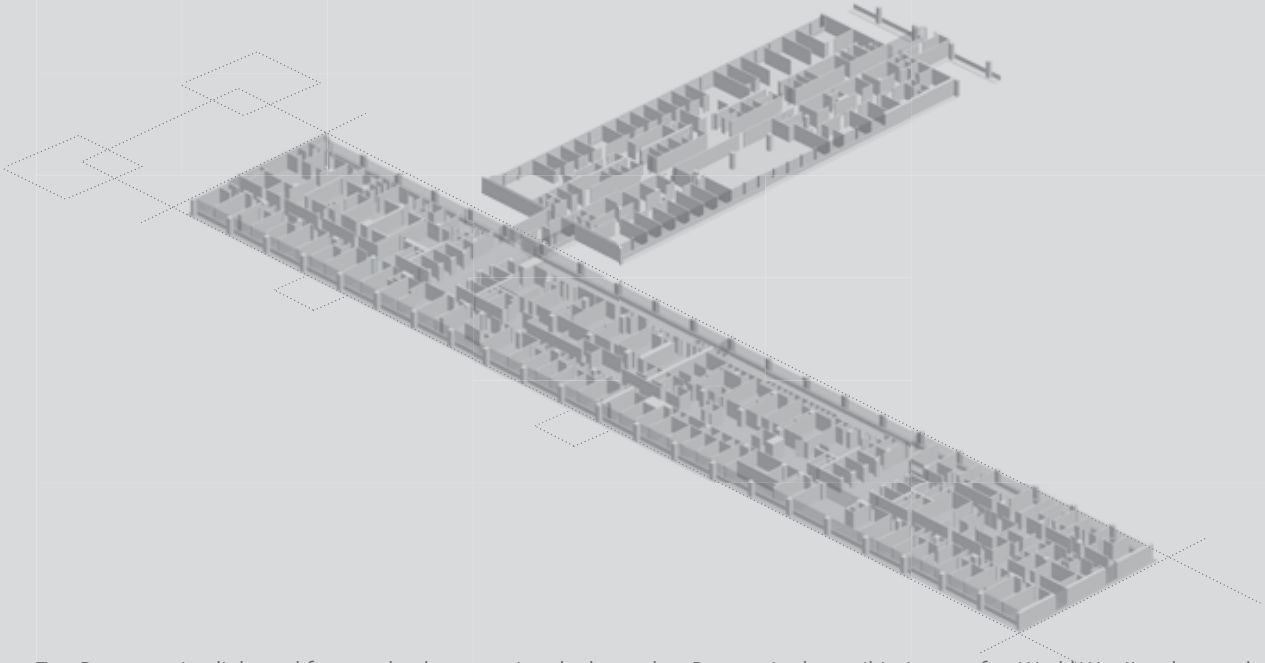
The thesis deals with health, as it relates directly to light; partly focusing on how light affects us *mentally*, partly on how light affects us *physiologically*. The concept of health is seen as a broad concept, a concept which relates to the general well-being and the general health, not only within a narrow context – be it medical, sociological or physiological – but in a wider context. The aim of this project is not to put health and light on a specific formula, but rather to accommodate variations and differences over time and place – in the form of differences in light.

The thesis considers light as a regional phenomenon and all the light experiments are based in Denmark. This is done in the recognition of the fact that both the nature and the daily and annual cycles of the daylight are very different from region to region. In Denmark, the light is characterized by the long transitions between day and night and the large seasonal differences. Conditions, which are very different from areas closer to the equator, where shorter transitions between day and night and smaller seasonal variations are characteristic features.

The project only deals with light in the indoor environment. Energy-saving and technical measures are not addressed in this thesis, and technology is only considered to the extent that it is relevant for the understanding of the interplay between daylight and artificial lighting. This does not mean that this is not a relevant feature in a broader context, and the thesis suggests further research be done in this field in the future.

The dissertation is broadly aimed at architects, doctors, engineers and planners of construction, working under *Danish lighting conditions*[12]. The method can be used in all phases of the construction, however it will be appropriate to implement it early on in the construction phase, preferably in the pre-project phase, to implement the method as efficiently as possible.

12 Nb. This not only includes latitude, but also the climatic weather conditions in Denmark.



Top: By separating light and form and only measuring the lux and daylight factors – without taking into account the light of the sun and the geographical orientation – we neither create a healthier nor a more sustainable light. Instead, we may look at the nature and the structure of the surroundings when planning the light, and base it on how the light is perceived, as shown here, in an earlier research project at The State Hospital. Here, the artificial lighting is based on how the daylight is perceived during the day – and not on the measurable light. ("Computer- and daylight controlled lighting at hospitals", www.godtsygehusbyggeri.dk, Carlo Volf MAA, Realdania Fonden and Sophus Fonden 2009)

Bottom: In the antibiotic era, after World War II and up to the present day, hospitals become larger and more compact. Formerly scattered pavilion-buildings are replaced by denser and taller building structures, based on more functionalist principles, such as minimizing the distances, through the use of double-corridors as shown here. Cheaper electricity results in artificial lighting often replacing the natural light in deeper and more low-ceilinged multi-storey buildings. Finally, more Euclidean forms become common – forms which do not utilize the sunshine as well as the earlier building typologies, without solariums or corner-rooms (dotted lines, here The State Hospital)

Methodology

Methodically, this dissertation has an interdisciplinary approach, where the problem area; *light, architecture and health* is unfolded from different angles.

Through *literature studies*, based on historical sources, the dissertation outlines what can be termed forgotten knowledge. This is followed up by more recent evidence-based knowledge about light and health.

The literature studies are subsequently followed by *field studies* of modernist buildings, all built and based on health intentions. The original intentions and strategies are identified and later evaluated, based on the collected empirical data and knowledge obtained in the literature study. Finally, *the practical light experiments*[13] explore and operationalize the obtained knowledge in practice, describing a new method.

The literature studies are conducted at The Danish Natural and Health Sciences Library (DNLB), which is part of The Royal Library in Copenhagen. Through access to scientific databases, knowledge has been gained, primarily from the database *Public Medicine*, also called PubMed. PubMed is an international database which collects medical publications from approx. 4,000 medical journals, dating back to 1966 and the scope knowledge has been gathered from a broad literature search in the area *light and health*.

Overall, the literature studies conceptualize *light and health*, its scientific background and its significance to *light* and *architecture* through the 19th and 20th centuries.

The field studies are conducted in the period 2010 - 2012 and include the following buildings, distributed around 55° N. latitude in this manner.

51°48'N, 0°05'W; The Peckham Health Centre in London
51°52'N, 0°09'W; The Finsbury Health Centre in London
55°66'N, 12°60'W; Skolen ved Sundet in Copenhagen
60°45'N, 22°69'W; The Paimio Sanatorium in Paimio

The Paimio Sanatorium in Finland is described through a field study conducted in June 2010. Here a former nurse at the sanatorium guides me through the sanatorium, and reveals the historical aspects and the health aspects of the building, providing access to the entire sanatorium. I visit the two English sanatoriums in May 2012, here I only get limited access to the buildings, later supplementing with other sources in the depiction of these sanatoriums. The Finsbury Health Centre still operates as a health center today, while The Peck-

13 Carried out at summer solstice 2012, equinox 2012, winter solstice 2012, and at equinox 2013.

ham Health Centre now is converted into private dwellings. I visit Skolen ved Sundet in June 2012, prior to the summer holidays. The school is empty and I get a guided tour around the premises, learning about the historical conditions and the original intentions of the architecture.

The practical light experiments are carried out June 2011 - March 2013, and consist of two experiments. First an experiment examining the glass and the effect of glass upon light and health and second an experiment describing the differences in the light relative to the time of day and year, depending on the geographical orientation and the architecture. The latter experiment is based on 8 scale rooms, mounted on the rooftop of The State Hospital in Copenhagen. All 8 rooms are photographed in controlled trials.

For this purpose the thesis develops a new method of representation called *simultaneous-time-lapse-photography,* photographing the different rooms in *the same* light. This method is, like the light experiments, based on the scientific method *similar conditions*.

The practical light experiments take place at the hospital ward[14] and unfold the new method in practice, through concrete examples in the form of test rooms, suggesting how to create a healthier light in the architecture.

The practical light studies are based on an overall strategy, where the orientation relative to the compass, the sunlight and the hours of sunshine, combined with evidence-based knowledge about health, determine the architecture.

The hospital ward is chosen, because many lessons about light and health historically stem from the hospital world. Here, light has traditionally played an important role in the healing process.

Another reason is the hope and the intention that future hospitals of Denmark will benefit from this thesis. An intention, which has indeed already been realized, since the method has been put into practice, forming the basis of the light and the architecture at *The New Herlev Hospital*, 2012-2017, designed by Henning Larsen Architects and Friis & Moltke Architects.

However, the thesis is not called *light, hospital architecture and health*, it only uses the hospital as an exemplary case, to clarify and illuminate the different health aspects of light and architecture, and it is the intention that the method can be used broadly and on different scales in architecture.

14 *The good ward,* published by Vejle County, January 2003.

1 LIGHT AND HEALTH

1. LIGHT AND HEALTH

Through time, sunlight has played a central role to health. Cities[15] and buildings are planned on the basis of the sun. Particularly the winter sun, which – based on experience – is considered important to the health during the cold and dark winter months. The concept of *winter east*[16], in this context, is quite essential. Being the point on the horizon where the sun rises in the far south, towards which, the facades should preferably be orientated without too much deviation. This, based on health considerations, primarily, because of two empirical observations, of such architects as e.g. *Vitruvius*[17]. One is that the early rays of the morning sun warm up the winter cold facades, whereby moisture and diseases can be avoided. The second is that the morning sun is generally milder and therefore considered healthier than the warm, more dangerous, afternoon sun, which conversely requires protection.

The physical surroundings are fundamental to health, and prevention often ranks higher than curing – simply because one is badly off once the disease strikes.

The doctor and architect *Hippocrates*[18] in detail describes the physical environment and its effects on the health. He warns against the double-edged sword of the sun and pleads for moderation and balance, as he warns against what we today know as sunstroke, or excessive exposure to sunlight, while at the same time recommending sunlight as a healing and preventative agent against a variety of diseases[19].

Since then, the concept of light and health has assumed different forms and meanings, and our relationship to the sun – like our behavior – has changed. Prevention of diseases is gradually supplemented and replaced by more therapeutic treatment and medical healing. Also our behavior is changing, from being exposed to sunlight most of the day, during the agrarian economy, to the industrialized work of today, which predominantly takes place in an indoor environment, protected from the light of the sun.

It is characteristic that the concept of light and health gains more significance as we enter the 20th century. At this time we no longer spend so much time outside, no longer being exposed to the sunlight in the same way as earlier, upsetting the balance that Hippocrates described, in favor of the darkness, often related to the densely populated industrial cities in the early era of the industrialization. Here, a more unilateral and more fanatical worship of the sun begins to take

15 Richard Hobday. *The light Revolution - Health. Architecture and the Sun*, p. 86. Findhorn Press, 2006.
16 Nb. Corresponding to a. 135° SØ at 56. latitude.
17 Vitruvius. *In De Architectura*. Book 6, chapter 1, p.170, book 9, chapter 7, p.270. Dover Publications 1960. Vitruvius describes the seasonal changes and how the sun can be planned in architecture.
18 A Greek doctor, born on Kos (460-370 B.C.) Source: The Great Danish, Gyldendals Open Encyclopedia, 2013.
19 Carter S. *Rise and shine – Sunlight, Technology and Health*, p. 58. Berg, 2007.

place. This happens partly because life in the cities neither offers outdoor work or sun, and partly – and perhaps in particularly – because new scientific breakthroughs on light and its effect on bacteria and diseases begin to challenge our way of thinking. Both factors influence Modernism, having implications on the architecture up until this very day.

A proper scientific awareness of the effect of light on health starts in the mid-1800s, and is partly due to the discovery of new and better optical instruments. In this context, Joseph Jackson Lister and his son Joseph Lister[20] from Glasgow, play an important role with their discoveries. The technical inventions and optical improvements of the father, in the 1830s, subsequently allow the son to study microorganisms under conditions not previously seen. Joseph Lister's studies lead to the discovery of the bacteria[21] and Joseph Lister becomes one of the pioneers in the new emerging science, bacteriology, a science which gradually replaces the otherwise prevailing *miasma theory*.

The miasma theory takes its name from the Latin term for foul air and is a general term including many theories about the connection between smell and disease. It is a relationship based on primary sensations, such as bad smell. Smell is, unlike bacteria, easy to observe and bad odors are therefore regarded as synonymous with disease. The miasma theory even suggests that bacteria may arise out of nowhere by so-called *spontaneous genesis*[22]. In the absence of any better explanation, this theory, in various forms, becomes the common perception for many decades. Through simple observations it is ascertained how diseases, such as *plague* and *cholera*, break out and spread in the immediate vicinity of foul air – which is therefore considered the primary source of the diseases.

It becomes the task of *Louis Pasteur* (1822-1895) to debunk the whole idea that bacteria occur spontaneously, and out of nowhere, in bad air. In one of his famous experiments[23] Pasteur, through a simple process[24], disproves that life can occur by itself, as he so to speak, keeps life from occurring.

I wait and I observe, I ask it, request it to initiate a creative process for me, it would be a beautiful scenery! However, it is disheartening![25]

The identification of bacteria in the 1870s and 1880s establishes a new relationship to health and disease, a relationship, which quickly expands also to include light. This happens in 1877, when the British scientists *Downes* and *Blunt*

20 K. Jensen. *Bekæmpelse af infektionssygdomme,* p. 12. Nyt Nordisk Forlag Arnold Busck, 2002. Joseph Lister, the founder of antiseptics in 1887.
21 Joseph Lister discovers that sepsis (bacteria) can be caused by a pollen-like dust, in doing so he helps to end the otherwise widespread miasma theory. Source: Encyclopedia Britannica, 2013.
22 Spontaneous emergence of organisms from non-living things include stories about mice that arise from old rags, blowfly of rotten meat and eel of mud. Among others, made by Aristotle. Source: The Great Danish, Gyldendals Open Encyclopedia, 2013.
23 By sterilizing a bottle of milk in an airtight bottle.
24 Schmidt Lars-Henrik, Steffensen Jens Erik. *Lys, luft og renlighed,* p.67. Akademisk Forlag (1986) 2004. By sterilizing, or pasteurizing, milk by brief heating to approx. 90 ° C and placing it in an airtight container in 1867.
25 Ibid. p.67.

demonstrate how sunlight can kill and inhibit the development of these newly discovered bacteria. By placing bacteria in different environments, respectively in *direct sunlight, indirect sunlight* and *darkness*, they observe, through the new and improved microscopes, how the bacteria only thrive in the darkness, deprived of the direct and energetic, ultraviolet light. In a modern, scientific way, they work with controlled trials consisting of test and control groups.

In another experiment[26] they affix four sealed glass tubes with Pasteur's solution, a solution consisting of sugar, water and ammonia, in a SE-facing window exposed to sunlight. In the control group they place four identically sealed glass tubes with the same solution, but protected from the sunlight, completely covered by thin sheets of lead. All the covered glass tubes show full bacterial growth after approx. one month, while none of the glass tubes, exposed to the UV light of the sun show any signs of bacteria. Downes and Blunt hereby scientifically demonstrate that sunlight works antiseptically and is deadly to bacteria, also through glass – that is clear, low-iron, laboratory glassware.

The UV pioneers Downes and Blunt and their discoveries of the effects of light on bacteria subsequent play a central role in the treatment of several diseases. Only a few years later the first scientific evidence of the positive effects of sunlight in the treatment of diseases arrives. Namely in the fight against the disease *tuberculosis*[27], which is actually caused by precisely bacteria.

In humble surroundings Niels Ryberg Finsen (1860-1904) starts his groundbreaking experiments, using light therapy in the treatment of the disease *Lupus Vulgaris*. Lupus vulgaris is a malignant skin tuberculosis, which often disfigures the face of the patient right under the skin, where the bacteria live. In his famous article of 1896 *Treatment of Lupus with concentrated chemical light*[28], Finsen describes how the UV light penetrates the skin and kills the bacteria. However, Finsen never succeeds to provide any medical explanation as to why his trials – which are often based on simple observations and studies – work, but they do, and Finsen in this way cures the disease without the otherwise often violent forms of surgery, common at this time. According to Finsen, it is the UV-light, or *the chemical light*, which is the cause, and Finsen uses both the UV-light of the sun and artificial lighting containing UV light – respectively called *heliotherapy* and *actinotherapy* – in his light treatments, for which he receives the 1903 Nobel Prize in Physiology and Medicine.

As described, Finsen´s attempts start rather modestly, in a small wooden shed behind the Copenhagen Municipality Hospital in 1893, at the Department of Anatomy[29]. This is quite telling about the general medical profession and its skepticism to his alternative light therapy treatment of skin tuberculosis. But within a few years Finsen puts the treatment in system and in 1896 he succeeds

26 Hobday R. *The healing Sun*, p. 91. Findhorn Press, 1999.
27 K. Jensen. *Bekæmpelse af infektionssygdomme*, p. 13. Nyt Nordisk Forlag Arnold Busck, 2002. Robert Koch identifies and isolates tuberculosis bacterium in 1882, and cholera bacterium in 1883.
28 Richard Hobday. *The light Revolution - Health. Architecture and the Sun*, p. 78. Findhorn Press, 2006.
29 Source: Niels Ryberg Finsen. The Great Danish Encyclopedia, 2013.

to establish *The Finsen Medical Light Institute*[30]. Amongst others, with the help of the rich patron Gustav A. Hagemann, who incidentally, a few years later, in 1900, becomes the driving force in one of the first sanatoriums in Denmark, *The Vejle Fjord Sanatorium,* where Finsen also treats patients using light therapy[31].

Although Finsen dies young, in 1904, only 44 years old, his pioneering work has great influence on other physicians and their work with light. Abroad, the new knowledge about the effects of light on health is recognized and practiced by e.g. the doctor *Auguste Rollier*[32], who uses heliotherapy at his clinics in Switzerland. Here, he doses light very carefully according to the patient's susceptibility to light. The exposure to UV light varies depending on the season; up to four hours per day in the wintertime and up to two hours in the summertime[33]. First legs and arms are exposed and then, gradually, also the torso and other more vulnerable parts of the body. The morning sun is considered more beneficial, because it does not contain as much UV light as the noon sun. The results are published scientifically[34], in particular demonstrating the different skin-types and their susceptibility to light. Also for Rollier, health is about creating a balance between *exposure to* and *protection from* the sun, although displaced from Hippocrates in favor of a more unilateral exposure to the sun, even a worship of the sun. Just like the Romans, Rollier plans his buildings towards the morning sun, to balance the exposure of the sunlight throughout the day and throughout the year.

However, the UV light not only proves to be beneficial in the treatment of diseases, it also turns out to be important as a health-supportive factor. In 1890, *Theobald A. Palm*[35] discovers that the disease *rickets* mainly occurs at northern latitudes – that is, where there is less UV light from the sun – while the disease is virtually non-existent further south, such as in Japan, where the sunlight is more prevalent. Based on his empirical studies, but without knowing why, Palm concludes that the sunlight has a direct, beneficial effect on the prevention of the disease, supporting the health.

However, at this point it is hard to imagine that any lack of sunlight, in itself, can form a health hazard and cause illness. Just like the term *deficiency disease* does not exist at this time. Only with the discovery of vitamin D and its importance for the ability to obtain and convert calcium in the body, the cause of rickets is recognized – and thus directly related to the lack of sunlight.

These UV pioneers draw a picture of the double nature of the sun; on the one hand, the sunlight has a lethal effect on bacteria; on the other hand, the sunlight seems to have a life-giving power due to the fact that our bodies have adapted to

30 Source: Gustav Adolph Hagemann. The Great Danish Encyclopedia, 2013.
31 From 1902. The treatments done especially through actinoterapi (artificial lighting), as the patients primarily receive heliotherapy at the sanatorium. Source: Niels Ryberg Finsen, The Great Danish Encyclopedia, 2013.
32 Hobday R. *The Healing Sun,* p. 104. Findhorn Press, 1999.
33 Ibid. p. 105.
34 La Cure du Soleil, 1914.
35 Carter S. *Rise and Shine – Sunlight, Technology and Health*, p. 41. Berg, 2007. Palm Theobald A. *The Geographical Distribution and Aetiology of Rickets.* The Practitioner 45, 270-272 ref.

the sunlight, using light to absorb and form substances, which the body would not otherwise be able to form itself. That the light of the sun, in this period, achieves a special status, is due to the discoveries of these UV pioneers.

However, there is also another reason why heliotherapy and the worship of the sunlight is gaining ground at this time. The belief in medical treatment is in a crisis[36]; for decades, diseases, such as tuberculosis, kill thousands and epidemic diseases are ravaging the large and often densely populated cities, without the doctors being able to prevent it or do anything about it.

Modern medical science is here, at the beginning of the 20th century, still in its infancy as a scientific practice. Despite the fact that more scientific knowledge is gaining ground, it still fails to celebrate any medical triumphs. Although the miasma theory, and the belief that bad smell and foul air in itself creates diseases, has been replaced by scientific knowledge about bacteria and bacteriology, people still die like flies without receiving any proper medical treatment. That light is recognized as an integral part of the treatment against diseases and in the maintenance of good health, should also be seen in this light.

Light almost becomes a weapon in the hands of the dawning hygiene movements around the 1900s and onwards to the 1930s, especially in the cities, where darkness and diseases belong to the everyday order. Based on the new, scientific knowledge of light and the impact of light on the body, an actual dosage of light is introduced, both as an antiseptic and a medical element.

On bacteria a hunt is launched; the little guy should be banished and destroyed for otherwise all is lost. As if one could save men thus, and as if not bacteria have their own raison d'etre as well as man[37].

It is ingrained in healthy Mortals two love light (...) the darkness of the tomb is synonymous with complete cessation of response, with death (...) terrestrial life craves the golden rays. They are the world's tonic which stimulate and enliven[38].

In this fight against diseases, a new kind of strategy is launched, namely to reduce the likelihood of becoming infected. Since bacteria can´t be seen with the naked eye, the fight against the diseases instead happens by preventing the disease through cleanliness and good hygiene, isolating and eliminating the source causing the disease. A strategy, which later proves to have great influence on the architecture, and on our understanding of healthy surroundings and a hygienic home. Just as it puts a question mark to the understanding of ourselves – are we part of the physical environment, or should we be protected from the physical surroundings?

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36 Carter S. *Rise and Shine – Sunlight, Technology and Health*, p. 66. Berg, 2007.
37 Schmidt Lars-Henrik, Steffensen Jens Erik. *Lys, luft og renlighed,* p. 88. Akademisk Forlag (1986) 2004. Sundhedsbladet 19. Volume No 4, p. 68 ref.
38 Carter S. *Rise and Shine – Sunlight, Technology and Health*, p. 58. Berg, 2007. In Henry Gauvains preface to the English translation of Auguste Rolliers La Cure du Soleil, 1927 ref.

It has even come so far that a doctor last year in earnest came with a proposal that there should be airtight houses with thick glass walls where the air would come in through small vents with filter appliances[39].

In this period, the architecture plays a crucial role in the protection against diseases – at least as long as the medical sciences can´t protect us against diseases through medication. However medical advances, including the discovery of penicillin[40] and vaccines[41] against tuberculosis, change this role of the architecture significantly in the years to come.

An end to light and health

Only two years after Niels Ryberg Finsen receives the Nobel Prize, *Robert Koch* receives the same prize in 1905 for his discoveries of a more medical nature, namely the medical treatment of bacterial diseases. The work of Koch is based on a more classical, medical approach, in order to reduce the ability of the bacteria to cause disease. An approach, which is also practiced by the maternity doctor *Ignaz Semmelweis*, fighting infections by using disinfectant bleach as a killing agent on bacteria.

This starts a new development, which allows us – instead of being subject to the physical environment and part of nature – to become able to medicate ourselves healthy and free ourselves from our environment, indeed even *protect* ourselves against nature. In this way, the physical surroundings – including the architecture – loose the affinity to health, a relation, which has otherwise been strong and inseparable through time. Architects with medical knowledge, and doctors with architectural knowledge become rarer, like doctors no longer involve themselves in the construction of schools and hospitals[42] to the same extent as before.

In this context it is noteworthy that medicine, and particularly the development of various vaccines, manifest themselves so clearly in the architecture. In my eyes, this not only shows an architecture losing its healing role after World War II. It also shows the close relationship between architecture and medicine – which manifests itself in the very *absence* of a healthy architecture, as better and more effective medications become widespread during this period and up to the present day. The architecture thus no longer offers the same framework for

39 Schmidt Lars-Henrik, Steffensen Jens Erik. *Lys, luft og renlighed,* p. 88. Akademisk Forlag (1986) 2004. Sundhedsbladet 19. Volume No 4, p. 68, ref.
40 The Scottish bacteriologist Alexander Fleming discovers penicillin in 1928. Kilde: Encyclopædia Britannica, 2013.
41 Bacillus Calmette-Guérin, also called BCG vaccine is a vaccine against tuberculosis detected by the French bakteriologists Albert Calmette and Camille Guérin in 1921. The vaccine is mass-produced and later globally distributed from 1945. Source: Encyclopedia Britannica, 2013. Other vaccines, such as vaccines against diphtheria (1943) and neonathal tetanus (1949), are produced and marketed globally in the same period e.g. from Denmark. Source: K. Jensen. *Bekæmpelse af infektionssygdomme*, p 44 Nyt Nordisk Forlag Arnold Busck. 2002.
42 A relation between medicine and hospital architecture, which is described in Adams Annmarie. *Medicine by Design: The Architect and the Modern Hospital, 1893–1943*. University of Minnesota Press. 2008.

fresh air, or for that matter natural light, as it did before. In deep, low-ceilinged buildings and building typologies, which let in less light and less fresh air, the preventive and healing elements of the architecture are lost and forgotten – in a period where neither light nor architecture are associated with health.

The sanatoriums are classic examples of this close relationship between architec- ture and medicine – and the power struggle between them. One example is The Vejle Fjord Sanatorium. It is originally designed by *Wilhelm Dahlerup* who, despite only receiving a 3rd place in the architectural competition, is chosen as architect for the building[43]. At The Vejle Fjord Sanatorium, a stay typically includes natural surroundings, and walks in the sun, along the so-called cure-paths, where light and exercise are prescribed for the paying patients, together with therapeutic treatment, practiced by *Dr. Christian Saugmann,* who, as mentioned earlier, is one of the pioneers behind the sanatorium movement in Denmark.

The final end of the sanatoriums reflects the slippage which occurs from a belief in the surroundings and their impact on the health, to a belief in that good health instead rests in the hands of medical treatment. A treatment which finally triumphs with the distribution of the *Bacillus-Calmette-Guérin vaccine*[44] during the late 1940s. The Vejle Fjord Sanatorium, with its flourishing period in the beginning of the 20th Century and its final end in 1957, is only one example out of many. The Zonnestraal Sanatorium closes that same year, together with The Christmas Seal Sanatorium east of Kolding, followed by the large sanatorium Vejlsøhus at the Silkeborg lakes, which closes only a few years later.

Common for all is their end; they all cease within a very short span of time and for the same reason; better medical treatment.

An interesting example of this development is incidently seen in the language and in the name of the asylums for the treatment of tuberculosis. Originally the tuberculosis patients are treated by so called *Luft und Liege-Kur,* originally inspired by the German and Swiss tuberculosis therapy in rural settings, such as Davos. These asylums are called *sanitariums*, derived from the word sanitas which includes healthy living in healthy, natural surroundings. At these sanitariums, isolated from the cities, light and fresh air are important parts of the treatment. But together with better medical care, the word sanitarium gradually is replaced with the present word *sanatorium*[45], which is derived from the word sanare, meaning *to treat*. At the sanatoriums, a more active and improved medical treatment becomes predominant and plays the leading role in the treatment of the patients.

In the following decades the *technological hospitals* move into the center of the cities[46] – in the same densely populated areas, and in the same lack of light and fresh air – which the sanatoriums fled from originally. Throughout this period,

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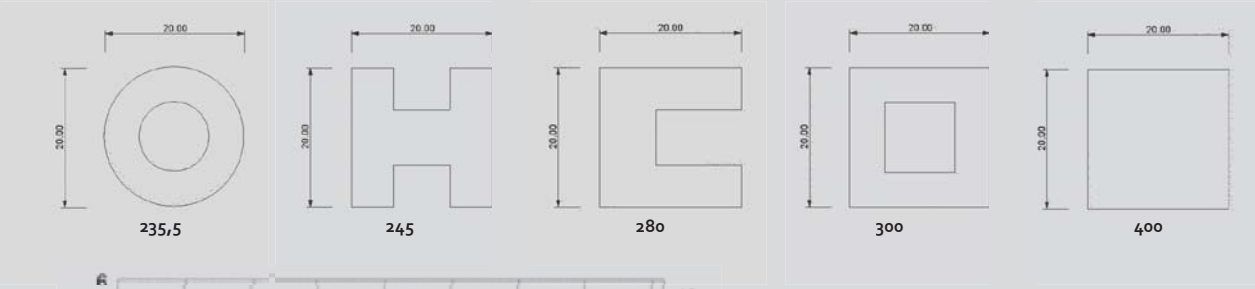
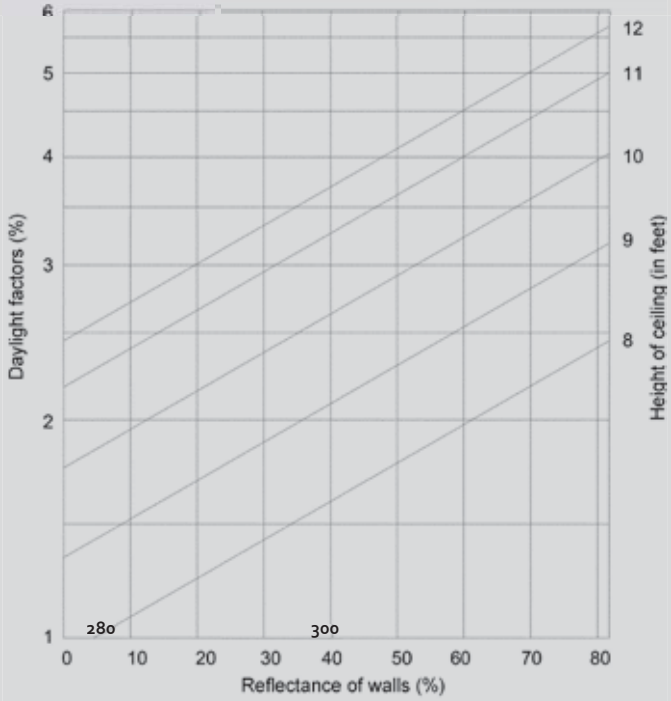
43 The sanatorium is by the way delayed by a nationwide strike in 1899. A strike, which proves indirectly to have a major impact on our relationship to the sun. The September Agreement results in reduced working hours and entitled workers to two weeks of holiday, paving the way for a worship of the sun, swimsuit and the beach.
44 Named after Albert Calmette og Camille Guérin, who discovered the vaccine in 1921.
45 Schmidt Lars-Henrik, Steffensen Jens Erik. *Lys, luft og renlighed,* p.15. Akademisk Forlag (1986) 2004.
46 Among others the first *superhospital* in Denmark; Glostrup Hospital, 1958.





Daylight factors, measured 20 feet from the window, compared to height of ceiling and reflectance of walls (ceiling=70%, floor=28%)

Top: The Zonnestraal Sanatorium. Before the antibiotic era (right) and after (left). The Zonnestraal Sanatorium inspires such architects as Alvar Aalto and his The Paimio Sanatorium. It is build as a temporary building while waiting for a medical cure for tuberculosis. The architect Jan Duiker expects, along with the board of the sanatorium, that the sanatorium will be obsolete within 30 years. This turns out to be true, the sanatorium is closed in 1957. Source: Overy P. Light, Air and Openness, p 20

Bottom: "The antibiotic era" has a huge influence on the architecture. The ceiling heights and the building forms are changing in the post-war period, in order to better exploit cubic and square meters. The result is lower ceiling heights in deeper buildings with less daylight utilization, which is no longer considered a prerequisite to health. Moreover, this is aided by the emergence and cheapening of artificial lighting in this period, making this change of buildings and architecture possible

from World War II and up until today, technology and the size of the hospitals seem to impress more than actual intentions regarding health and healing seem to do.

After World War II we enter an era which, by the virtue of the discoveries and commercialization of the previously mentioned vaccines, is often termed *the antibiotic era*[47], a period ranging from 1945 to the present day. That the architecture loses its relation and affinity to health, not only manifests itself in the fact that the sanatoriums are closing. It also manifests itself in the new post-war architecture, demonstrating less understanding of the importance of light to health, less understanding of the direct sunlight and less understanding of *the clear, low-iron glass*[48] and its importance to the quality of the light. All factors, which many nursing homes and hospitals in the 20s and 30s where taking for granted.

At the technological hospitals, the light is planned in a more scientific way, using measurable quantities, measured in lux and in daylight factors, not taking into account the fundamental differences between eastern morning light and western evening light, or for that matter the body's various needs for light, during the day and the year. The new hospitals in the antibiotic era are often characterized by their simple geometric, Euclidean shapes, which actually do not utilize the daylight as well as the previous building typologies, such as the classic E-, H-and U-shaped buildings utilizing the daylight from multiple angles and with several corner-rooms, flooded with sunlight from two sides, often with solarium-rooms, oriented towards the sun. Instead, these classical typologies are replaced by more compact building shapes, which all in all, do not utilize the sunlight as well, reducing the actual number of sunshine-hours inside the building during the day and during the year. At the same time, deeper building-plans and lower ceiling heights are implemented. Instead of previously recommended ceiling-heights of 14 feet[49] – equivalent to approx. 4.25 m – the ceiling heights are lowered to the current 2.7 m. The increased glass areas can´t compensate for the reduced ceiling heights and the increased depths in an architecture, which is instead based on the necessary artificial lighting[50] – together with mechanically driven ventilation. In this context it is interesting that the electricity prices during this period – that is, from the late 1940s and until the oil crisis in 1972 – fall, enabling the architecture to takes less account of the daylight, simply because the artificial lighting becomes cheaper. White, hygienic walls help increasing the daylight factor at the new hospitals, compensating for the lowered ceiling heights. Horizontal window openings also become common in this period, letting less direct skylight into the building – thus reducing the healthy light. But more on this later. This development not only applies for hospitals, but generally within the built environment.

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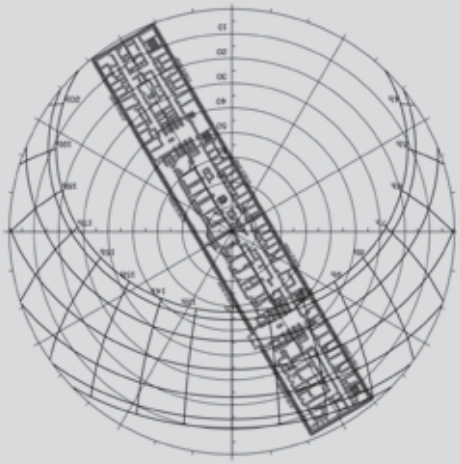
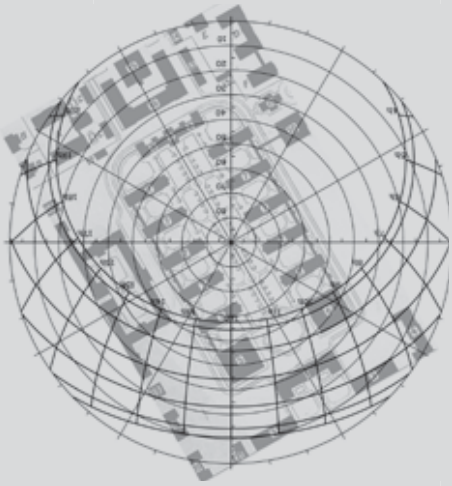
47 Dr. Margaret Chan, Director General of the World Health Organization uses this term in the article *Maintaining momentum in an era of austerity*, www.who.com 2011.

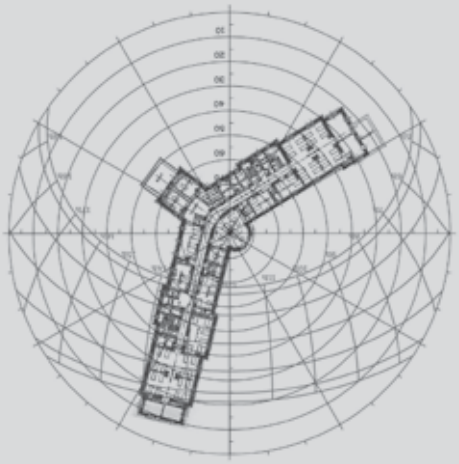
48 Carter S. *Rise and Shine – Sunlight, Technology and Health*, p. 68. Berg, 2007. Amongst others the *Vitaglas* by Pilkington Brothers from the 1920s, transmitting more UV light. It is used in over 300 hospitals in the 1930s.

49 Adams Annmarie. *Medicine by Design: The Architect and the Modern Hospital, 1893–1943*. University of Minnesota Press. 2008. As such recommended by the architect Henry Saxon Snell at the Royal Victoria Hospital in Montreal, Canada, ref.

50 Volf C. *The necessary daylight and the necessary artificial lighting.* Arkitekten 07, vol 113, p. 62-65, 2011.

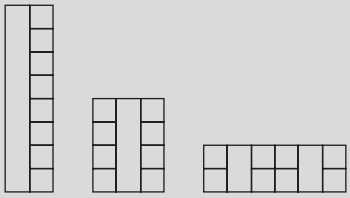






Top: The technological hospital, The State Hospital, is planned based on measurable light. A light planning, which does not take into account the direct sunlight or the geographical orientation. As shown, there is only access to the winter morning sun through a small light opening, at the end of the double-corridors

Bottom: 1. In the antibiotic era: The orientation of The State Hospital (1970) breaks with 2. the orientation of the old Frederiks Hospital (1910). Where the wards at Frederiks Hospital face S/SE, the central complex of The State Hospital is laid out in an axis, where half of the wards are facing NE, receiving virtually no morning sun throughout the dark winter season, while the other half receive too much afternoon sun and evening sun during the summer. 3. Before the antibiotic era. Henry S. Snell's hospital, The Royal Victorian Hospital in Montreal, 1893, Canada. As shown, Montreal is located more to the south than Copenhagen, with more daylight during the winter and less daylight during the summer. The building is oriented in order to balance the morning sun both summer and winter. The morning sun is utilized, while the evening sun is shielded. An orientation, and a building form, which later inspires Alvar Aalto in The Paimio Sanatorium



Three corridor typologies, each with 8 wards. Before the antibiotic era; Gentofte Hospital, 1927 (left) with daylight in the corridors. Followed by the antibiotic era; Glostrup Hospital, 1958 (center) and The State hospital, 1970 (right). Source: Computer- and daylight controlled lighting at hospitals, Carlo Volf, www.volf-design.dk

The ability *to light up the rooms from the inside*, using artificial lighting, seems to eliminate the need for the tall *portrait windows*, which were common in the early 1900s. Instead new and lower window types are introduced, such as *Fenêtre en longueur* – as advocated by e.g. Le Corbusier – a window type favoring the view, but at the expense of the skylight and the amount of daylight reaching deep into the building.

The missing geographical orientation

The most striking difference between the old sanatoriums and the new technological hospitals seems to be the fact that the new hospitals are no longer planned according to the sun and the geographical orientation. What was formerly common sense – such as orientating the patient wards so that they received morning and midday sun, a.o. based on the empirical experiences[51] of *Florence Nightingale* on the relationship between mortality and sunlight – is now neglected and forgotten. Instead, the light at the new hospitals is planned based on the concept of *a cloudy sky*, using scientifically measurable lux and daylight factors, as mentioned earlier. A method which completely ignores the sun and the geographical orientation.

At the post-war super-hospitals the experiences of Florence Nightingale and the importance of the winter sun are overlooked, resulting in the fact that the hospitals are often planned in wrong axes. One example is The State Hospital which, placed in an axis exactly perpendicular to the principles of Nightingale, can be seen as a typical example of the missing understanding of the importance of sunlight to the health in the antibiotic era.

The State Hospital is built at the same site as the old *Frederiks Hospital*. The latter is built in 1920, inspired by Nightingales pavilion principle, with south-facing pavilions, separated from each other to minimize the risk of infection, at the same time receiving plenty of sunlight with the wards oriented towards S-SE, an orientation determined by the sun. Here the sun shines into the wards throughout the year – also during the dark wintertime. A practice which, incidentally, is not only common in Denmark and in England, but is also widely accepted and deployed in other parts of the world. During my period of study at NRC and Jennifer Veitch in Canada, I made a field-study to Montreal to see *The Royal Victoria Hospital*[52], designed by the Scottish architect *Henry Saxon Snell* in 1893. Here, I was able to study how the original hospital was planned according to the sunlight, in collaboration with doctors[53]. However, later additions to The Royal Victoria Hospital are not structured in the same careful manner according to the sun, thus becoming another typical example of the antibiotic era – and an architecture which loses its importance to the health.

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51 Nightingale F. *Notes on nursing: What is and what is not.* 1859. Based on F. Nightingales experiences from the Crimean War 1853-56.
52 As mentioned on the previous page.
53 Adams Annmarie. *Medicine by Design: The Architect and the Modern Hospital, 1893-1943*. University of Minnesota Press. 2008.

And a new beginning

Seen from a health perspective, several questions can be raised against this development. New research[54] clearly documents that daylight affects our health and well-being, and publications like *Healing Architecture*[55] restore light as an important factor in the design of the physical environment at hospitals. Remarkably, it is the same driving medical forces, that in the 1940s abolished the healthy architecture, which today, with the greatest of ease, restore the importance of the physical environment, including light and architecture, based on the recent discoveries about Vitamin D and in particular the discovery of *the non-visual light*[56].

Today, cracks in the belief in a purely medical treatment are discerned. In many ways, we are returning to the basic realization that medicine and technology alone, do not support the health in the best way, and that the environment may be more important to our health than we have imagined through the past 50 years. In several scientific publications both daylight and natural surroundings are re-introduced as important factors to healing and to health.

Where the light of the sun in the pre-antibiotic era was considered the first line of defense against bacteria, it is increasingly the last line of defense which is used today at the hospitals, namely antibiotics such as *vancomycin* in the fight against the infections that constitute a major problem today; hospital infections[57], which not only amount to great expenses[58] in terms of more bed days[59], but also represent a real health threat. In Denmark it is estimated that around 8-10% of all bed days are caused by hospital infections, corresponding to approx. 400,000 bed days[60] per year in Denmark.

Several factors suggest that the era of antibiotics is over. According to the WHO[61], we are facing a global crisis in antibiotics, looking at an increasing number of multi-resistant bacteria, while we, unfortunately, see fewer, new medical responses, in the form of effective vaccines against these bacteria.

In this context, there is good reason to restore the significance of architecture and reestablish light and the physical environment as a factor, important to the overall health and to the prevention of diseases.

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54 Berson David M, Dunn FA, Takao M. *Phototransduction by Retinal Ganglion Cells That Set the Circadian Clock*. Science 295, 2002; Jens Hannibal. *Neurotransmitters of the retino-hypothalamic tract.* Springer 2002; Munch IC, Møller M, Larsen PJ, Vrang N. *Light-induced c-Fos expression in suprachiasmatic nuclei neurons targeting the paraventricular nucleus of the hamster hypothalamus: Phase dependence and immunochemical identification.* The Journal of Comparative Neurology, 2002.

55 Frandsen AK, SBI. *Helende Arkitektur*, p. 23. 2009.

56 Berson David M, Dunn FA, Takao M. Op. cit.

57 Frimodt J, Ugeskrift for Læger 173/2, 01.10.2011: Over the years, Danish hospitals have regularly participated in national prevalence studies, which unfortunately – in relation to the increased attention in this area – has shown relatively constant frequencies of HI of 8-10 %.

58 Plowman R, Graves N, Griffin MA, Roberts JA, Swan AV, Cookson B, Taylor L. *The rate and cost of hospital-acquired infections occurring in patients.* Journal of Hospital Infections. PubMed, 2001.

59 Hassan M, Tuckman H.P., Patrick R.H., Kountz D.S., Kohn J.L. *Cost of hospital-acquired infection*. National Institute of Health. PubMed, 2010.

60 Iflg. prof. Kjeld Møller Pedersen, University of Southern Denmark, *What you did not know about Denmark*, DR2 d. 25.06.2013.

61 Dr. Chan Margaret, Director General, WHO. *Maintaining momentum in an era of austerity*, www.who.com 2011.

2 LIGHT AND DISEASE

2. LIGHT AND DISEASE

As mentioned earlier, in the chapter *light and health*, light has played a central role through the 20th century in efforts to cure diseases, both as a preventive element and as a therapeutic and healing element. In this chapter, I will go deeper into some of the diseases that may be treated and prevented, using light as a non-medical treatment, diseases which are today mainly treated medically.

According to the WHO, four major diseases are currently threatening the western world today, these diseases are *cardiovascular disease, cancer, obesity* and *depression*. All of these diseases are affected by light and can be treated with light. For both cardiovascular disease[62] and cancer[63], there seems to be a striking correlation between latitude and dissemination. The further away we move from the equator, and the UV light of the sun, the more the cholesterol levels increase, also increasing the mortality from cardiovascular disease and several types of cancer. Sunlight seems to play an – albeit still unclear and complex – role in the development of these diseases.

However, other diseases are also assuaged and prevented by the UV-light of the sun. The UV-light seems to have a positive effect on diabetes 2, lowering the concentration of glucose in the blood[64]. The sunlight also increases the formation of vitamin D necessary for the calcium uptake in both bones and teeth, and especially children, aged 0-6 year, may increase their resistance to dental diseases like *caries*[65] if exposed to the sun. That is, if the sun is allowed to penetrate the skin, forming the active vitamin D3, which is a prerequisite for the calcium uptake in the body. Today, many well-meaning parents unfortunately prevent this by lubricating their children in sunscreen morning, noon and evening.

Finally, several studies suggest that sunlight has a positive effect on disorders such as *dementia, multiple sclerosis, Alzheimer's disease, Parkinson's disease, psoriasis* and infertility. However, most of these positive effects only occur, if the UVb-light is allowed to penetrate the skin and form the active vitamin D3.

Vitamin D3 – a sunshine vitamin

Niels Ryberg Finsen not only studied the chemical effect of UV light on diseases and bacteria. In the years leading up to his death, he also fostered an

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62 Wang TJ, Pencina MJ, Booth SL, Jacques PF, Ingelsson E, Lanier K, Benjamin EJ, D'Agostino RB, Wolf M, Vasan RS. *Vitamin D Deficiency and Risk of Cardiovascular Disease*. American Heart Association, 2008.
63 Giovannucci E, et al. *The epidemiology of vitamin D and cancer incidence and mortality: A review (United States)*. Springer 2005.
64 Taheri E, Saedisomeolia A, Djalali M, Qorbani M, Civi MM. *The relationship between serum 25-hydroxy vitamin D concentration and obesity in type 2 diabetic patients and healthy subjects.* Journal of Diabetes & Metabolic Disorders, 2012.
65 Brown T, Creed S, Alexander S, Barnard K, Bridges N, Hancock M. *Vitamin D deficiency in children with dental caries – a prevalence study*. Archives of Disease in Childhood, 2012.

emerging interest in light and its prophylactic and disease preventing effects. Among other things, he discovered that light seems to have a positive effect on the immune system, and Finsen´s many empirical observations suggest that the chemical UV light may actually be directly beneficial to the health. However, Finsen never succeeds in proving his theory.

When Finsen dies in 1904, the vitamin D is yet to be discovered, it is not discovered until later, in 1922[66]. But there are indications that vitamin D is exactly what Finsen early discovers the effects of. In one of his empirical observations, cats often lay in the sunshine licking their fur after nocturnal fights. Finsen does not consider this a coincidence. Today, it turns out that this relates exactly to vitamin D; cats literally *lick the sunlight* when they lick their fur – eating the vitamin D that the fur produces when exposed to sunlight. Actually, some of the D3-vitamin pills that can be purchased at the pharmacy are derived from the fur of pigs. But what is Vitamin D? And how does vitamin D affect our health?

The vitamin D is in fact not a *vitamin* at all. It is originally misclassified as a vitamin and is in fact a so-called *steroid hormone*, that is, a substance which the body – unlike vitamins – can produce itself[67]. The UVb-light of the sun converts 7-dehydrocholesterol into the skin to a so-called inactive vitamin D, which in turn, via the liver and the kidneys, is converted to the active vitamin D3, 1,25 (OH) D. The formation of vitamin D3 is therefore not the result of the sun alone, or for that matter a result of the body alone, but the result of a complex interaction between the body and the environment. A relationship which, historically, has resulted in sunlight – and the importance of vitamin D – being shrouded in mystery, just like vitamin D itself has been relatively unexplored until recent days.

The discovery of vitamin D – and in particular the discovery of what *the lack* of sunshine and vitamin D can cause to the human body – has since then been supplemented with new knowledge. Today, new scientific studies confirm the early discoveries of Niels Finsen, clarifying the effects of the UV light on the health and the general well-being. Researchers[68] have discovered that our immune system is critically dependent on the vitamin D in order to function. The so-called killer cells[69] – also known as *Thymus cells,* fighting bacteria, viruses and cancer – simply do not work without vitamin D3.

We have discovered that the killer cells of the immune system, called T cells, are equally dependent on vitamin D, as a car is dependent on a battery to start[70].

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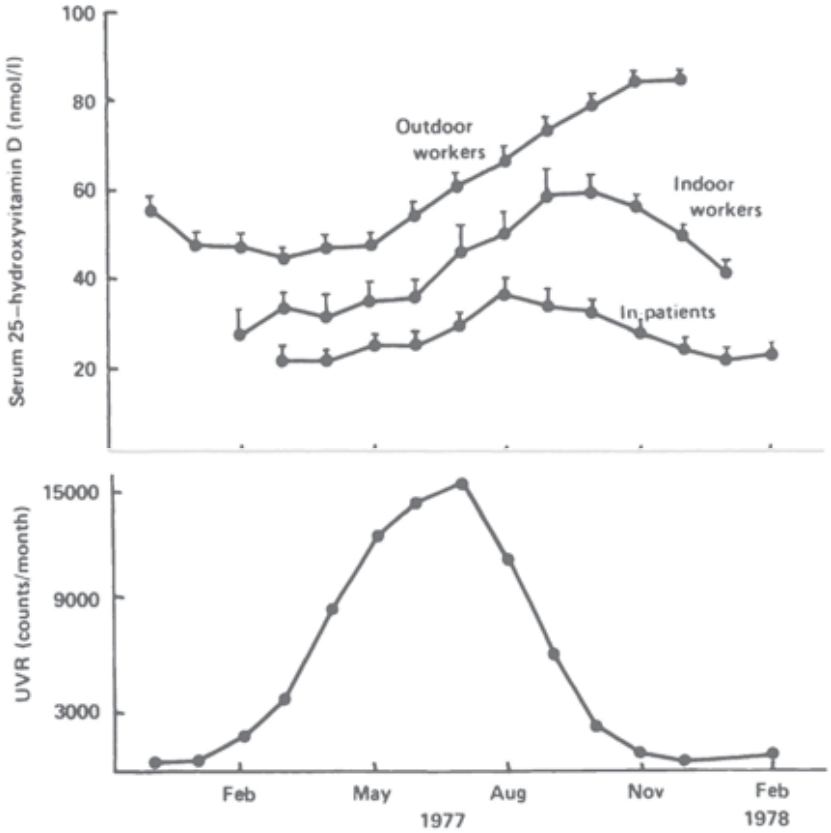
66 McCollum EV, Simmonds N, Becker JE, Shipley PG. *Studies on experimental rickets. XXI. An experimental demonstration of the existence of a vitamin which promotes calcium deposition.* 1922. J. Biol. Chem. 53:293-312.
67 Source: The Great Danish, Gyldendals Open Encyclopedia, 2013.
68 Among others, Professor Carsten Geisler at Department of International Health, Immunology and Microbiology, University of Copenhagen.
69 T cells, also known as Thymus cells, are formed early in the bone marrow and mature in the Thymus. They are a vital part of the immune defense system of the body. Source The Great Danish Encyclopedia, 2013.
70 In an interview, Professor Carsten Geisler, Department of International Health, Immunology and Microbiology, University of Copenhagen. The magazine Videnskab.dk, 2010.

This is another argument for doing something about the vitamin D deficiency, which almost half of the Danish population suffers from – and a reason not to protect us too drastically against the sunlight, using clothing and sunscreen, or for that matter solar protective glass.

In this context, especially children up until 6 years of age, are very much dependent on an effective calcium uptake for the growth and development of their bodies. The elderly, who quite often[71] suffer from calcium deficiency and *osteoporosis*[72], are likewise a vulnerable group in particular need of vitamin D3.

It may well be a problem that we are being advised to cover our skin with clothing and sunscreen when we go out in the sun during the summer, I am thinking especially of children, who are encouraged to be covered from head to toe. For it may cause vitamin D deficiency and we would not want to go back to the time when children developed rickets, ie osteoporosis, because of vitamin D deficiency (...) It's like a double-edged sword. But I do believe that the two messages can go hand in hand[73].

Words, which could have been uttered by the father of medical art, Hippocra-



Variations in vitamin D3 in 3 different groups of the population over the year; as shown hospitalized patients, who in general are older and do not receive enough UVb light, seem to lack vitamin D3. Source: Devgun MS, Paterson CR, Johnson BE, and Cohen C. "Vitamin D nutrition in relation til season and occupation". Am. J. CLIII. Nuir. 34: 150 1-1504, 1981

Variations in the UVb light during the year in Dundee, Scotland, at 56 N. latitude, the same latitude as Denmark. There is virtually no UVb light in the period October to March, a period which is also called the UV-winter. However, as shown on the charts, vitamin D can be stored in the body through the winter. That is, if the skin is exposed to the sunlight during the summer. Source: Ibid

71 Up to 80% of the elderly people suffer from vitamin D deficiency in Denmark. Source: www.osteoporosedoktor.dk.

72 The common forms of osteoporosis are caused by the fact that all people, after 30 years of age, annually lose 0.5-1% of their skeleton. This eventually leads to age-related osteoporosis. Source: The Great Danish, Gyldendals Open Encyclopaedia, 2013.

73 Carsten Giesler, ibid.

tes, who also describes the opposing effects of the sun on humans, recommending the same balance. The sun of course, may be unhealthy, causing disorders such as aging of the skin and the development of common skin cancer, *cataract*, *melanoma*, etc.

However, vitamin D deficiency in Denmark is generally a result of too little sun during the winter, the sun being the primary and most important source of vitamin D. But actually we are able to store vitamin D in our fat deposits, so that vitamin D formed during the summer period, from April to September, can last all through the winter.

But the latitude and the UV-winter is not the only cause of vitamin D deficiency in Denmark. The architecture also seems to play an important role here, due to the fact that the glass in architecture serves as an effective UV barrier, separating UVa from UVb. The healthy UVb light does not penetrate normal *float glass*[74], only the *clear, low-iron glass*[75]. In this context, the architecture may be a further explanation of the vitamin D deficiency in Denmark, taking into consideration that we spend up to 90% of our time in the indoor environment[76], behind glass eliminating the UVb light.

Ordinary float glass and solar protective glass prevent us from producing vitamin D in the indoor environment. Instead, we are forced to capitalize on the deposits, built in the short periods we spend outdoors during the summer months. However, according to a British study[77], this requires a minimum of 30 minutes of daily sun exposure on the arms and the face through the summer period, from April to October, which is far from what we all receive today.

The mystery of vitamin D seems to be about finding the right balance. However, it seems the solution to this duality is not found in the exclusion of the UVb light, but rather in a balance, which neither penalizes UVa or UVb.

The skin – and skin cancer

The same balance applies when we talk about skin and skin cancer. Again, glass seems to play an – albeit still unclear – role. The skin is, in itself, a balance continually stabilizing around an equilibrium between different dichotomies, such as humidity, drought, cold, heat, light and darkness, etc. As we humans migrated north to areas with less sunlight and less light intensity, our skin becomes brighter, opening up to let in more of the vital UVb light – thus enabling us to produce more vitamin D in the body.

In this way, the skin balances the UVb light without exposing the body to the harmful side-effects of the UVb-light. Similarly, the skin adapts to the

74 Ferrous glass, which is one of the most common types of glass in Danish construction today.
75 Diamond glass transmits approx. 10% UVb light, see also the chapter Glass.
76 According to SBI, op.cit.
77 Hobday R. *The Healing Sun*, p. 27. Findhorn Press, 1999. Nb. Applicable for UK, where latitude and weather conditions are similar to Denmark.

regional light, by turning darker in regions with more sunlight. An adaptation which occurs in two ways: partly by the formation of *melanin*[78], mainly stimulated by UVa, and partly by the thickening of the outer skin, *epidermis*[79], primarily caused by UVb.

Today we generally expose ourselves less to the UV light than we did before the time of the industrialization, when we worked outdoors most of the day. Yet skin cancer assumes epidemic proportions in the Western world today. Why is that, one might ask? The explanation to this question does not follow any simple, rational principles, but may be found in the sophisticated natural defense system of the body and the skin against the UV-light of the sun.

A Danish study[80] shows that male workers working outdoors – as farmers, construction workers and fishermen – have about 20 percent less risk of developing skin cancer and melanoma than employees working indoors. The study examines all workers who have suffered from skin cancer in the period between 1970 and 2003. It gives no clear explanation as to the role of the sun, but suggests that the skin gradually acclimatizes to the seasonal changes in the sunlight when working outdoors, thereby avoiding the dangerous sunburn. Earlier, we spent more time outdoors, therefore, we were able to gradually build up a protection against the sun. The problem with our current way of living is that we do not receive any UVb radiation inside, only outside. In this context, we become more vulnerable to sunburn, because the skin has not been adapted to the UV radiation of the sun.

Much of the explanation to this paradox points to behaviorial patterns, however it also points to architecture – more particularly to the glass and the quality of the glass. Common ferrous and coated glass types influence and change the UV spectrum and the distribution of the light, resulting in less UVa radiation and virtually no UVb radiation. This lack of UVb radiation prevents the skin from forming the protective thickening of the epidermis, actually making the skin more vulnerable when exposed to the natural environment and the natural sunlight outside.

The correlation between exposure to sunlight and risk of developing cancer seems to follow a very complex, and currently far from clear, pattern, and does not seem to follow the classical exposure-protection strategy, as we have seen with R. Koch and I. Semmelweis; we are not less likely to become sick if we expose ourselves less to the UV-light of the sun.

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78 A dark pigment found in skin, hair, eyes, and in regions of the brain (substantia nigra), and which provides color from dark yellow to brown to black. Source: The great Danish, Gyldendals Open Encyclopaedia, 2013.
79 The outer layer of the skin. Source: The great Danish, Gyldendals Open Encyclopaedia, 2013.
80 Hansen J, Tinggaard M, Mikkelsen P, Meier Rasmussen K, Petersen A, Funch Lassen C, Meersohn A. *Mapping the risk of cancer (1970-2003) among employees in Denmark.* Kræftens Bekæmpelse, 2010.

In fact, UV light may actually prevent cancer when we talk about cancer, where cancer of the internal organs is concerned. Studies[81] show that the UV light – and the formation of vitamin D3 – reduce the development of cancers such as *colon cancer* and *breast cancer*, a discovery supported by the fact that the incidences of both breast cancer and colon cancer actually increase with the latitude[82]. Areas with less UV light subsequently result in less vitamin D, thus showing a higher incidence of these cancer types. Again, this research confirms the efficacy of vitamin D in the prevention of diseases and shows how exposure to sunlight, overall, may have a positive effect on the health.

In this context it is important that the exposure to sunlight occurs gradually, through daily and regular exposure, in order for the skin to adapt and produce melanin to avoid the sunburn often causing the skin cancer. Widespread indoor activity, in an environment devoid of UVb light, and with only short, intense exposures to UVb light in the outdoors, e.g. on vacations and the like, may in this context be one of the explanations for the increasing incidences of skin cancer[83] in Denmark.

Finally, the chances of recovery for most types of skin cancer are good, equivalent to the fact that more than 95%[84] actually survive the disease. All in all, much suggests that the positive effects of exposure to UV light far surpass the negative sides. A previous study[85] shows that seamen exposed to excessive UV light actually have a reduced risk of developing cancer of the internal organs. This result is supported by other recent studies[86] relating vitamin D deficiency to the spread of cancer of the internal organs and to several other disorders, such as diabetes 2 and elevated cholesterol levels. Disorders, which are becoming more common in Denmark[87], also leading to an increased risk of cardiovascular diseases[88] which in the UK alone cause 139,000 deaths every year[89].

Senior researcher Lotte Husemoen from the Research Centre for Prevention and Health in the Capital Region says:

When we have adjusted for other factors, people with a very low level of vitamin D in the blood has a 65 percent increased risk of developing type 2 diabetes than those with a higher level of vitamin D in the body.

However, the fear of skin cancer does not always follow these rational con-

81 Bower, Colston, Stein, Hedley, et al. *Topical calcipotriol treatment in advanced breast cancer*. The Lancet 337, 1991, 701-702.
82 See also p. 43.
83 Friis Krarup A, Lind Behrens C, Thorgaard C, Køster B, Darsøe L. *Solundersøgelsen.* Kræftens Bekæmpelse, 2010.In DK more than 9,000 annually develop skin cancer, ref.
84 Hobday R. *The Healing Sun*, p. 46. Findhorn Press, 1999. Nb. Applicable for the UK, which skin type-wise and weather-wise is comparable to Denmark.
85 Peller S, Stephenson CS. *Skin irradiation and cancer in the US Navy*. American Journal of Medical Science, 1936
86 Hollick MF. V*itamin D: The importance in the prevention of cancers, type 1 diabetes, heart disease and osteoporosis*, American Journal of Clinical Nutriciance, 2004.
87 According to The Danish Radio, october 31. 2012.
88 Up to 1.200 %. Source: The Faculty of Health Sciences, Herlev Hospital.
89 Hobday R. *The healing Sun*, p. 55. Findhorn Press, 1999.

siderations, although it seems that the UV light of the sun – and the subsequent production of vitamin D3 in the body – seems to play a predominantly positive role to the health. Another positive side of the UV light is that it generally lowers the appetite and thus acts as a preventive health factor when it comes to obesity, a disorder which, according to WHO[90], is assuming epidemic proportions throughout the Western world.

We do not receive enough UV light, partly because we spend approximately 90% of the time in the inside environment, behind glass reducing the UVa radiation and eliminating the UVb radiation. This is not made any better by the fact, that we lubricate ourselves in sun lotion during the summer, which correspondingly reduces the UV light by up to 95%.

In this context it is often disturbing to see that it is neither easy nor interesting – or lucrative for that matter – to the large pharmaceutical companies to document these positive sides and impacts of the UV light on the health. It is often far easier and more lucrative to heal.

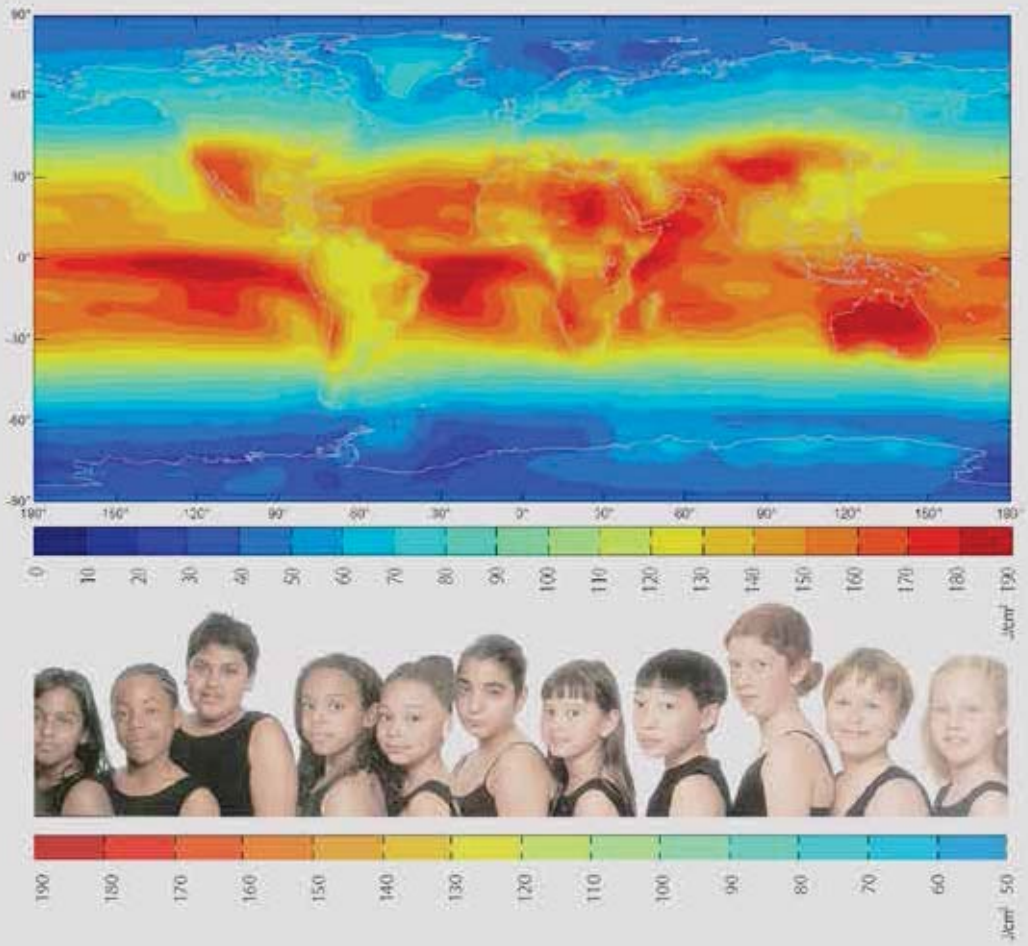
Well-documented, evidence-based studies, based on *in vivo* test and control subjects are needed in order to demonstrate these effects of the light; experiments, which are often more expensive to perform than inaccurate, statistical surveys. For these reasons, research initiatives often run into a lack of willingness by the medical foundations to support studies of such non-medical nature.

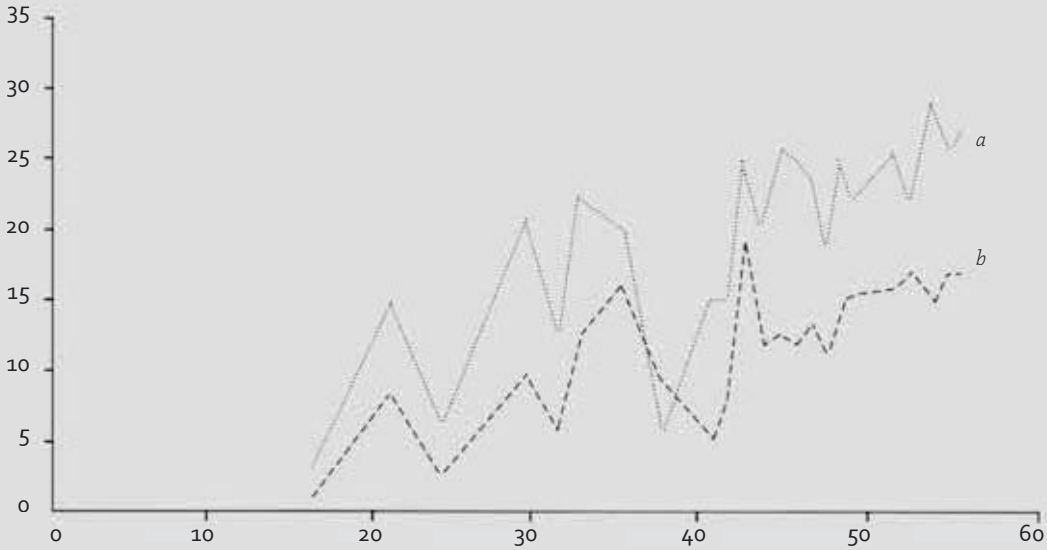
As we have seen with Niels Finsen, the medical profession is skeptical and remains hesitant about any alternatives to medical and surgical interventions. Interventions which only work to heal and therefore unfortunately often turn out to be more difficult and painful for the patient – not to mention expensive to the society – than more preventive actions, such as light therapy.

While healing is easy to identify and easy to appreciate, it is often much harder to appreciate more preventive health interventions, such as the benefits of a healthier architecture and natural daylight. On this basis, it is no wonder that the doctors overlook the sunlight and often tend to be more willing to dose vitamin D in its medical form. However, this becomes no less paradoxical and problematic, considering that the medical treatment of vitamin D deficiency[91] – contrary to the exposure to sunlight – actually may have negative side-effects, causing excessive vitamin D levels in the blood. According to recent studies[92], it seems that medical treatment with vitamin D might even be harmful.

To conclude, the development of skin cancer as a disease, is not the result of how much time we spend in the sun, it is rather a complex result of how we adapt to the sunlight according to skin type, and how we balance the exposure to the UV light, e.g. in the architecture. In this context, a complete protecti-

90 Together they annually cause about 35 million deaths worldwide – more than any other disease.
91 In U.S. and Denmark a.o., the health agencies are under pressure from physicians and the pharmaceutical industries, wanting to raise the daily recommendation of the vitamin. Source: Berlingske, Knowledge, 31.05.2012.
92 Durup D. *Copenhagen Vitamin D-study.* Journal of Clinical Endocrinology and Metabolism, 2012.





The protection of the body against the sunlight is partly a thickening of the skin and partly the formation of melanin. Depending on the latitude and the sunlight, the skin balances exposure to the light and protection from the light. This balance, shown here from the equator to Scandinavia, moreover, is an evolution over time, from the left toward the right. As humans, we have adapted, emigrating north, to the scarce, but vital sunlight. A dark skin needs to receive 6-10 times as much sunlight as a white skin to produce enough vitamin D. *Bottom.* The relative frequency (y) of breast cancer (a) and colon cancer (b) compared to the latitude (x). Source: Richard Hobday, The healing sun, 1999, p 71, 73

on against the sunlight appears to be an unsustainable and even downright unhealthy balance. To eliminate the UVb light, as most types of coated and solar protective glass do, is an inappropriate solution, causing us to produce less vitamin D, which in the end may result in an increased risk of developing both cancer and skin cancer.

Here again, the clear low-iron glass[93] is healthier, being the only glass which actually transmits UVb light, thus supporting the production of vitamin D and our health in the indoor environment.

Sunscreen

Today, sunscreen and the fear of the sun have become an integrated part of our culture and everyday life throughout the summer period, however, sunscreen is actually a quite recent phenomenon. It was originally created and marketed by L'Oréal in 1935, reportedly at the request of a chemist in the company who suffered from severe sunburns when he sailed[94]. However this *Ambre Solaire* would prove to be suitable for a wider range of users, being the right product, at the right time. In fact, sunscreen is marketed along the Riviera in May 1936[95], at the same time as the workers are legally entitled to two weeks paid vacation – incidentally the promotion happens in the form of images of tourists, wearing the new swim suit which exposes the body to the rays of the sun to an unprecedented extent, thus necessitating alternative protection. However, the success of the sunscreen may also be a result of other factors, such as social, psychological and even political factors[96].

However, one can rightly ask whether sunscreen creates the appropriate balance between exposure and protection; a unilateral and indiscriminate use of sunscreen may indeed be problematic. Partly because – as Rollier described – there are large differences in skin types, some have more need for sunscreen than others, while others do not need sunscreen at all, partly because differences in age often demand diverse considerations.

Finally, an Australian study[97] actually links the dramatic increase in the skin cancer *malignant melanoma* with the use of sunscreen. Sunscreen – like glass – often does not block the entire UV spectrum, some parts are transmitted while other parts are reflected and absorbed, thus paradoxically, sunscreen may actually cause relatively more damage, because parts of the UVb spectrum is omitted, preventing the skin from producing its natural protection, namely a thickening of the *epidermis*.

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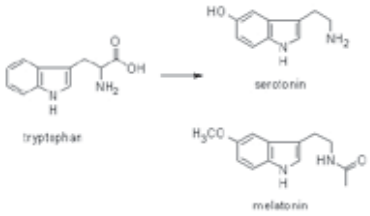
93 See also the chapter Glass.
94 Carter S. *Rise and Shine – Sunlight, Technology and Health*, p.102. Berg, 2007.
95 In Denmark this happened earlier, in 1899, following The September Agreement
96 WHO´s international cooperation with UNEP, United Nations Environment Programme, WMO, World Meterological Organization, ICNIRP, The International Commission on Non-ionizing Radiation Protection, an agreement on an international UV Index.
97 Garland CF, Garland FC, Gorham ED. *Could Sunscreens Increase Melanoma Risk?* American Journal of Public Health 82, 4, 1992, p. 614-615.

A missing piece in the lighting puzzle

In recent years, the discovery of a new type of light-sensitive ganglia cells[98] has revolutionized the importance of light and the way in which we as architects and planners work with both daylight and artificial lighting. The importance of daylight and its positive impact on the health has once again been established as a fact. A concrete consequence of this is a change in the building requirements BR2006 – as it happened in 1899 on the basis of the discoveries of Niels Finsen.

BR 6.5.1. The requirement for daylight must be viewed in the context of the general health aspects of daylight...( )[99]

Such a formulation echoes back to the thoughts of Modernism and the time before effective medical treatment and antibiotics. However, the missing piece not only consolidates Modernism and its mantra of *more* light and *more* health, it also restores darkness as an important health factor. Darkness increases the formation of the sleep hormone *melatonin*, which, among other things, reduces the risk for several diseases, including cancer. On the other hand, too much light at the wrong times of the day, actually may increase the risk of developing cancer. All in all, the restoration of light and health is not merely an echo of Modernism and it´s concepts of light and health. *The missing piece in the lighting puzzle* paints a more complex and nuanced picture of the concept of light and health than the glass architecture of the 1920s did. Thus, new evidence-based knowledge actually breaks with Modernism. A break, which means that, rather than focusing on light itself, we should be more aware of the interaction between the circadian rhythm of the body and the various graduations of light and darkness during the day. Architecturally, this means that instead of focusing on light and openness, we may study the balance between openness and closedness[100].



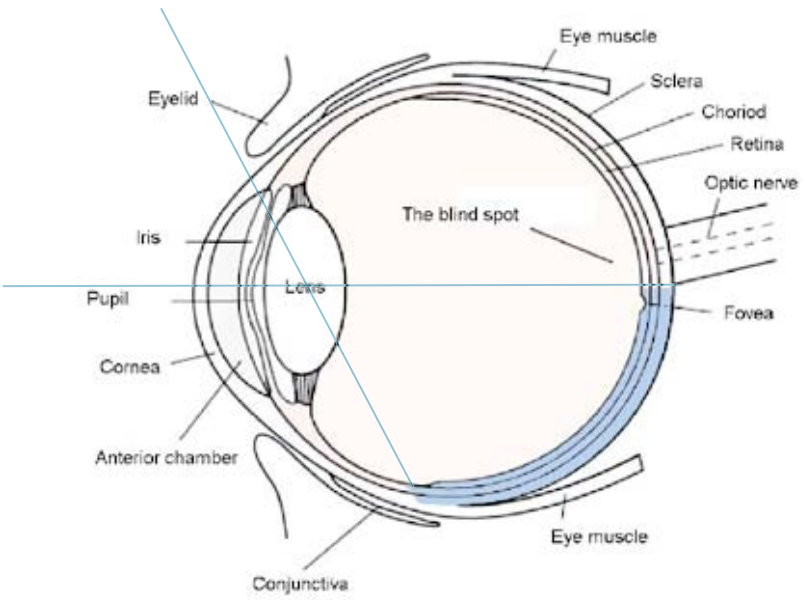
There is a close link between the formation of serotonin and melatonin – and between light and the formation of serotonin. Serotonin is namely, via the amino acid tryptophan, converted into melatonin when it gets dark

The circadian system[101] is a vital and very complex system. It is controlled and synchronized by short-waved, blue light[102], synchronizing more than 200 clocks in the body and thereby controlling many different factors and functions in the body, both directly and indirectly, including factors such as hormone production, appetite, body temperature, activity level, blood pressure, peristalsis, etc.

The missing piece in the lighting puzzle consists strictly speaking of a fifth type of photosensitive ganglion cell[103] in the eye. A primitive ganglion cell,

98 Berson David M, Dunn FA, Takao M. *Phototransduction by Retinal Ganglion Cells That Set the Circadian Clock.* Science, 2002. Intrinsically photosensitive Retinal Ganglion Cells, abbreviated ipRGC.
99 BR 2010, 6.5.1, 1.
100 Volf C, Bille M. *Nearness by a distance*. The Royal. Danish Academy Schools of Architecture, Design and Conservation. 2011. see www.volfdesign.dk.
101 *Circadian* directly translated means *around the day.*
102 Corresponding to approximately 480 nm.
103 Apart from the four generally known. Rods (the contrast vision) and the R, G and B cones (the detail vision).

The eye has a visual system and a non-visual system. The visual system consists of four cells, R, G, B cones and the B/W Rods. The non-visual system consists of a fitfth, primitive, photosensitive ganglia cell, located in the lower region of the retina (blue area). Therefore, they primarily receive skylight. Architecturally, this means that tall or high-placed windows stimulate the circadian rhythm better than low, horizontal windows

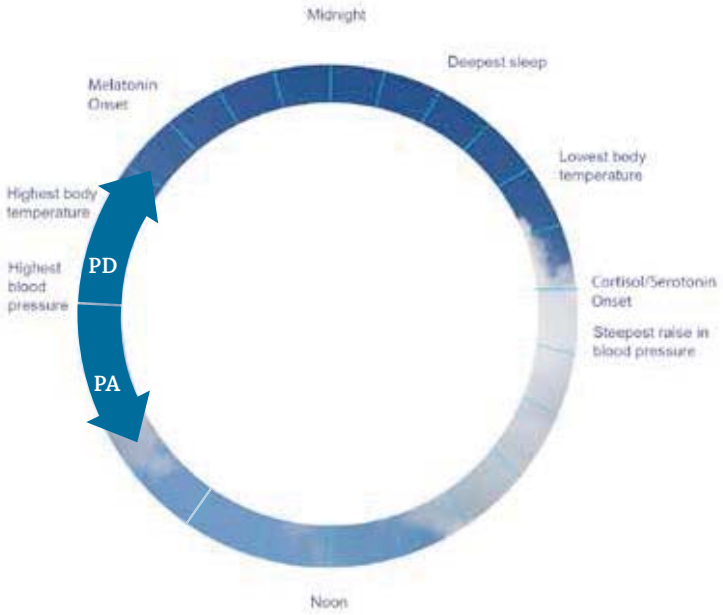


which controls two entirely different processes in the body, both discovered and published in 2002, respectively in *Science*[104] and in *The Lancet*[105]. While the former establishes a relationship between light and the lack of the sleep hormone melatonin, the latter establishes a relationship between light and the production of *serotonin* – a happiness hormone which creates good mood, activity and wellbeing.

These are two separate hormones, but there is, however, a direct connection between the two. Melatonin is synthesized from serotonin. That is, the production of serotonin determines the amount of melatonin. To illustrate this, we are often more tired and sleepy at night, after a long day outside in the sun. The light stimulates the production of serotonin, which again, over time, increases the levels of melatonin in the body. Moreover, there are indications that this relationship also works the other way round: The presence of increased melatonin at night releases more serotonin during the day, which corresponds to the fact that we wake up more fresh and active – having slept in full darkness. So this is a very complex, opposing relationship between the darkness-hormone melatonin and the happiness hormone serotonin. Both hormones are controlling and regulating our circadian rhythm, from activity to rest, being controlled by the light-signals from the ganglia cells.

These photosensitive ganglia cells are mainly located in the lower part of the retina, which is not a complete coincidence, since it is here the highest inten-

104 Berson David M, Dunn FA, Takao M. *Phototransduction by retinal ganglion cells that set the circadian clock*. Science, feb 2002.
105 Lambert GW, Reid C, Kaye DM, Jennings GL, Esler MD. *Effect of sunlight and season on serotonin turnover in the brain.* The Lancet, 12, 2002.



The circadian clock. From sunrise to sunset, from activity to sleep. Light and darkness affect both blood pressure, appetite, sleep, activity, etc. The blue arrows indicate the border between light advancing the next day, through phase-advance (PA), and light delaying the next day, through phase-delay (PD). In other words, light affects us quite differently, depending on whether we receive it before or after PM. 18.00

sity of the blue, short-waved skylight is received. In total, there are approx. 5,000 photosensitive ganglia cells, transmitting light signals to the *supra-chiasmatic nucleus* (SCN), using the photo pigment melanopsin Opn4. In this way, light controls the circadian rhythm, via the production of melatonin in the pineal gland and the production of serotonin in the brain stem.

When we speak of the circadian rhythm, the timing of the exposure to light is absolutely essential. This timing can both support and obstruct the circadian rhythm. This happens through the shifts in what is called the *dark-night-ratio*, making the light an active factor, which can alter the circadian rhythm. While early morning light *advances* fatigue and the need for sleep the following night – which is very healthy, because it improves the sleep period. Light during the evening conversely *delays* the fatigue and reduces the need for sleep, thus working counterproductively on the health. In other words, light can support the circadian rhythm and the health, as well as it can undermine both.

This happens through what is respectively called *phase advance* (PA) and *phase delay* (PD). When exposed to light late in the evening, before bedtime, the sleep period is delayed and the sleep impaired. Conversely, nocturnal sleep is facilitated and improved when exposed to light in the morning, by phase-advance (PA)[106].

106 Lockley Steven W, Foster Russel G. *Sleep – a very short introduction*, p. 124. Oxford University Press, 2012.

Melatonin

Melatonin is secreted from the pineal gland and defines what is called the biological night. As mentioned earlier, the light inhibits the production of melatonin, thereby providing a higher level of activity during the daytime. As day active creatures, this enables us to utilize the daylight, being more alert, both physically and mentally. Conversely, *the lack* of light during the day results in higher melatonin levels and lower levels of activity, which in turn may result in poorer recovery and impaired sleep, resulting in increased risk of diseases. Various studies[107] with subjects show that the bodily circadian rhythm is approx. 24.5 hours by nature. Light acts as *a cue* – a signal – to the body to wake up, in this way synchronizing the circadian rhythm to the physical world, shortening the circadian rhythm to correspond to the rotation of the earth around its axis.

Serotonin

Serotonin[108] can be termed as a happiness-hormone, and as such, it helps to regulate mood, appetite, pleasure and memory. Serotonin is thus an important hormone for our general well-being and for our health, and can help in the treatment of both seasonal-affective-disorder (SAD) and depression.

If the word serotonin sounds familiar, it is because it is often mentioned in connection with Prozac, the socalled happiness-pill, which is the medical response to serotonin deficiency. The happiness-pill contains the SSRIs, which is short for *selective serotonin reuptake inhibitors*, a drug which prevents the normal reuptake of serotonin, extending the period in which the serotonin continues to operate and circulate in the bloodstream.

It is no coincidence that the consumption of Prozac raises dramatically in November, in line with the fading sunlight and daylight. This is when the impact of seasonal depression (SAD) begins to show.

In the darkness during the winter, serotonin is transformed into melatonin. Serotonin being a precursor to melatonin, the levels of serotonin in the body are thus lowered. The lack of serotonin results in mental discouragement, just like the presence of melatonin causes fatigue. All in all, this results in a depression-like state. But as the light re-appears in the springtime, the fatigue disappears and the light again stabilizes the levels of melatonin, increasing the levels of serotonin, which again increase the overall well-being.

Studies [109,110] indicate that the amount of sunlight – along with the quantity of stored vitamin D in the body – contribute positively to maintaining high levels of serotonin throughout the winter and until spring. The levels of sero-

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107 Sack RL, Brandes RW, Kendall AR, Lewy AJ. *Entrainment of Free-Running Circadian Rhythms by Melatonin in Blind People*. The New England Journal of Medicine, 2000.

108 Serotonin is a neurotransmitter, which is transported via the bloodstream – also known as a hormone. It is produced in certain areas of the brain. Source: The Great Danish, Gyldendals Open Encyclopedia, 2013.

109 Lansdowne ATG, Provost SC. *Vitamin D3 enhances mood in healthy subjects during winter.* Psychopharmacology 135, 1998.

110 Partonen T, Leppämäki S, Hurme J, Lönnqvist J. *Randomized trial of physical exercise alone or combined with bright light on mood and health-related quality of life.* Psychological Medicine, 1998.

tonin in the brain therefore actually seem to depend on how much sunlight we have received through the last summer. A critical time in this context is the early spring, when the serotonin-levels and the mood have not yet fully stabilized after the winter darkness; vigor and energy, however, have returned, explaining a higher suicide rate in the springtime.

In Denmark approx. 5% of the population suffers from seasonal-affective-disorder (SAD), while 10% suffer from winter blues, in the form of a milder precursor of seasonal-affective-disorder, the so-called sub-SAD[111]. Last year in November the media estimated that approx. 460,000 Danes were prescribed SSRI Prozac, a number which is steadily increasing and which has in 2012 alone increased by 18% compared to 2011, and doubled since 1999.

Today, treatment with short-waved light is an internationally recognized non-medical treatment[112] of winter depression and is commonly used in the treatment of people suffering from SAD. The treatment works most efficiently[113] when the exposure to light happens during the morning hours. It seems that we are most susceptible to light in the morning, simply because light supports the natural formation of serotonin, which takes place at this time of the day. Diseases such as *dementia* are also related to serotonin and can similarly be treated and improved non-medically, utilizing bright light in the morning hours.

Finally, the circadian rhythm varies with age. This is due to many factors, including variations in the general sleep patterns. However, the light and the anatomy of the eye also play an important role. The circadian rhythm is impaired with age, due to the fact that the eyes transmit less of the short-waved light, stimulating the primitive ganglia cells, as we get older. This due to the fact, that the cornea turns yellow with age – the complementary color to the blue light, stimulating the circadian rhythm. This reduces the amount of blue light reaching the photosensitive ganglia cells in the retina. Elderly people may therefore need more light, in the form of more outdoor activity – or clearer glass[114] – to reset the circadian rhythm and improve their, often poor, sleep.

Light and depression

According to the WHO, depression is one of the diseases that potentially threaten to undermine the modern welfare state[115]. Depression today represents the 4th major disorder in the Western world, second only to cancer, cardiovascular disease and obesity. In the future it is expected that depression will be one of the conditions resulting in the greatest loss of healthy life.

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111 Christoffersen J. *Light, health and wellbeing*. Arkitekten 09. 2005.
112 Epperson CN, Terman M, Terman JS, Hanusa BH, Oren DA, Peindl KS, Wisner KL. *Randomized Clinical Trial of Bright Light Therapy for Antepartum Depression: Preliminary Findings*. Journal of Clinical Psychiatry, 2004
113 Martiny K. *Winter depression should be taken seriously*. Ugeskrift for Læger 173. 2011.
114 See chapter 4 Glass.
115 Hobday R. *The Healing Sun,* p. 34. Findhorn Press, 1999. WHO estimates that expenses to treatment of depression in the U.S. amount to approx. 44 billion. $.

The lack of light is closely linked to depression and light therapy is a recognized non-medical treatment for most forms of depression. As we have seen, light influences the production of serotonin, directly affecting the mood[116]. Light, therefore, has a positive anti-depressive effect[117], not only reducing the need for other medications, but also increasing the efficiency of other medicine. Light as a form of treatment for depression is most effective during the morning hours[118, 119] and not during the evening hours, when the light actually seems to have the opposite effect – both delaying and impairing the nocturnal sleep. Again, this is about the production of serotonin, which is best stimulated by light in the morning.

However, to have any effect, the light must have a certain intensity and quality, and again the architecture and the quality of glass become central factors. A previous study[120] shows that solar protective glass has *a drowsiness factor* when we talk about the intensity of the light, the shadow-rendering and the color-rendering, changing the visual perception of the physical objects and spaces.

However, it turns out[121] that many glass types not only have a drowsiness factor, affecting the physical environment, they also have a sedative effect, directly affecting our bodies. This due to the fact that the transmittance of glass varies and influences the non-visual parts of the light, subsequently reducing the production of serotonin. The clear low-iron glass, all being equal, provides more of the blue, short waved light, which stimulate the missing piece in the puzzle lighting, thus providing a better mood, a higher level of activity – and an improved sleep.

Darkness and health

Our sleep is regulated by two independent factors; *a homeostatic factor* and *a circadian factor*[122]. While the homeostatic factor is controlled internally by the body, the circadian factor is controlled by cues from the environment, in the form of light. These two sleep factors work quite differently. While the homeostatic factor builds up gradually throughout the day, the circadian factor fluctuates around PM. 18.00. Light before this time advances sleep by *phase-advance* (PA), while light after this time delays the sleep by *phase-delay* (PD).

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116 Golden RN, Gaynes BN, Ekstrom RD, Hamer RM, Jacobsen FM, Suppes T, Wisner KL, Nemeroff CB. *The efficacy of light therapy in the treatment of mood disorders: a review and meta-analysis of the evidence.* American Journal of Psychiatry, 2005.
117 Tuunainen A, Kripke DF, Endo T. *Light therapy for non-seasonal depression*. Department of Psychiatry, University of Helsinki. PubMed, 2004.
118 Krivisky K, Einat H, Kronfeld-Schor N. *Effects of morning compared with evening bright light administration to ameliorate short-photoperiod induced depression- and anxiety-like behaviors in a diurnal rodent model.* Journal of Neural Transmission/ PubMed, 2012.
119 Lewy AJ, Bauer VK, Cutler NL, Sack RL, Ahmed S, Thomas KH, Blood ML, Latham Jackson JM. *Morning versus Evening Light Treatment of Patients With Winter Depression*. Journal of American Medical Association, 1998.
120 Frandsen Sophus. *Low-energy windows and daylight quality*. The Royal Academy of Architecture, 1996. p. 6.
121 See chapter 4 Glass.
122 Lockley Steven W, Foster Russel G. *Sleep – a very short introduction*, p. 18. Oxford University Press, 2012.

At certain times during the day, these two sleep patterns meet, providing the so-called *gates* to sleep. This happens in the evening, when the homeostatic sleep pressure and the circadian sleep pressure meet, creating a pathway or a gate into sleep. But it also happens – albeit to a lesser degree – right after lunch- time, when the circadian need for sleep has not completely disappeared, while the homeostatic need for sleep has increased since the morning hours. On this background, it is no coincidence that many southern countries benefit from this latter gate to take a healthy siesta after lunch.

The sleep period is no longer regarded as an unconscious state, but rather as the foundation of all activity and good health. Poor sleep and deprivation of sleep[123] can cause chronic diseases, such as cancer, cardiovascular diseases, type 2 diabetes, together with other disorders such as obesity, stunted growth, cognitive impairments and poor learning – just like poor sleep also weakens the immune system[124].

Research[125] indicates that we, in the Western world, generally receive too much light during the evening, impairing our sleep, which again impairs our health. In our industrialized society we sleep on an average only approx. 7 hours a day, often suppressing the need for sleep by going to bed too late at night. Before the industrialization, our sleep pattern was longer and varied more compared to the season. During the wintertime we could sleep for up to 10 hours[126] and during the summer significantly less. These seasonal variations was primarily caused by one factor – the amount of daylight.

However, darkness and areas with darkness are not wellcome in many cities today, because darkness may result in increased risk of crime. Therefore the illumination of the 1900s is spreading to large parts of the cities all over the world, illuminating the skies at night. In fact so much so, that e.g. migratory birds and turtles – using light to navigate – no longer seem to be able to orient themselves in relation to time and place. Similarly, the opportunity to see the stars and the moon above is often impaired by the *light pollution* created by dense city-development and excessive use of artificial lighting. Also stressing our circadian rhythm, when living in a society, where *circannual* differences between summer and winter, and *circadian* differences between day and night, are not taken more seriously. Our 24/7-society questions the relevance of darkness – a concept, which Modernism fought because it was unhealthy and harbored bacteria. But a concept, which we today may consider downright healthy.

123 Ibid, p. 91-102.
124 Lockley Steven W, Foster Russel G. *Sleep – a very short introduction*, p. 91-111. Oxford University Press, 2012.
125 Gooley J, Chamberlain K, Smith KA, Khalsa SBS, Rajaratnam SMW, Van Reen E, Zeitzer JM, Czeisler CA, Lockley SW. *Exposure to Room Light before Bedtime Suppresses Melatonin Onset and Shortens Melatonin Duration in Humans*. The Journal of Clinical Endocrinology and Metabolism, 2011.
126 Lockley Steven W, Foster Russel G. *Sleep – a very short introduction*, p. 18. Oxford University Press, 2012.

3 ARCHITECTURE AND HEALTH

3. ARCHITECTURE AND HEALTH

Architecture is a man-made, physical balance, a balance between various factors, such as cold and heat, light and darkness, etc. Architecturally, several different strategies have been used throughout time to achieve this balance. Through the previously described affinity between light and health, light, and the planning of light, has often played a central role in these efforts. However, this role has not always been one-sided, for as often as architecture has created the foundation for life and health, it has also created the foundation for disease and death. In the same way the role of the architecture has not only been built on light and health, but rather on the fear of *darkness* and *disease*, and often it appears to be devastating diseases which lead to a healthier architecture.

Cholera

While mortality rates in general decline in the rural areas from the mid-1700s, the opposite is the case in the cities. In the new major cities created by the industrialization, people are living close together, often under deplorable conditions in so-called corridor-properties and back-to-back housing. Here, mortality rates increase with the density of the population[127]. Under these poor physical conditions several diseases occur, amongst those a disease that will affect architecture, a disease called cholera. Cholera claims its first fatalities in cities like Manchester, which is, with its large weaving mills, the birthplace of industrialization. The city of Manchester has grown from a population of approx. 17,000 in 1760 to approx. 400,000 in the mid-1800s. In *Friedrich Engels* eyewitness account the city is characterized as:

Bad ... and irregularly built, with dirty backyards and alleys full of coal smoke and with a special uninhabitable appearance in the original crimson, but eventually black smoky tiles, which is still the common building material here. Basement Apartments are common, wherever feasible, these subterranean small holes are occupied, and a very significant proportion of the population is living in them[128].

The same miserable conditions prevail in Copenhagen when cholera breaks out in 1853. The city has grown significantly through the 1800s, but because of military defense and political conditions, it has not grown beyond the demarcation lines and ramparts, which are completely deserted. People are living extremely close together without any sanitation or sewerage. Cholera affects 7,219 people and kills 4,737 out of a population of approx. 110,000 in only 16 weeks[129]. A not very skilled medical profession is engaged in hefty disagreements about the

127 Schmidt LH, Kristensen JE. Lys, luft og renlighed, p. 39. Akademisk Forlag. (1986) 2004.
128 Marx K, Engels F. *Die lage der arbeitenden Klasse in England*, p. 274. Werke 2, 1845.
129 Jensen K. *Fighting infectious diseases,* p. 15. Nyt Nordisk Forlag Arnold Busck. 2002.

cause of this sudden and violent outburst of cholera. Is it contracted through poor diet? Polluted air? Or is it caused by the lack of sunlight? Some doctors call for wider streets and more sunlight and air. However, these requirements are not met, and the cholera has no impact on the Building Act, which does not change as a result of this disease.

Yet cholera indirectly causes Copenhagen to expand and the ramparts to be abolished. As part of a new health strategy, aimed at preventing new epidemics, new and healthier housing is planned. This triggers a new architectural development which, unlike the existing housing, is planned to provide plenty of light and air. *Brumleby*, built 1854-56 by the architects *M.G. Bindesbøll* and *Wilhelm Klein*, is an example of this new and healthy architecture, an architecture differing from the existing, tall and dense architecture within the ramparts, by being low and scattered, providing more sunlight both outside and inside the terraced houses. However the construction also differs in another way, namely in the way that doctors and architects work side by side, creating a healthier architecture, an architecture which does not only rely on sunlight and health, and a belief in the physical environment and its importance to our health – but also on the fear of infectious diseases.

Rickets

Another disease that affects the architecture has its Danish name from its origin, namely the English factory towns, as previously described, a disease called *English disease* or *rickets*. Rickets is often described as *the hidden disease* due to the fact that it occurs gradually and without any actual disease. This is the reason why it is often overlooked compared to other, more visible, diseases. But rickets is a widespread disease in the densely populated and industrialized cities of the late 1800s. The lack of fresh air and sunlight, together with predominantly indoor factory work, means that people do not get enough sunlight and vitamin D. The disease results in a lower calcium uptake leading to poor bone growth and fragile, soft and often deformed bones. The disease especially affects children who are more vulnerable to calcium deficiency, needing calcium for the growth and the development of bones.

However, vitamin D is at this stage not discovered, and again the medical profession is as ignorant about the treatment, as it is divided about the cause of the disease. Some believe that it is an infectious disease and some believe that the lack of exercise in the cities may be the cause of the disease, while others believe that the lack of sunlight and a poor diet is causing the disease.

In spite of the most varied and extensive research, we have practically no real knowledge of the nature or the causation of this widespread malady or the factors that determine its onset (Ferguson 1918:17)[130].

130 Carter S. *Rise and Shine – Sunlight, Technology and Health*, p.40. Berg, 2007.

We may surmise that lack of exercise and fresh air… allows the generation of some harmful product, and so by auto-intoxication brings about the disease (Findlay 1908:17)[131].

In the absence of specific knowledge, the therapeutic treatment is quickly divided into two irreconcilable camps: one considers the disease to be best controlled through diet, the other that the disease is best controlled through a healthier environment with more sunlight. The latter consider themselves more democratic because sunlight – unlike a good, balanced diet – is all cropped, regardless of their income. Considering that the disease is often found in the densely populated, poor parts of cities, this does not seem to be all wrong.

However, it is only later with the discovery of vitamin D in 1922[132], that the medical profession realizes that rickets is caused by the lack of this vitamin. The discovery of vitamin D – and especially the discovery of what the lack of vitamin D can cause to the human body – strengthens the already close relationship between light and health. A relationship that will prove to have a huge impact on the architecture during the early Modernism, founded exactly in this period, with its mantra of light and health, fighting the prevailing darkness and diseases in the cities.

Tuberculosis

There is a saying that *all diseases occur in the dark and are cured in the light*. Tuberculosis – or *the white plague* as it is also called – is, in principle, such a disease and arguably the disease which appears to have the greatest influence on the relationship between architecture, light and health. Tuberculosis is a highly infectious and fatal disease, which is transmitted by the bacteria *Mycobacterium Tuberculosis* through water drops. In Finland and Denmark, people are mandatorily committed as soon as the disease is contracted – simply to avoid any further spread of this disease, spreading aggressively through the air.

The disease lays the foundation for entirely new architectural principles and new building laws, such as The Building Act of 1899. A building act which, as something new, stipulates that all habitable rooms must have access to daylight, also increasing the minimum width of the street in order to let the – for the tuberculosis bacteria – lethal UV light down to the street level, where people breathe. The Building Act of 1899 immediately has a huge and fundamental impact on the architecture in Denmark – with consequences which actually characterize the architecture right up until today. If we compare e.g. to Amercan and Canadian architecture, the Building Act creates a clear architectural expression through most architecture in Denmark, putting specific minimum requirements to the street widths, at 18 meters, and stipulating a minimum floor area of 6 m^2 in

131 Ibid, p.41.
132 Ibid, p.40. Theopald Palm already in 1890 shows a direct correlation between the lack of sunlight and the emergence of rickets, by comparing the incidence in the UK to more sunny countries, such as Japan and China. However, more than 30 years will pass before this causation is recognized and before the medical profession recognizes the recommendations of Palm, which is why rickets often is termed the hidden disease, ref.

all residential rooms, also requiring direct access to daylight and fresh air. Finally, it puts an end to the speculative so-called corridor housing and back-to-back housing. These requirements for daylight in residential rooms subsequently mean that buildings are being optimized for the daylight in often sleek, E, H, and U-shaped building-typologies. On this basis, there is nothing new under the sun when Louis Kahn says:

A room is not a room without natural light[133].

Rather, this statement sounds like an echo of The Building Act of 1899. This quote, however, must be seen in relation to the more lenient requirements regarding access to daylight in America, resulting in larger, deeper and often square building shapes. Building shapes which may present a better land use pr. m^2 – but which result in a significantly poorer utilization of the daylight.

William Hesketh Lever´s vision of a healthy city, Port Sunlight, near Liverpool, 1888. The city is an example of how sunlight, at this time, becomes a tool in the attempt to improve the public health and prevent diseases such as tuberculosis and rickets. However, seen from a daylight perspective, the sunlight does not seem to be very well planned. As shown, the main axes are facing N-NW, providing little morning sun throughout the dark winter period

In England, Sir William Hesketh Lever plans an entire new city for the workers at Lever Brothers[134]. Lever´s high personal ideals of light and health are partly manifested in the fact that he markets his main product, a hand-soap, under the name of *Sunlight*[135]. Lever directly compares the antiseptic properties of the soap with the, newly discovered, antiseptic effects of the sunlight on bacteria. Indeed, this is part of the explanation for the name of the city, *Port Sunlight*. The planning of the light in the city, however, does not differ from any existing cities, it neither has a specific structure, or a particularly conscious plan for the sunlight, geographical orientation, or time of day or activity.

In Europe, the struggle against tuberculosis and rickets materializes in several new social movements, partly supporting a new and healthy architecture, and partly fighting the existing architecture and its darkness and diseases, such as tuberculosis. In England, numerous health movements emphasize the seriousness of the fight against the darkness, sometimes even in the form of declarations of war, as here, from the organization *The Sunlight League*:

We declare war against the powers of darkness; smoke and slums must go…our new houses must be placed so as to receive the sun…we seek to multiply the sources of information and education to such an extent that…no man or woman shall be stricken with disease for lack of knowledge of the light that heals[136]

When it comes to the planning of the new industrial cities, the new health strategy helps to create more focus on light, assisted by several doctors, who see the new opportunities in these health aspects of the sunlight.

133 Kahn Louis I. *Law and Rule in Architecture.* From a lecture, 1961.
134 Nb. Later Unilever.
135 Carter S. *Rise and Shine – Sunlight, Technology and Health*, p.85. Berg, 2007. Sunlight 1924:5-6, ref.
136 Ibid. p.75.

The evolution of the sciences of light brings us naturally to the logical developments which have been made in the last two or three years... All forms of Rickets and many forms of Tuberculosis readily respond to irradiation...the most remarkable therapeutic use, however, is general irradiations of the whole body given as a tonic to maintain the health at the highest standard of efficiency[137].

The close relationship between light and health manifests itself in many different ways. From *the open planning*, promoted by initiatives from *The Royal Institute of British Architects* (RIBA) in the 1930s[138], to the planning of urban green spaces, inspired by Ebenezer Howard's ideas and sketches in *The Garden Cities of Tomorrow*[139], and finally through a more detailed planning of the light, as practiced by the architects *Parker & Unwin*[140], in an effort to optimize the natural light in their houses, based on the sunlight, the geographical orientation, the time of day and the activity.

The general rule, then, would seem to be, so to contrive as to get the sunshine into a room at the time when it is most likely to be occupied. Let the study or breakfast room be east or south-east, a general living room or drawing room be south or south-west. A good western window in the room we most occupy during the latter part of the day. It gives us many an extra hour of daylight; while the opportunity it affords us of habitually seeing the bright color of sunset is a privilege which is worth some effort to obtain[141].

However, light is not only applied in the fight against diseases throughout the 1920s and 1930s, light is also used as a more preventive and *prophylactic* element, i.a. in the new social housing and schools built in this period. As in the age of cholera, architects and doctors work together, building a new and healthier architecture.

The health requirements, you should ask for a home can be summarized into three words: light, air and cleanliness. The homes very much have influence on the general health. Thus, an over-population in form of a conglomeration of many people in small rooms, form a large physical and moral risk of contagion[142].

In this period, the bathtub is highlighted as a product of beauty and hygiene, actually hygiene becomes an ideal of beauty in the struggle against superfluous ornamentation. A fight, which often results in clean, geometric and Euclidean shapes. Light is regarded as the only ornamentation in otherwise quite uniform, clean surfaces which – bathed in light – so to speak, are cleaned by the antiseptic rays of the sun. *Jan Duiker* is an example of an architect who is able to combine

137 Ibid. p. 62, Leonard Dodds, 1928, ref.
138 Ibid. p. 91.
139 Ibid. p. 87. This happens in 1899, through The Building Act 1899.
140 Ibid. p. 88. In the beginning of the 1900th century.
141 Ibid, p. 88. Parker/Unwin, 1901, ref.
142 Schmidt Lars-Henrik, Steffensen Jens Erik. *Lys, luft og renlighed,* Akademisk Forlag (1986) 2004, p. 172, ref. Haandbog for nutidshjem 1948, b. 2, p. 9.

these clean, simple forms with the faith in light as *a serum* of health. Where *Adolf Loos* and *Walter Gropius* in principle work with the same simple shapes – based on a moral context; the style is to be cleaned of redundant work and eclectic styles, creating class divisions in society – Jan Duiker not only cleans the style, the style in itself must be cleaning[143]! This extra aspect of hygiene is considered a welcome rationale, strengthening Modernism, a style that will soon conquer the whole world, *an international style* where nothing reveals its origin, sterile and cleansed from *ornaments and crimes*[144] against purity – and against healthiness.

Jan Duiker and Bernard Bijvoets Open Air School in Cliostraat is a good example of this *hygienic style* and its clean and very powerful expression. However, it is also an example of the major problems that such a style invoke. The large glass facades create heat-related problems. Duiker meets the criticism, defending the style by claiming that people have not yet become accustomed to the new style, instead Duiker suggests simple behavioral changes, such as airing out in the morning and opening up the windows away from the sun in the afternoon. However, these heat problems prove to be a recurring problem for this clean glass architecture and the international style gaining ground in the period after World War I. The glass architecture is simply too hot in summer and too cold in winter, as it is based on a strategy of exposure to sun. However, this exposure overemphasizes the sunlight and proves to cause problems with overheating. There are disagreements as to why this overheating takes place; Jan Duiker erroneously believes that the large windows do not cause overheating, as long as the roof is well enough insulated[145]. However, all in all, this international, hygienic style, characterized by simple, Euclidean shapes, do not distribute the hours of sunshine as well as the classical E-, L-and H-shaped typologies, where more spaces receive sun from multiple angles, providing more hours of sunshine during the day and the year. Yet the same glass architecture and Euclidean buildings are conceived today, architecture which is confusingly similar to the simple, geometric glass utopias, which *Paul Scheerbart*[146] dreamt about in the 1920s. Buildings which do not take into account the light- and heat-radiation of the sun, the geographical orientation or the geographical location for that matter. This modernist, international style is very much alive today, as seen in the glass architecture of Saudi Arabia, which is confusingly similar to the glass architecture of Paris or London – when we ignore the inches thick solar protective glass which allows these utopias.

We may question this international style and we may have to abandon the mindset of Jan Duiker and Le Corbusier, in the emerging age of mass production of architecture. Architecture which, in principle, could be built anywhere, quite independent of the geographical orientation and the geographical location. In the following, I will review some examples of modernist glass architecture and study

143 Overy P. *Light, Air & Openness,* p. 129. Thames & Hudson, 2007.
144 Loos Adolf. *Ornament und Verbrechung* , 1908.
145 Overy P. *Light, Air & Openness,* p. 130. Thames & Hudson, 2007.
146 Scheerbart P, *Glasarchitektur,* 1914. Member and founder of Die Gläserne Kette, together with Bruno Taut.

their simple, often symmetrical shapes, their original intentions and limitations, and how the solutions of today clash with the original intentions in what I call *failed strategies*.

Failed strategies

In England, *The New Health Society*, formed in 1926[147], helps to promote the use of a completely clear low-iron glass in the 1920's, also known as *Vita glass*. It is produced by Pilkington Brothers Inc., and is a particularly clear glass which allows the entire spectrum – also parts of the UV light – to penetrate the building[148]. This glass is recommended and used in England, Scandinavia and the Netherlands, particularly in hospitals and school buildings, which are incidentally planned in a collaboration between architects and doctors. At a press conference, organized by The New Health Society, physician Dr. Belfrage promotes the clear Vita glass in the following way:

Ultra violet consisted of invisible rays.... It had been proved that they had a stimulating effect on the general growth, power of resistance to disease, and on the richness of the blood.... ordinary window glass...was quite un-transparent to the health giving ultra-violet rays[149].

This low-iron, clear Vita glass is actually used in approx. 200 schools and 300 hospitals[150] in Europe in the pre-antibiotic era. But what happened to these buildings? And what happened to the clear Vita glass? In the following field studies we will have a closer look at this.

The Peckham Health Centre

The Peckham Health Centre is located in South London and is designed by *Owen Williams* in 1935. Williams is one of the pioneers of *The British Movement* and one of the first to work with *curtain walls*, full glass facades, in England. The Peckham Health Centre is originally a social experiment – *The Peckham Experiment*[151] – initiated to improve the public health in England, which occurs primarily by preventing diseases. Families, mainly belonging to the poor working class, can here avail of services, including family counseling, a gym and a swimming pool. All the while, Dr. Scott Williamson and his wife Dr. Innes Pearse oversee and study the families through the fully open and transparent glass structures inside the building. There are no fixed walls, only key pillar structures, enabling the large, unbroken expanses of glass, and all rooms appear open, flooded by the light of the sun.

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147 Carter S. *Rise and Shine - Sunlight, Technology and Health*, p. 68. Berg, 2007.
148 Ibid. p. 68. Berg, 2007. Vita glass is produced and marketed by The Pilkington Brothers in the 1930s and consists of low-iron glass with a high content of quartz.
149 Ibid. p. 68.
150 Ibid. p. 68.
151 Overy P, *Light, Air & Openness*, p. 66. Thames & Hudson, 2007.

PUBLIC NOTICE

Southwark Council

www.southwark.gov.uk

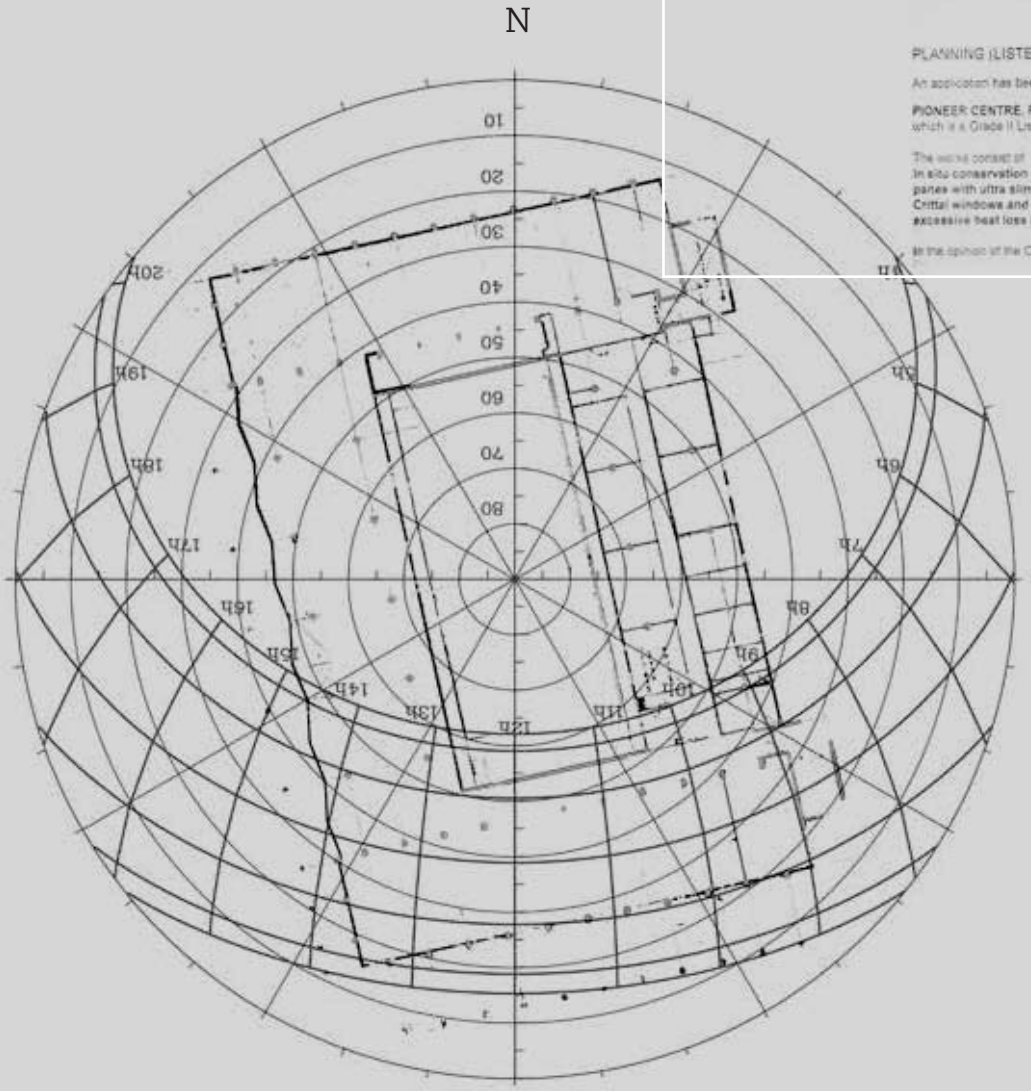
PLANNING (LISTED BUILDINGS AND CONSERVATION AREAS) ACT 1990

An application has been received by the council for consent to carry out works at

PIONEER CENTRE, FROBISHER PLACE, LONDON, SE15 2EE
which is a Grade II Listed Building

The works consist of
In situ conservation of the existing "Crittal" **steel window frames** and replacement of glass panes with ultra slim double glazed **sealed units in order to prevent** further deterioration to Crittal windows and fabric of the building **due to excessive condensation**, also to prevent **excessive heat loss in winter time and excessive heat gain** during the summer.

In the opinion of the Council this development may alter the setting of the listed building



The Peckham Health Centre, 1938 (left), with the clear Vita glass, and the building today (right), renovated with solar protective glass.

The NS-axis, with the large facades facing E and W, opens up for the morning sun and for the evening sun equally. This may work further south, where there is less seasonal variations, and where the sun sets earlier during the summer. But here, at 51° N. this orientation neither utilizes the sparse morning sun during the winter, nor shields against the late evening sun during the summer.

The sunlight creates heat problems, especially in the W-facing facade, from early afternoon until late evening, at times of the day when the building is already warm.

Above: The result; an application for solar protective glass in front of The Peckham Health Centre, or The Pioneer Centre as it is named today

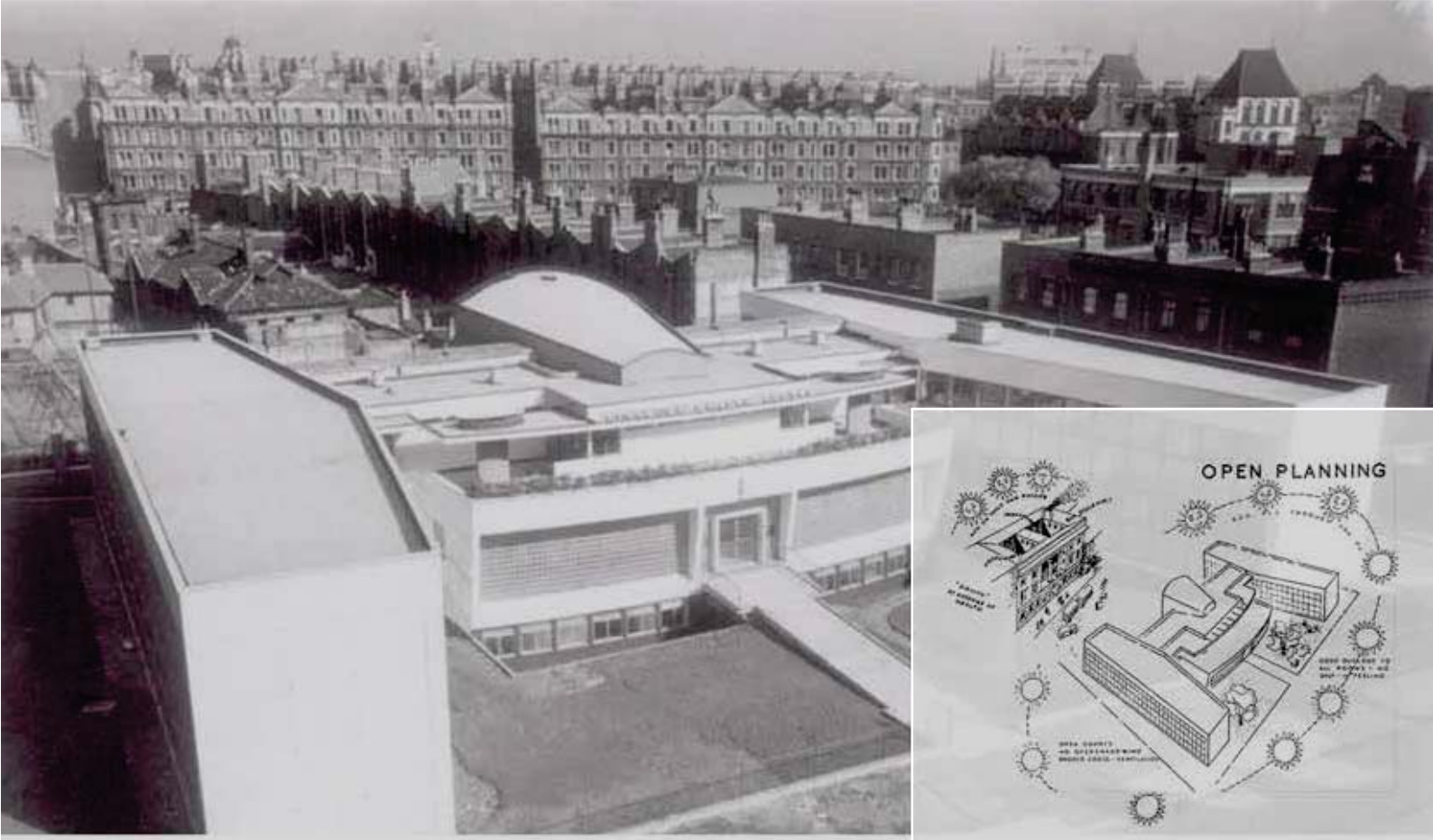
Today The Peckham Health Centre is renamed *The Pioneer Centre* and is converted into residential housing. The fascination with light from the 1930s meets the thermal problems of today, which Jan Duiker also adressed. With excessive overheating during the summer and too high a heat emission during the cold winter, this open planned architecture constitutes a major problem when it comes to sustainability and well-being due to the large areas of glass. As a consequence the original, thin, single-paned *crittal-steel windows* are replaced by new solar protective glass panels, primarily to the west – and currently an application has been sent to the local authorities to replace all the glass facades of the listed building. Concrete evidence of the heat problems created by too much glass is seen in the application to the local authorities on the previous page, to replace the original Vita glass with poorer, solar protective glass. This is primarily caused by the large glass facades offering no protection from the sun, especially the evening sun, which seems to require some sort of shielding and protection. The Peckham Health Centre is generally oriented to maximize the sunlight – in an open planning. As described earlier, the Royal Institute of British Architects (RIBA) in the 1930s[152] promotes initiatives and new methods to optimize the sunlight in the construction. The Peckham Health Centre is, with its open plan and maximized orientation to the sunlight, a physical manifestation of this statement.

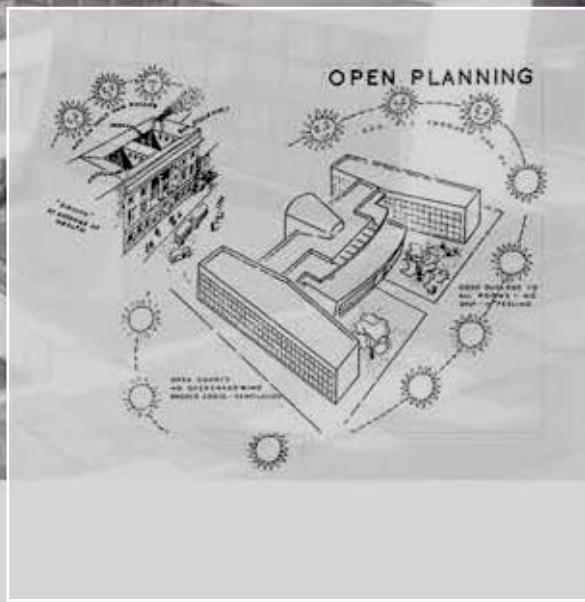
However, this strategy proves to be problematic in relation to the geographical orientation, and if we look at the architecture, there are some fundamental problems when we are talking light and health. The eastern facades of the building receive virtually no morning sun throughout most of the winter. The western facades, on the other hand, receive too much – and too late – sun, throughout the hot summer period. In other words, the shape of the building is neither balanced for the winter sun nor for the summer sun. The symmetrical and rectangular shape and the completely identical, symmetrical facade distribution opens up to the sun – but does not shield against the sun, and this creates problems, letting in light late in the day, when light is less beneficial or, for that matter, healthy. The undifferentiated glass facades and the symmetrical and open building plan are both conditions which live up to the requirement of high daylight factors, however they do not take into account the large differences between the morning sun and the evening sun or the large differences between the summer sun and the winter sun. In other words, The Peckham Health Centre does not succeed to create the right balance between too much and too little sunlight.

The Finsbury Health Centre

While The Peckham Health Centre prevents disease, *The Finsbury Health Centre* primarily treats people who are already sick. The Finsbury Health Centre is located in a poor working-class neighborhood in north-east London and is designed

152 Op. cit. p. 63.





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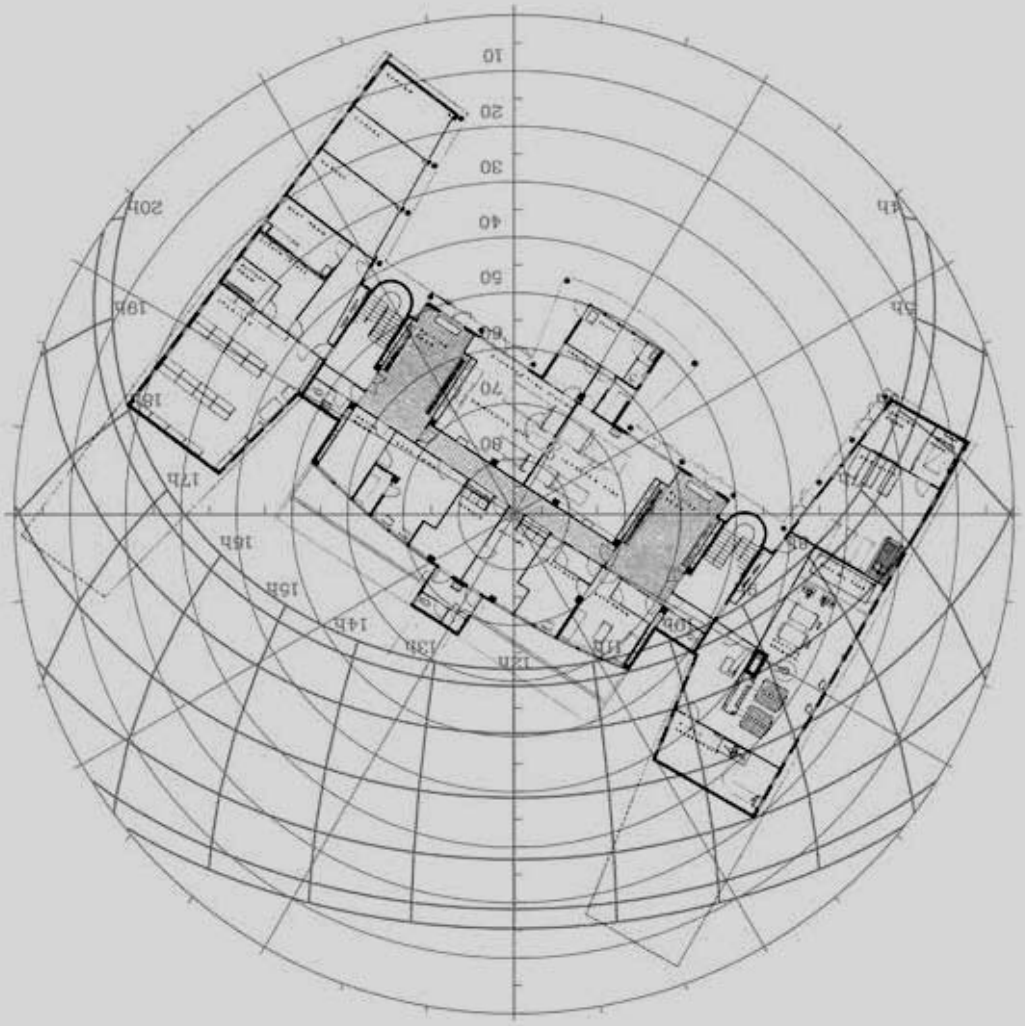


The Finsbury Health Centre is laid out in a SE-facing axis. The open glass facades to the E, S and W create problems with too much solar gain, while the building has hardly any glass areas to the N. The building is based on the open planning promoted by RIBA, in an intention to optimize the sunlight during the day, in contrast to the dark backyards without sunlight, as shown on the drawing (top)

by *Bertholt Lubetkin* in 1938. Lubetkin is a Russian émigré and a strong supporter of the new modernist movement in Europe. Like Paul Scheerbart, he believes that glass is the answer to a new architecture, reflecting a new, modern and democratic world. The Finsbury Health Centre primarily facilitates the treatment of diseases such as tuberculosis and rickets, and the patients are hospitalized on wards receiving daylight from both sides by continuous, glass panels, glazed with clear single-layered Vita glass which can be opened during the summer.

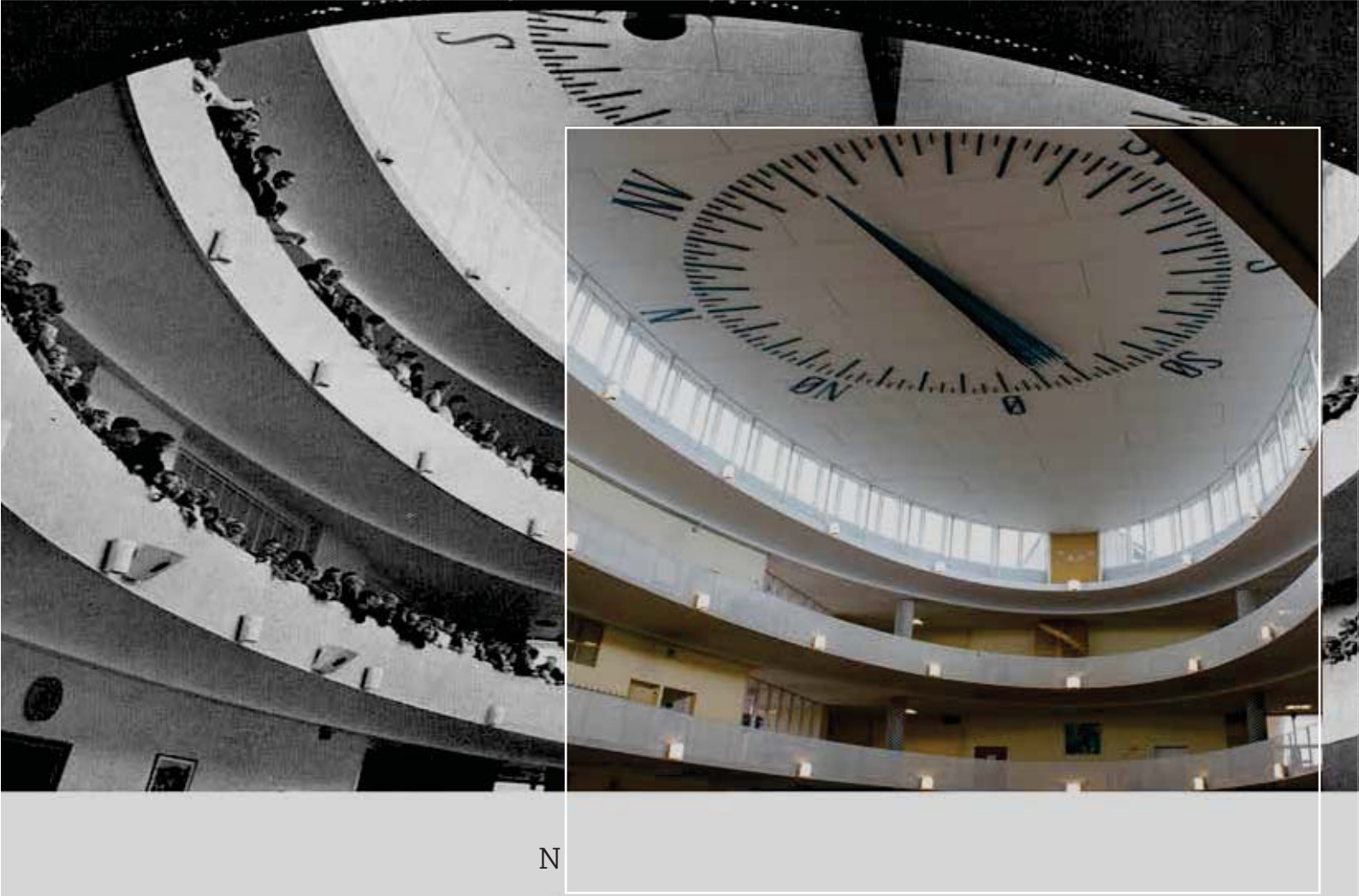
Like The Peckham Health Centre, The Finsbury Health Centre uses abundant glass, albeit not a curtain wall solution as at The Peckham Health Centre. Instead, continuous, horizontal windows provide light throughout all rooms of the narrow building. A solution which – in the same way as at The Peckham Health Centre – not only provides plenty of light, but also excessive heat problems during the summer as well as cold drafts during the winter. Again, the heat radiation from the sun is completely overlooked in the attempt to maximize the sunlight, as motivated by RIBA. The result also remains the same; namely that the completely clear Vita glass today is replaced by solar protective glass[153]. Again, the strategy fails and the glass loses quality, whereby the daylight is considerably impaired. Again, the original intention of natural and healthy daylight fails.

The Finsbury Health Centre also has a completely symmetrical building shape, but, unlike The Peckham Health Centre, Bertholt Lubetkin doesn't utilize the north-facing facade, which acts as the rear of the building, with a recessed parking lot with limited access and a closed facade. Another difference is that The Finsbury Health Centre is laid out in a SE-facing axis, while The Peckham Health Centre is orientated S-SE. As a consequence, there is more morning sun in The Finsbury Health Centre during the winter time and less late evening sun during the summer time. But again, a completely symmetrical building shape, together with an undifferentiated planning of the glass facades, means that the sunlight is not balanced. There's nowhere to seek refuge from the sun, simply because the building – in the spirit of modernism – is trying to optimize the daylight. However, optimizing the daylight is not the same as balancing the daylight – creating a balance between too much sun and too little sun through the day and through the year, or creating a healthier light for that matter – again a strategy that fails.

Skolen ved Sundet

Jan Duikers hygienic open air school in Rotterdam inspires several similar buildings in Scandinavia. One of them is *Skolen ved Sundet,* designed by *Kaj Gotlob* 1938. Here, light and fresh air play a major role, both at the school and at the associated open air school. The building is laid out as an EW-orientated ellipse, with the main facades facing N and S. The straight EW-axis is no coincidence, since the school is established as a training project for children, learning to navigate in the world and to relate their place in the world to the four cardinal points,

153 A replacement currently taking place, 2012-14.



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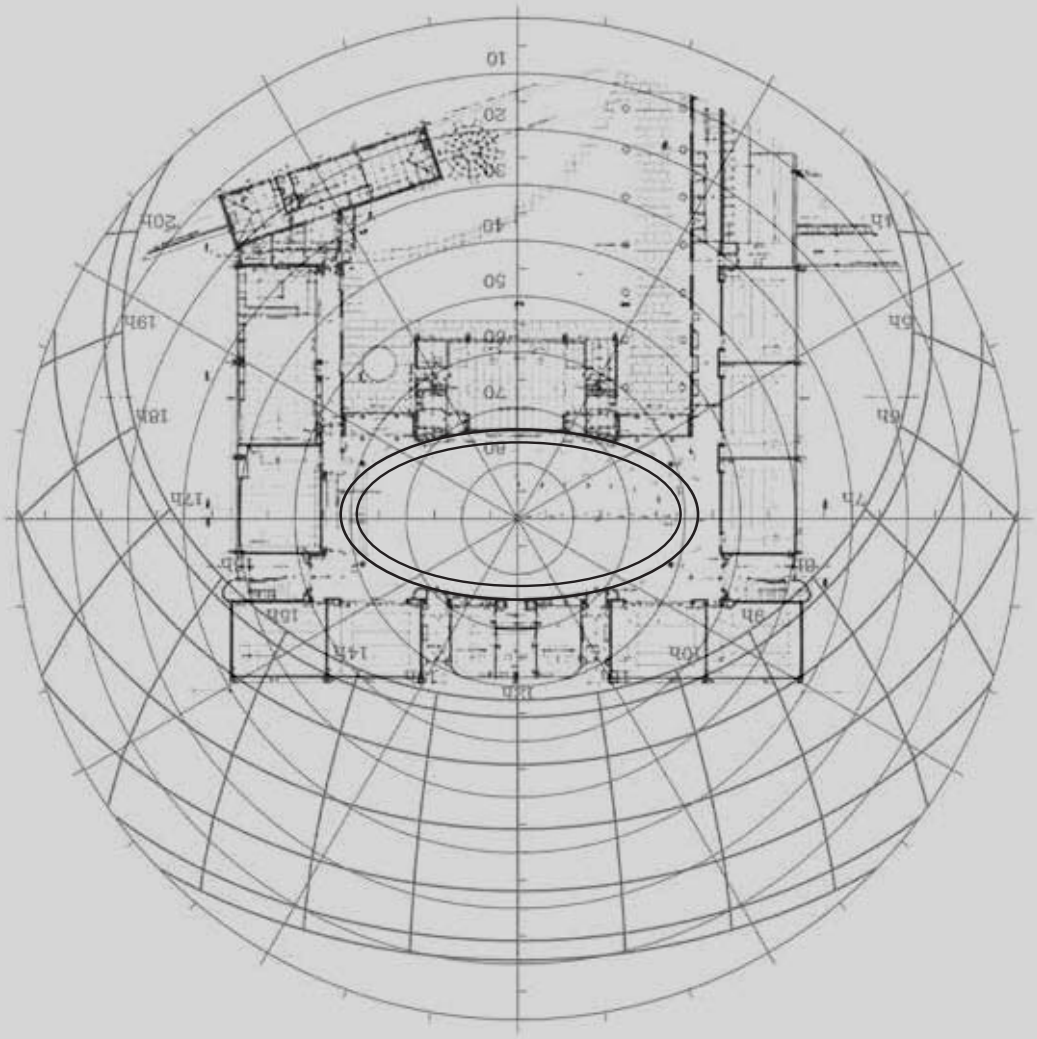


Skolen ved Sundet, 1938 (left), and the building as it looks today (right). The school is laid out in a EW-facing axis, with a N-side which does not receive sunlight throughout the winter period. During the summer, the morning sun and the evening sun are not differentiated or balanced. This creates too much light and heat during the hot summer period. A problem, solved by means of technology, using solar protective glass, however resulting in a significantly poorer daylight

well aided by an arrow head in the ceiling, hovering over a map of Copenhagen, carved into the linoleum floor.

In many ways Skolen ved Sundet is similar to the previous buildings, and many conditions are indeed the same. The EW-orientated axis again optimizes the daylight – as we have seen in both the English sanatoriums. Again, the shape of the building is symmetrical. There is no difference in the planning of the morning light and evening light, and again the undifferentiated glass facades consist of large, unbroken horizontal areas of glass, similar to The Finsbury Health Centre.

The building does not balance the sunlight during the day and year, inasmuch as the EW-oriented axis exploits the winter sun, but in many ways opens up too much for the hot summer sun which, is allowed to shine throughout the day on the large glass areas of the building. This creates a need for shielding, a need which Kaj Gotlob is aware of and seeks to solve by means of exterior marquees, integrated in the building. However, they are manually operated and, as a consequence, seldom used during the long winter periods, therefore deteriorating.

Today, they are newly renovated and automated, but according to the staff, not to their satisfaction, because there are problems with the automation controlling the old, listed awnings. Instead, the windows are also here replaced. As in the other examples, the Vita glass – the preferred material of the sanatoriums – is replaced with solar protective glass, which again decreases the quality of the daylight. As I shall later touch upon, this not only results in poorer daylight, it also results in less healthy daylight. The need for artificial lighting is incidentally increased along with the use of the solar protective glass. The artificial lighting gains power because of the reduced daylight, as shown in the simultaneous-time-lapse-photographs with clear glass and solar protective glass on the previous page.

Overall, these examples confirm the same development in the buildings with large glass areas. Buildings which may meet the rules of Modernism, optimizing the daylight, also meeting the demands for high daylight factors of today, but all of which confirm that light and health is not only about optimizing the daylight, but rather about finding a proper balance in the sunlight during the day and during the year. Accommodating the need for light and darkness during the day, and at the same time maintaining the clear glass, which seems to be a necessary prerequisite for a good and healthy daylight.

The Paimio Sanatorium – an exception which proves the rule

The fascination of glass without regard for solar radiation and without careful planning according to the geographical orientation seems therefore not to produce a rational balance between *exposure* to and *protection* against the sunlight. A symmetrical building shape also fails to produce this balance. This fascination with glass, however, is not shared by all modernist architects, as shown here in Alvar Aalto's description of his colleague Gunnar Asplund and his architecture at the World Exhibition in Stockholm 1930.

... This is not a composition of stone, glass and iron as a visitor who despises Functionalism might imagine[154].

Although Alvar Aalto writes in his characteristic and neutral 3rd person, there is little doubt that he too does not consider glass and concrete alone as the key elements of good architecture. Both Alvar Aalto and Gunnar Asplund really are strange representatives of Modernism, and they break early with the international style, breaking with the idea of an architecture made entirely out of glass.

The Paimio Sanatorium is built in the period 1929-1934, and The Paimio Sanatorium is one of Alvar Aalto´s – and one of Scandinavia´s – first modernist buildings. The architectural clarity and purity of the sanatorium draws admiration from around the world and Aalto is immediately recognized in Finland, and perhaps even more so abroad, as a modernist architect.

However, in many ways The Paimio Sanatorium breaks with Modernism and its mantra of light and openness. At The Paimio Sanatorium the border between *inside and outside* is not dissolved, and the fascination with glass is not prominent. The Paimio Sanatorium has neither the large glass areas nor the openness between inside and outside, which we have encountered in the previous examples. On the contrary, the borders are *emphasized* in several places, such as in the entrance, where a canopy breaks the autonomy of the daylight outside the building – in the same way, the autonomy of the artificial lighting is broken with the circular skylights in the cross-section of the building, letting more light deeper into the sanatorium. Alvar Aalto does not dissolve the boundary between inside and outside, on the contrary; he stresses this border and differentiates the light in the building. For Aalto it is not about the amount of glass or the size of the glass sections, but far more about *the location* and *the design* of the light openings.

The treatment of patients at The Paimio Sanatorium is compulsory and lasts up to 6 months. It takes place in a rural setting north of the town Paimio, in Finnish Pemar, spun by a certain *magical mountain* atmosphere. From the exterior roof terrace, at the height of the treetops, there is a good view to the clear, blue ridges, far in the distance. Tall pine trees surround the sanatorium, which looks like a sleek ship, with its glossy black painted concrete foundation and its tall, white facades, only approx. 7.5 m deep.

Immediately before Aalto begins the construction of The Paimio Sanatorium, he visits Jan Duiker and Bernard Bijvoets recently completed Zonnestraal Sanatorium, a modernist sanatorium, designed in the hygienic style, treating diamond workers, suffering from lung diseases and tuberculosis, set on the outskirts of the diamond city of Amsterdam. There is hardly any doubt that Aalto is inspired by this building, which, with its white walls and sunlit rooms and balconies, in many ways are reminiscent of The Paimio Sanatorium.

154 Schildt G. *Alvar Aalto, his Life*, p.294. Alvar Aalto Museum, 2007. At the World's Fair 1930.

However, in several ways, the two sanatoriums are quite different. The Paimio Sanatorium is built at a time when electrical lighting, as something new, becomes an integral part of the architecture. Alvar Aalto, only 30-year-old, sees in Paimio Sanatorium the opportunity to exploit the synergies and *the interplay* between the daylight and the new artificial lighting, as part of what he, a few years later, calls a humane and a rational light[155]. The Paimio Sanatorium is not glass architecture, as this would create a cold and dark sanatorium throughout the winter months and a too bright and hot, sanatorium during the summer months. At the latitude of Paimio, the summer sun rises at approx. AM. 3.30 and sets at PM. 22.30, equivalent to approx. 19 hours of sunlight. The northern geography thus emphasizes the necessity of an interaction between light and darkness, and a protection from the sun, a protection which The Zonnestraal Sanatorium completely neglects, in an open planning and a far more unilateral worship of the sun.

In fact, the northern location of The Paimio Sanatorium may indeed be one of the main causes of Aalto's early break with Modernism and the international style, a style which does not take into account any regional differences in the daylight. When it comes to light, the large seasonal variations at Paimio, 60° N. latitude, pose very different challenges to the architecture than is the case at The Zonnestraal Sanatorium, located at 52° N. latitude. While the latter is largely based on glass and natural light, the northern geography of Paimio invokes an integration and a balance between the necessary daylight and the necessary artificial lighting[156].

However, Aalto's break with Modernism is not only due to the high latitude and its special lighting conditions. In 1928, Alvar Aalto meets Poul Henningsen on one of his short, intense trips abroad, and Poul Henningen's Critical Revue fuels Aalto's skepticism towards an international style, just as the meeting with Poul Henningsen has an impact on Aalto's early interest in light. Besides physical exercise, light is one of the treatment strategies for tuberculosis, and hacing to create a sanatorium without daylight half of the year, this is one of the reasons why Aalto early in his career takes the light and the interaction between daylight and artificial lighting very seriously.

As mentioned earlier, light becomes essential in the planning of the physical environment for patients suffering from tuberculosis at this time and The Paimio Sanatorium, with its slim building shape and the tall windows, provides plenty of daylight. The windows face S-SE, they are vertical *portrait windows*, located in the middle of the rooms and drawn into the facade, to reduce the solar heat – already here a marked difference from all the previously described buildings, such as The Finsbury Health Centre and The Peckham Health Centre.

However, there is an even more marked difference, if we study the light and

155 Aalto A. *Rationalism and Man.* A lecture at the annual meeting of The Swedish Society of Industrial Design. 1935.

156 Volf C. *The Necessary Daylight and the Necessary Artificial Lighting*. Arkitekten 07, vol 113, p. 62-65, 2011.

the differentiation and placements of the windows at The Paimio Sanatorium. Alvar Aalto creates sequences and differences in light; in some places, there is light deep into the building, in other places near the facade. He works with the cross-section, working with the adaptation of the eye over time. An adaptation, which indeed also sets the scene for a necessary break with Modernism and its abolition of the border between inside and outside, and a break with the open planning, we have studied earlier.

Aalto seems to understand the adaptation of the eye, working with the sequences over time, which means that The Paimio Sanatorium is perceived as brighter than the previous examples, despite their large, unbroken areas of glass. Again, The Paimio Sanatorium proves to be an exception to the rule, if we look at its relatively small glass areas.

Alvar Aalto places the largest windows in the main central staircase, so that the landings and the steps are flooded with daylight – which is not a coincidence, since both physical exercise and daylight are integral parts of the therapeutic treatment of tuberculosis. The steps are deep and low, and the yellow staircase is designed so the often disabled and infirm patients may easily exercise while receiving the morning light through the major NE-facing windows on the stairs.

In the ward section, all corridors are single corridors, receiving daylight from small NW-facing windows. When Aalto wins the competition to build The Paimio Sanatorium, the jury, in its concerns, states that the sanatorium may be too small. Proposing, among other things, to build deeper, adding double corridors instead of single corridors in order to make more room.

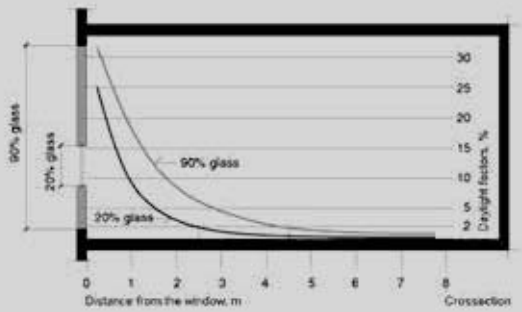
...The relatively large area of external wall could be reduced to a certain extent by widening the building. The volume of the building is small...[157]

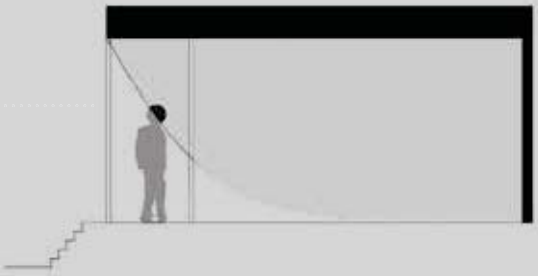
But Aalto succeeds to maintain the slim shape of the building, and the day-lit, single corridors. Probably due to the fact that light is – at this time – considered healthy and essential in the treatment of diseases, like tuberculosis.

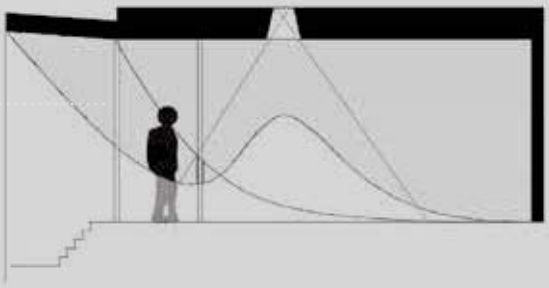
However, what separates The Paimio Sanatorium from the other buildings presented earlier, is that the architecture is carefully planned according to the geographical orientation and the sun throughout the year. Here, The Paimio Sanatorium differs significantly from The Zonnestraal Sanatorium and the previously described buildings, which all bear the mark of a more undifferentiated and unilateral worship of the sunlight.

The Zonnestraal Sanatorium in 1928. The sanatorium is, as opposed to The Paimio Sanatorium, built around a completely symmetrical axis, N-NW is to the right

157 Source: *www.alvaraalto.fi/net/paimio, 2013.*

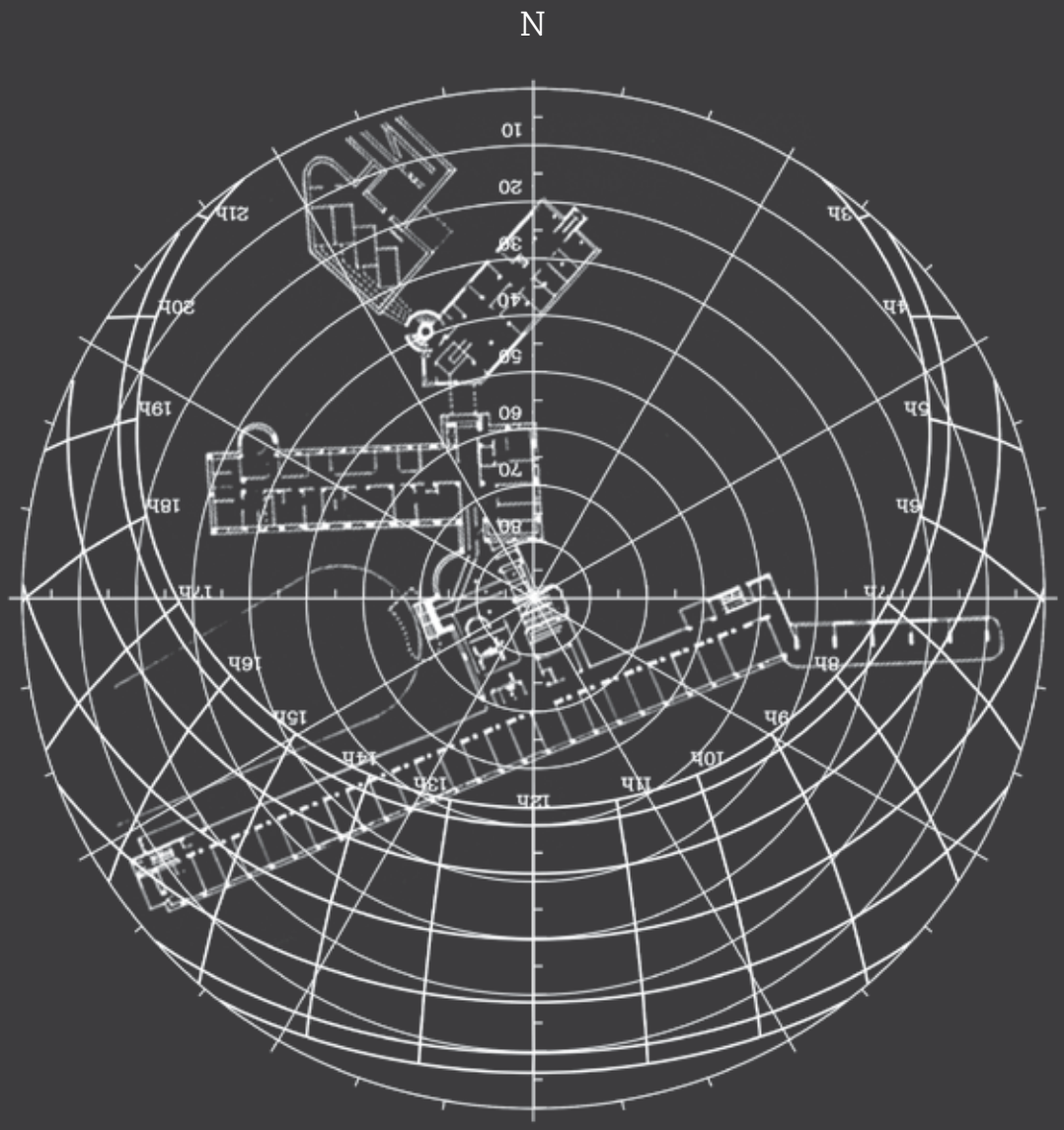






Top: At The Paimio Sanatorium, Alvar Aalto does not dissolve the border between inside and outside. On the contrary he reinforces this border. As here, with a cantilevered canopy breaking the autonomy of the daylight outside, before entering the building

Left: The canopy and the skylights (bottom) change the adaptation of the eye – shown here in relation to a building without a canopy (center). This adaptation takes place over time; when entering under the canopy, through a dark, black-painted hallway, you step *out into the light* in the foyer, which is flooded by light from skylights and singular lighting fixtures in the ceiling



The Paimio Sanatorium is located at 60° N. latitude in Finland. The asymmetrical plan of the sanatorium balances the sunlight at the northern latitudes. The asymmetrical building opens up towards SE, utilizing the morning light, while at the same time shielding of the evening sun. This not only allows the use of the clear and healthy glass, it also balances the sunlight, preventing too much – and late – evening sun during the summer, when the sun sets at PM. 22.30. At the same time, the asymmetrical shape of the building protects against too much – and too early – morning sun. The orientation of the building also utilizes the winter sun throughout the cold, dark winter period, from sunrise AM. 9.15 until sunset PM. 14.45

The Paimio Sanatorium is markedly different from the aforementioned buildings because of two factors; the shape and the orientation of the building relative to the sun. The Paimio Sanatorium is asymmetrical in its form, and the orientation of the building is not laid out in a classic modernist NS-axis, but in an inclined NE-axis. This inclined NE-axis means that the building open up to the morning sun, while facing away from the evening sun. The orientation of the building is a result of Aalto's work and his efforts to balance the large differences between the summer sun and the winter sun, here at 60° N. latitude. Alvar Aalto actually alters the shape and the orientation of the building on the site – by moving around the wooden boards for the casting of the concrete foundation. In this way, Aalto succeeds to balance the evening sun and the morning sun throughout the year. In this context it is worth noting, that The Paimio Sanatorium is built as a part of Finland's major employment plans in the 1930s, therefore all work is performed by men and women, by hand. The construction progresses slowly, and Aalto therefore has ample opportunity to alter the orientation of the building in the way best suited to balance the sun, during the whole year of 1929-30.

The main-building with the patient wards faces S-SE, with the open balcony wing facing S. The vast majority of all windows are placed in the S-SE-facade. In this way all rooms receive the morning sun during the summer, as well as morning and evening sun throughout the winter. The main orientation of the building – together with the closed facades facing NW – protects against the late evening sun during the summer, which sets as late as PM. 22.30, also protecting against the early morning sun, which rises at AM. 03.30. The low sun is actually shielded by the angled balcony building during the summer, right up until equinox. From equinox, the asymmetrical shape of the building lets the sun pass from approx. AM. 06 – at a time when we are physically about to wake up. In this way, the early morning sun neither disturbs the sleep nor the circadian rhythm of the patients during the summer. At the same time, the building opens up to the healthy winter sun – as Florence Nightingale advocated – all the wards receive sunlight from sunrise to sunset all through the dark and cold winter period.

Overall, the geographical orientation of the building seems to play a very important role in the balance between light and darkness. However, the typology of the building and the shape of the building also plays a crucial role in the balance between too much and too little sunlight – a balance which makes Paimio Sanatorium an exception to the rule. At The Paimio Sanatorium the response of the building to the asymmetrical light of the sun is simple. It is asymmetry.

The asymmetrical shape of the building balances several different needs. It balances the morning sun and protects against the evening sun, also balancing the need for sun during the winter with the need for protection against the sun during the summer. The asymmetry of the building also extends the hours of sun, during the day, since the angle of the balcony wing creates an opening towards the afternoon sun, prolonging the period of sunlight by up to one hour during the day. The front of the building opens up toward the morning sun, with the

Right: At The Paimio Sanatorium, Alvar Aalto renovates the original windows in 1974-75, here one of the large windows in the NE-facing communal areas. Exceptionally, Aalto succeeds in renovating the sanatorium without degrading the natural daylight and the clear Vita glass. *Left:* The SEB Bank 2011. Not only the color-rendering be impaired, also the shadow-rendering becomes more blurred and dull. Partly because the intensity of the light deteriorates, partly because the solar protective glass itself forms large diffuse, light-emitting surfaces

The Finsbury Health Centre: To the left the original solution in the NW-facing facade with the clear Vita glass, cross-ventilation and blinds. To the right, the renovation of the SE-facing facade with solar protective glass which reduces the overheating of the large glass facades, making reduntant the blinds

Skolen ved Sundet. Parts of the S-facing facade has been renovated and the original clear Vita glass (left) has been replaced with solar protective glass (right)

Inside, the solar protective glass (right) changes and reduces the intensity of the light markedly. The artificial lighting is far more pronounced to the right due to the reduced daylight. The photographs are recorded simultaneously

back angled away from the evening sun, protecting against overheating in the afternoon during the hot summer months. Finally, the NW-facing facades of the building have a significantly reduced window area, leaving the angled, N-facing balcony building without any windows at all.

In many ways, the asymmetrical shape of the building reflects openness and *exposure* towards the morning sun and closedness and *protection* from the evening sun.

Energywise, this means that the building is heated by the sun in the morning, at a time when the building is coldest, while at the same time protected form the solar heat when it is warmest, e.g. protected from overheating in the evening when the sun is in the W. At this time, both the building temperature and the body temperature is high. This proves to be smart, especially during the summer, when the sun is barely below the horizon for more than 5 hours. Basically, all this is due to the asymmetrical shape of the building.

To conclude these field studies, Alvar Aalto seems to orientate The Paimio Sanatorium well according to the sun, also planning the shape of the building in a better way than the other modernist buildings studied so far. Instead of facing the building towards the sun, as Le Corbusier and other modernist architects do, Alvar Aalto orientates the building away from the sun, not *optimizing* the sunlight, but *balancing* the sunlight in relation to both the seasonal and the circadian rhythm. Where the other failed strategies manifest themselves in the necessity of solar protective glass, The Paimio Sanatorium is an exception to the rule.

In 1974-75, the sanatorium is renovated and refurbished and the original Vita glass is replaced, but – exceptionally – the low-iron, clear glass is maintained; actually the clearest glass I have seen. A renovation which includes the implementation of more artificial lighting on the wards and new windows and later also air-conditioning. All alterations, which Aalto carried out when the patients or the staff asked for them. According to Alvar Aalto, a building exists only for those who use it.

While all his initial thoughts on cross ventilation and doors which do not clatter during cross ventilation, splash-free sinks, radiators mounted in the ceiling so as not to spread germs by hot-air circulation, and chairs with the right seating-angle for the breathing-impaired lung- and tuberculosis-patients – are all gradually being replaced – the clear, low-iron Vita glass is maintained. This makes Paimio *an exception* to the rule and an example that it is possible to renovate a modernist building *without* using solar protective glass and without impairing the natural spectrum of the daylight. A spectral distribution which, as we shall later see, holds importance to the health. The Paimio Sanatorium shows that it is possible to build with the clear, low-iron glass, if the building is oriented and planned, in relation to the geographical orientation and the sun.

The asymmetrical daylight – a showdown with the legacy of PH

In his work with both daylight and artificial lighting, Poul Henningsen avoids the direct light source, working only with symmetrical light, quite independent of the architecture – and the light of the sun

In Denmark, *Poul Henningsen*, often abbreviated PH, and his functional registrations and systematic work with light becomes characteristic of the new, rational light planning. The work of Poul Henningsen is primarily based on the idea of avoiding the direct light source; this applies to both artificial lighting and to the sunlight. He sees the light *symmetrically* and, in this respect, often completely fails to study the direct light of the sun. Poul Henningsen and the traditional light planning based on *a cloudy sky,* has left its mark on the way architects work and still characterizes the planning of light today. Many architects in Denmark continue to work on the basis of the heritage of Poul Henningsen, followed by Sophus Frandsen, who often carried out his light experiments at the School of Architecture *when the weather allowed it – that is, when it was cloudy and the daylight conditions fairly constant*[158]. As Sophus Frandsen himself mentions[159], it is because the lighting conditions under a cloudy sky are easier to maintain and compare in practical light studies.

However, when we talk about light and health, the sunlight is just as important as the sky light, and this is where I am inclined to criticize this aforementioned practice. A cloudy sky specifically neglects the geographical orientation and the direct sunlight, and their fundamental importance to architecture and health. A cloudy sky is based on a theoretical state with the daylight being stable and unchanging over time, not taking into account the direction and the asymmetry of the light over time and place. A cloudy sky neither takes into account how the light *walks* into a room, or for that matter how the darkness *walks* into a room. In Denmark, long transitions between day and night are characteristic and predominant – transitions which last up to 4 hours a day – and due to this fact, it may be beneficial to plan the light according to this.

While the skylight always renders a symmetrical image of the light through a light opening, the direct sun always renders the space asymmetrical, creating a direction in the space. Overall, this fundamental difference is due to the fact that the skylight is *mirrored* through the light opening, while the rays of the sun consist of parallel rays penetrating through the light opening. It is two very different types of light, not only in terms of direction and shadow-rendering, but also in terms of intensity and color-rendering. Architecturally, the direct sunlight creates differences between otherwise identical spaces. Depending on their geographical orientation, the direct sunlight creates large differences in light during the day, differences which stimulate our circadian rhythm in various ways. This makes the geographical orientation important, not only for the light and for the architecture, but also for how we thrive in a building. The light depends on the time of day and the time of year, and affects us differently – as we have seen, the morning light works therapeutically while the evening light does not. Nevertheless, the geographical orientation has, since Modernism, lost its importance, in the same

158 Frandsen Sophus. *Low-energy windows and daylight quality.* The Royal Academy of Architecture, 1996, p.3.
159 Ibid. p.3.

way that the anchoring[160] to the place has lost its importance, and along with this, also the regional light. This is evident by the widespread use of daylight factors, which completely ignore these facts, and in this context may prove to be less appropriate, not only in terms of health – but also in terms of sustainability in the architecture. So, in order to restore the geographical orientation, it is necessary to break with Poul Henningsen and his neglect of the direct sun and the significance of the geographical orientation.

Thomas Alva Edison and his marketing of standardized, concrete housing is another example of the same mindset. Quite in the spirit of Modernism, and by mass production, Edison wants to create good, rational architecture accessible to people regardless of their income – and regardless of the geographical orientation and location as well. However, the houses become a disaster for Edison, not only in terms of daylight, but also economically. As Alvar Aalto describes it:

Even such a notable man as Thomas Alva Edison wasted years of his life trying to solve the problems of the standardized house using technological methods. In this protracted effort, he suffered his life´s only real defeat. A building is not in the least a technological problem; it is an architechnological problem[161].

By the word *architechnological* Alvar Aalto lays down that technology in itself may not be able to create good architecture and Aalto's words can be interpreted in the way that the site, and the anchoring to the site through the geographical orientation, are fundamental elements of good architecture.

But does a building need to take into account the geographic orientation at all? To answer this question, I will use the car as an example. In the car, we have a space which, for obvious reasons, does not relate to the geographical orientation – and which, incidentally, has large glass areas. In the car we see a need for both air conditioning and solar protective glass – a matter of course in most cars, reducing the heat gain from the sun. However, also reducing the contrasts, discoloring the light of the surroundings to a larger or lesser extent. A discoloration which seems to be dynamic; especially at dusk, where you may experience the large influence of glass on the light and the colors by comparing the light through the windshield to a rolled-down side-window; the difference is significant. Yellow, bright and warm colors are dimmed and experienced darker, as the daylight appears to be darker, seen through the windshield of a car – quite similar to later in the evening.

Now, a building is not the same as a car. Nevertheless, the comparison is interesting, and this is not the first time it is put forward, in as far as the car may be seen as a technical solution to the missing relationship to the geographical orientation. In the late 1930s, Alvar Aalto tries to oppose the increasing standardization of the architecture in the US, in this regard, he also compares the house to the car:

160 J.f. Schulz CN. *Genius Loci – towards a phenomenology of architecture*, 1980.
161 Schildt G. *Alvar Aalto, his Life*, p.503. Alvar Aalto Museum, 2007. Excerpts from Alvar Aalto's speech; *The reconstruction of Europe is the Key Problem for the Architecture of Our Time*, Zurich, 1941.

As opposed to a car, a building has a fixed relationship with nature: it belongs inseparably on a specific plot and land, and is affected by the specific natural conditions that result from the site's distinctive character. We can confidently assert and at least theoretically prove that no two building sites in this world are alike. We may define the ideal goals of architecture by saying that the purpose of a building is to act as an instrument that collects all the positive influences in nature for man's benefit, while also sheltering him from all the unfavourable influences that appear in nature and the building's specific environment[162].

The statement must be read in connection with Aalto´s fear of the increased standardization, as seen in the mass production of cars at the Ford plants. Aalto fears that the mass production of cars will also inspire a mass production of houses, through a standardization solely based on technology. Basically, Aalto believes that man often finds it easier to adapt to technology than to adapt technology to man, believing that technology, in itself, can not support the complex human needs. Although Aalto doesn´t mention light, excessive heat or for that matter, the geographical orientation, all these factors are implicit in this fear, all factors being very closely tied to the place. If a building loses its anchor-point to the site, it also loses its meaning and its value to man. Alvar Aalto gets even closer to this in the following:

The most remarkable standardization institute of all is nature. Nowhere else does one find such thorough and effective standardization. Let us take a plant or a tree. We find that every blossom on a spring-flowering fruit tree differs from all the others. If we investigate further, we realize that this difference is not fortuitous. The blossoms face in different directions; they are shaded by different branches, leaves, and adjacent blossoms. This determines the variety of forms. Each blossom has a different position, a different relationship with the stem, a different orientation[163].

When we plan a house, it is anchored to the place. Its orientation allows the light to enter in different ways compared to E, S, W and N. However, the geographical orientation also provides a geographical anchoring point in time, *a temporality*, to a building. Much evidence suggests that the restoration of a healthier architecture also leads to a restoration of the geographical orientation and the time of day. The sun determines *where* and *when* the solar radiation is present. Just as the geographical orientation determines the distribution of the light and the heat radiation of the sun. In this way the geographical orientation is not only a useful tool in the design of architecture, but also an important prerequisite for the use of clear, low-iron glass in architecture. In this respect, the geographical orientation is a tool which can help to solve the problems *architechnologically* and not just *technologically*.

162 Ibid. p. 501.
163 Ibid. p. 502.

4 GLASS

4. GLASS

A showdown with glass as an immaterial building block

At The Paimio Sanatorium, Alvar Aalto manages to maintain the preferred building material of the 1920s and 1930s, the clear *vita glass*. But why is this clear glass a standard in several hospital buildings and school buildings of this time? Why is it marketed under the name vita glass, a name, which literally means the glass of life? And how does this clear glass affect the health? To answer these questions, we will take a closer look at glass as a building material and perform the first light experiment, which may help to clarify the effects of glass on the health.

In the early Modernism, light is almost described as a building material in itself, in a new, rational, democratic and healthy architecture. Light is considered *an immaterial building block,* released from the architectural form and place as something which unconditionally adds value to the architecture.

Kein Material überwindet so sehr die Materie wie das Glas. Das Glas ist ein völlig neues, reines Material in welchem die Materie ein- und umgeschmolzen ist. Von allen Stoffen, die wir haben, wirkt es am elementarsten[164].

A building block, with which the architects can design and draw. Instead of past symbols of richness, such as ornaments and cornices, the architect now instead paints with light itself.

A la place de l'ornementation vient aujourd'hui la lumière[165].

It is in this emerging light euphoria that the association *Die Gläserne Kette* is established. The group consists of young experimental designers, including *Bruno Taut, Walter Cropius* and *Hans Schauroun*. Light should not only create new buildings, but a whole new culture based on a new ideology, using glass to break down otherwise solid masonry and make the buildings hover and reflect the surroundings and create life, light, openness and transparency, without any boundaries between the inside and the outside.

It is no longer possible to keep apart the inside and outside[166].

Openness, not only architecturally, but also in a democratic sense. Architecture becomes a political matter and light becomes the common denominator for both a healthier and a more open society. Thoughts that inspire Modernism right up until today and which still seem to influence the modern, crystalline

164 Behne Adolf, in Bruno Taut´s magazine *Frühlicht*, 14.
165 Giedion Sigfried. *Cahiers d´Art*, 6, 1929.
166 Moholy-Nagy László. *The New Vision*, 1947, p. 62.

versions of the glass architecture of the 1920s. Paul Scheerbart, the ideological founder of Die Gläserne Kette, describes it this way.

We live for the most part within enclosed spaces. These form the environment from which our culture grows. Our culture is in a sense a product of our architecture. If we wish to raise our culture to a higher level, we are forced for better or for worse to transform our architecture. And this will be possible only if we remove the enclosed quality from the spaces within which we live. This can be done only through the introduction of glass architecture that lets the sunlight and the light of the moon and stars into our rooms not merely through a few windows, but simultaneously through the greatest possible number of walls that are made entirely of glass – coloured glass. The new environment that we shall thereby create must bring with it a new culture[167].

Light and glass become an ideological project which Scheerbart manages to communicate, at least on the theoretical level. But when it comes to more practical matters, the first glass-utopias are dubious. Scheerbart for example describes – contrary to fact – how the glass material is in fact an advantage during the summer heat.

Perhaps the honored reader apprehends that glass architecture is a bit cold. But – during the warm season the cold is quite agreeable[168].

In general it seems as though the concept of light as *an immaterial building block* is sometimes more poetic than real. Light itself is invisible to the human eye, visible only when it reflects the shape or the surface of a material, and to talk about light in itself is an abstraction, which tells us nothing about the light actually perceived by the human eye.

The boundary between the inside and the outside is in fact only *partially dissolved* by the means of glass. The glass always constitutes a barrier and a loss of light, either in the form of reflectance between air and glass, or in the form of absorbance due to the iron content and coatings. Both provide varying light losses of 10-100%[169].

As the architecture opens up to the daylight through the 20th century, the need for some sort of protection against sun, heat and cold becomes obvious. This necessitates an increased complexity of glass as a building material, and the development of glass as a multi-layered *insulating glass unit*[170].

167 Scheerbart P, *Glasarchitektur,* 1914.
168 Ibid.
169 Johnsen K, Christoffersen J. *Dagslys i rum og bygninger. SBI 219*. 01. 2008, p. 67.
170 Also termed IGU.

Much has happened since Paul Scheerbart, Bruno Taut and *Mies van der Rohe* designed their first glass utopias in the 1920s. Glass has become a high-tech building material, which means that architects today are faced with new challenges when requirements for light and energy meet in the traditionally weakest point of the envelope; the light opening.

Paul Scheerbart and his fascination with glass as an immaterial building block seem far from reality today. Instead of being single glazed or coupled windows with single glazing, the vast majority of all glass production today consists of 2 - or 3-layered high-tech, coated glass. The possibilities of combining unique characters have multiplied in these insulating glass units, where even thin nano-coatings, which would normally be destroyed or washed away by the rain, can be maintained on the inside of the glass, lasting the life span of a window, in glass areas which can easily be produced in sizes up to 6 by 4 m.

However, it is not only the size of the glass that changes in pace with these technological changes. So does the glass itself. Glass is no longer simply a crude product of soda ash and quartz. Glass is a high-tech building envelope, which has energywise developed markedly in the recent decades. But naturally this development affects the quality of the light, and today it matters which glass composition is chosen, both when it comes to energy and light – or health for that matter.

Basically, there are two types of glass; the standard, ferrous float glass and low-iron glass, such as the Vita glass. Low-iron glass is melted at higher temperatures, at which the impurities, in the form of iron and other metals, evaporize so that the silica content, and thereby the light transmittance, becomes higher. The low-iron glass therefore has a higher light transmittance, up to 91% per glass layer, thus affecting the natural daylight least. Incidentally, the low-iron glass, is the only glass also transmitting parts of UVb light.

Adding iron decreases the melting point of the glass, and ferrous glass types often have various impurities in the glass, which is why ferrous glass types have lower light transmittance. However, the ferrous glass is both easier and cheaper to manufacture than the low-iron glass, which is why it is the far most common glass type in Denmark today.

However, apart from this, glass can be further divided into two types; namely glass with *soft coating* and glass with *hard coating*.

Glass with soft coating

The vast majority of solar protective glass today consists of glass with soft coating. I.e., glass having coatings of metal oxides and catalytic layers, which are evaporated onto the surface of the glass through a non-heat-consuming, magnetronic process. Soft coatings are used to reduce the amount of transmitted solar energy through the glass, while at the same time reducing the

external heat loss through the glass. Most types of glass with soft coatings have a lower visual reflection – compared to glasses with hard coating – because the soft coatings are usually placed behind the outer layer of glass. The soft coatings can be used in combined coatings, creating a large complexity and multiple expressions. In this context, an important concept is *the selectivity* of the glass, i.e., the ratio between the light transmission and the energy transmission. With current technology, this ratio does not exceed 2:1, meaning that twice as much light as solar power is transmitted through the glass – obviously however, not without affecting and imparing the spectral distribution of the natural light.

The soft coatings also reduces the external heat loss, lowering the U-value in order to ensure a better insulation. This can be done through the use of *low-energy coatings* and in the coming 2020 requirements for the built environment, such low E coatings are required. But common to all soft coatings is that they, in one way or the other and to a lesser or greater extent, change the spectral distribution of the natural daylight.

Glass with hard coating

Another type of glass is glass with hard coating. A hard coating typically consists of metal oxides or a catalytic layer which is burned into the glass surface in a pyrolytic process, at high temperatures, at the glassworks. These hard coatings consist of reflective layers on the outside of the glass and essentially have a solar protective function, reflecting parts of the sunlight. However, this results in a high loss of light and often creates a non-neutral look, compared to glass with a soft coating.

Today, glasses with hard coatings form a relatively small part of the market in Denmark. One of the main reasons for this is that new requirements of positive *Eref*[171], in practice, illegalize glass with hard coatings. They can´t meet the stricter energy requirements, because they have a higher U-value than glass with a soft coating, quickly resulting in a negative Eref. Instead, glass with hard coatings are used as interior glasses, behind ordinary float glass with soft coating. This combination reduces the high-reflective look of the hard coating, at the same time reducing the transmittance of solar energy and the risk of overheating. However, the coating also here affects the light quality which, no matter what, deteriorates.

Glass and light

The focus of this development in glass is predominantly based on an energy discourse, focusing on heat and not light. But naturally this focus not only affects the long-waved IR radiation. It also affects the light quality.

171 Eref = solar gain – heat loss. The requirement for a positive Eref means that solar gain must be higher than heat loss. Source: Institute of Technology, DTI, 2013.

In general, solar radiation can be divided into three parts; the short-waved radiation (UV), the visible radiation (380nm-780nm) and the long-waved radiation (IR)[172]. The visible part of the light is a relatively small part of the total radiation from the sun, and the short-waved radiation forms an even smaller part, while the long-waved radiation constitutes almost half of the total solar radiation, in the form of heat.

A great deal of knowledge and technical skills have been applied in an effort to reduce the long-waved radiation and the thermal problems it can cause, without compromising the visible light. However, this will not succeed without more or less compromising the quality of the daylight. For glass is not a neutral material, glass affects the light in a room. Through its materials, it influences both the color- and the shadow-rendering, affecting the spectral characteristics of the light, also affecting the health.

If we study the UV light, all ferrous float glass types eliminate the UVb spectrum, and the glass acts as a very effective barrier, separating the UVa light from the UVb light at 320 nm. The development of glass has not only borne positive results, one can even speak of *healthy* and *less healthy* glass because of their different solar and thermal coatings. Today there is a tendency to see glass as the solution to a sustainable and healthy architecture. However, I may have to disappoint the readers on this point, there seems to be no direct correlation between the use of glass and health. Conversely, glass architecture, sustainable architecture, or for that matter healthy architecture seem quite far from each other. Often glass architecture challenges the glass, when meeting the energy requirements, resulting in poorer glass, and subsequently a poorer light quality. For the same reason, multiple types of glass and glass variants are developed, all with their own particular characteristics. But common to them all is that they compromise the light quality, the fascination of glass and natural light thus, paradoxically, results in less natural light in a building.

The effect of glass on the health is not yet fully understood. The following is an attempt to explore this area. This is done through a practical light experiment[173], which studies this effect further. The light experiment studies different types of glass and their transmittance of the short-waved light, stimulating the circadian rhythm. A total of 14 different glass samples are examined, including today's answer to the Vita glass, *the diamond glass* and ferrous glass types, along with other glass types, both with soft and hard coatings. All glass types are assessed through their color-rendering. However, as something new, a tool that can compare the effect of the different types of glass on the health is introduced; a tool that is named *the unhealthiness factor*.

172 Source: www.lysviden. dk/grundviden, 2013.
173 A light experiment are carried out by Volf C, Markvart J & Correll DD, in a collaboration with Aarhus School of Architecture, DTU Photonics and SBI.

The unhealthiness factor

The unhealthiness factor is a new concept, introduced for the first time in this thesis. The unhealthiness factor relates to the ability of the glass to transmit the light, which supports and stimulates the circadian rhythm of the body. The light which is, according to the discovery of the missing piece in the lighting puzzle[174], central to our general health and well-being. The more of this light that the glass absorbs or reflects, the higher the unhealthiness factor becomes, see Annex p. 192.

The unhealthiness factor is derived from a light experiment, which is carried out under controlled conditions[175].

In the first part of the study (a) a Munsell color chart[176] is placed under cold artificial lighting[177] in a closed, black space and subsequently photographed. Between the light source and the Munsell color chart 14 different samples of glass are now individually placed, one at a time, after which the color chart is again photographed, first in light transmitted through the glass, and subsequently in the light without glass. The recordings without glass serve as a reference. All shots are taken with a SLR camera with fixed aperture and fixed shutter speed. The different effects of the different glass types are compared through eight colors[178].

As can be seen from the results (see the annex), the different glass types affect the color-rendering very differently. In general, especially the warm colors are impaired, mainly affecting the skin tones, which for most of the glass types become significantly flawed, while the blue and green colors are largely enhanced and appear more clearly. However, this does not mean that there is more blue and green light passing through the glass. On the contrary, when measured, less of the healthy short-waved light is actually passing through the different glass types.

This is documented in the second part of the light experiment (b) where the spectral distribution of the light is measured using a spectrometer[179]. All types of glass are measured under the same artificial lighting and in the same manner. Again, the common reference is without glass. As can be seen from the curves and the measurements, the short-waved light varies for each of the total 14 samples of glass, compared to the reference curve without glass, see the annex, p. 192. The light[180] stimulating the circadian rhythm is reduced by up to 35% in the spectral area, marked with a scale that indicates *the unhealthiness factor* for each glass type.

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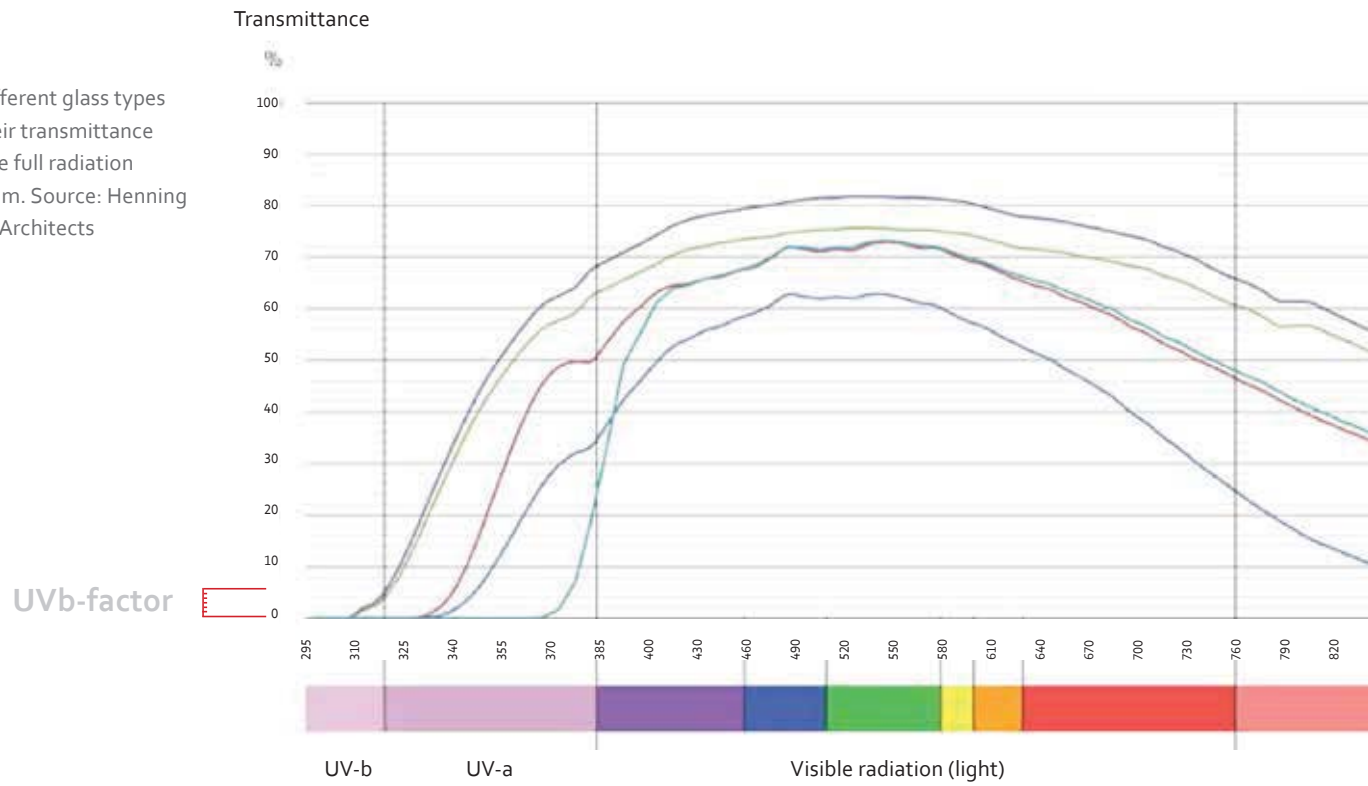
174 Berson David M., Dunn Felice A., Takao Motoharu. *Phototransduction by Retinal Ganglion Cells That Set the Circadian Clock*. Science feb 8, 2002, et al.
175 At the light laboatories at SBI, May 2012.
176 A professional tool, providing basic colors and gray scales for the calibration of photography.
177 LED with a color temperature of approx. 5,200 K.
178 Based on a standard Munsell Color Chart.
179 The measurements are performed in collaboration with DTU Photonics, at the light laboratories at SBI, May 2012.
180 Appr. 480 nm.

This reduction in the quality of light may be related to a previously described *drowsiness factor*[181], a factor, which not only seems to blunt the environment, and their color- and shadow-rendering, but even ourselves. This happens by reducing the amount of the short-waved light that stimulates the production of serotonin, which again increases the levels of the sleep hormone melatonin in the body, not only making us more lethargic and tired during the day, but also reducing the quality of sleep.

Healthwise, this – at least on paper – means that there are differences in the unhealthiness factor for the different glass types, which make up the standard building materials of today. Experimentally, however, no studies have been made of this short-waved light and its impact on the circadian rhythm. This experiment, however, sets the stage for further studies in this field and can temporarily conclude that the amount of light that stimulates the circadian rhythm is reduced to a varying degree through glass.

The annex shows all the measurements and the photo recordings of the various types of glass, presented together and in order, starting with the reference, without glass, followed by the highest unhealthiness factor and ending with the lowest unhealthiness factor, which is found in the clear, low-iron glass.



Five different glass types and their transmittance over the full radiation spectrum. Source: Henning Larsen Architects

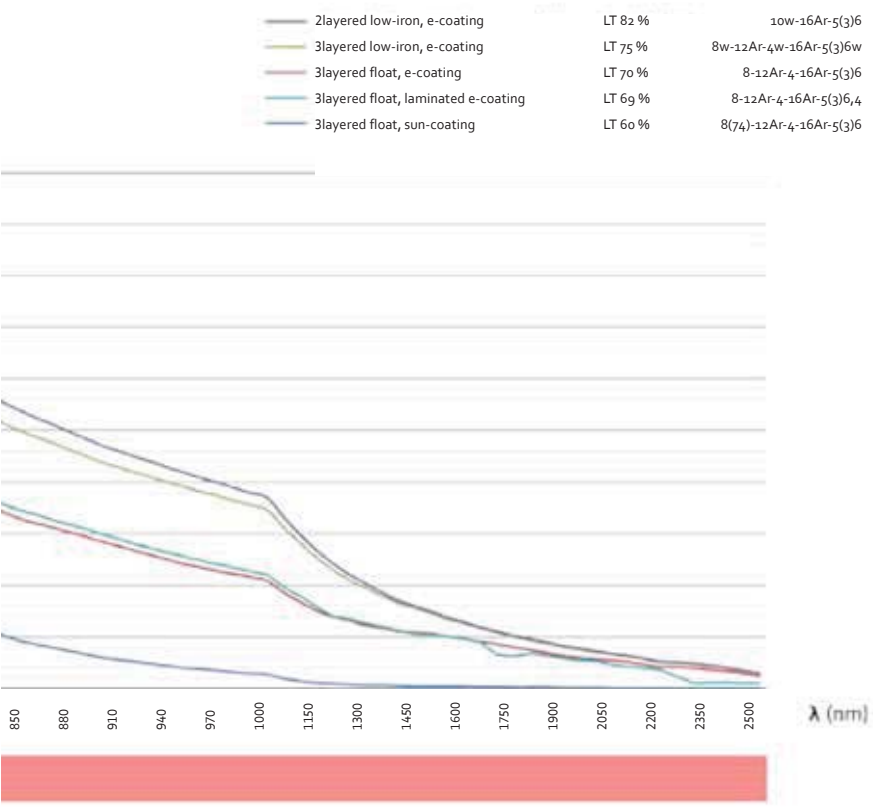
181 Frandsen S. *Low-energy windows and daylight quality.* Royal Academy of Fine Arts. 1998, p. 6.

The UVb-factor

As shown on the graphs below, the common types of float glass function as an effective UV barrier. A barrier, separating UVa (380nm-320nm) from UVb (320nm-280nm). Again, only the clear, low-iron glass transmits the UVb light.

As previously mentioned, this separation may have negative consequences for health. In this context it is interesting that the clear, low-iron *diamond glass*, is the only type of glass, which breaks the UV barrier of the glass, transmitting parts of the UVb light, which stimulates the vitamin D production and works as an antiseptic agent on bacteria.

A higher UVb-factor thus means a higher antiseptic radiation. In this context, *the clearest glass* actually also means *the cleanest building*. Which, at a hospital, may be rational, especially considering that severe hospital infections (HI) – along with vitamin D deficiency – today represent a real health problem at Danish hospitals[182]. Although the UVb content through diamond glass is relatively modest, as seen below – only 5-10% is transmitted through the low-iron glass – it is yet a factor that has positive impact on the health, and therefore a factor which will in this thesis be called *the UVb-factor*.



IR radiation (heat)

182 Op.cit. p. 42.

What comes first – the glass or the building?

All in all, glass has a materiality that varies, not only affecting the light and the architecture, but also the health. Glass is not just glass and this materiality, or quality of the glass, depends – besides on the climate – primarily on one thing; the architecture.

One can rightly ask what comes first; the building or the glass? The choices are often closely related when it comes to glass and architecture. The choice of glass can directly determine the architecture, like the architecture can directly determine the choice of glass. As a consequence, the lack of understanding of the materiality of glass may lead to poor – even downright unhealthy – light in the architecture.

Architects and engineers each contribute with different fields of knowledge within the architecture. Architects come up with ideas and wishes for buildings and facades with high daylight factors, and engineers come up with advice on materials and glass types for the buildings. Often the architects call the poor, solar protective glass *the engineers favorite*. However, in reality, the architects, indirectly, choose these certain glass types, through the form of the building, its geographical orientation and the glass areas. Quickly the choice of glass is fixed and can often only be changed using a limited palette of options, determined by the architectural design in relation to the geographical orientation and the solar radiance. These options quickly become *technological* choices, based on different solar protective glass types, if the architects do not make conscious *architechnological* choices – based on the location and the geographical orientation.

As we have seen, the fascination with light and glass as a building material can directly impair the daylight, if the direct sunlight and the geographical orientation, together with the quality of the glass, is not involved in the architectural planning. The architects may ask themselves what glass material and which light should be present in a building. Is it a building in which you spend a lot of time during the day? Is it a building that should contribute to people's general health?

Very often good daylight quality is challenged by ambitious requirements for energy efficiency together with efforts to maximize the daylight. It is, as we have seen earlier in the open planning of the 1930s and the failed strategies, conditions which do not necessarily go hand in hand, often resulting in a poorer quality of daylight, sometimes to an extent, where one can ask oneself whether it is appropriate, or for that matter sustainable – if the health and the light quality is taken into account.

Glass has a certain ability to appear transparent and neutral. However, the materiality of the glass affects and colors the entire background for the adaptation of the eye, and all the reference points and its anchoring to whiteness, light balance and intensity. All this happens on a fairly unconscious level. Depending on the focus, the glass shifts in nature, changing character during the day, as the light increases or decreases. Transparency turns to reflection and hot becomes cold.

This never constant change is probably in reality the character of the glass. It has not one real character, but is indefinable and ever changing, difficult to anticipate as *a material building block*. What seems one moment clear and transparent, in the next moment becomes specular and impenetrable. This varying nature of glass is often the excuse for not working with its materiality, however it is – as we have seen – a poor excuse, especially when it comes to light and health.

When we talk about solar protective glass, the architecture and the anchoring point of the building to the geographical orientation plays a very central role. Solar heat gain – and thus the need for solar protective glass – varies in relation to E, S, W and N. As we have seen, the sunlight is asymmetrically distributed between the four corners of the world. To the W and the S, there is often a greater need for solar protective glass than to the E and N.

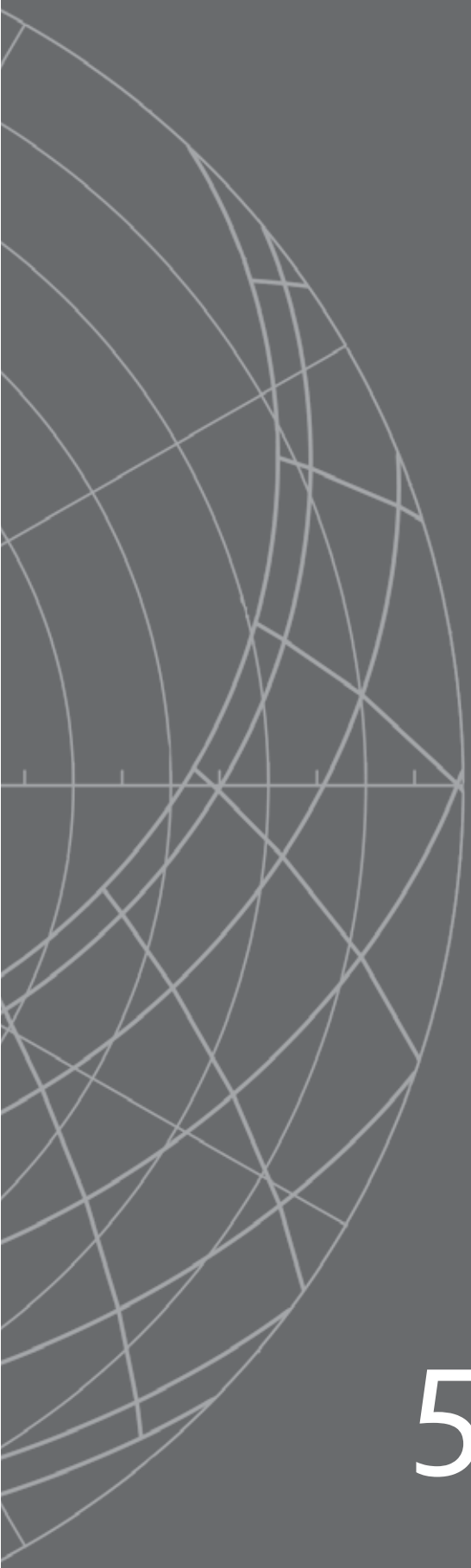
Technology and solar protective glass enables us to create a glass architecture, independent of the incoming solar radiation. However, as Aalto previously described, a building is not a technological problem – it is an architechnological problem.

A symmetrical building often results in asymmetrical use of solar protective glass, simply as a necessary response to the sun and its asymmetrical solar radiation. However, as we have seen, the subsequent impairment of the light is not appropriate when we are talking health.

Instead, it would be more rational to build with the clear, low-iron glass and plan the architecture in relation to the compass and the sunlight, in order to build with the healthy, natural daylight and build with as low *unhealthiness factors* as possible.

In other words, it may be advantageous to start with the glass before planning the building. Likewise much suggests that we can not avoid the clear glass, if we want to build a healthier architecture in the future.

With this conclusion I will lead up to the next part, which sets the stage for a new method, a method for both planning the daylight, the artificial lighting and the architecture in relation to the geographical orientation – based on the healthy, low-iron glass.



5 A NEW METHOD

5. A NEW METHOD

Introduction

By now, we have had the opportunity to study the various factors affecting light and health. Partly through a litterature study of light and health, and partly through field studies, describing various architectural examples of healthy architecture, together with a practical light experiment, describing the different glass types and their *unhealthiness factor*.

What are the lessons to be learned from this knowledge so far, and how can we build a healthier architecture in the future? Basically, more questions arise, than there are answers, but this is of less importance, because there is not just one correct and healthy architecture. However, in particular, two main points arise.

A lack of awareness of the geographical orientation and its importance to the light and to the health.

A lack of awareness of glass as a material building block.

The light of the sun is distributed quite differently in relation to the time of day and the geographical orientation. Evidence suggests that a healthy architecture may consider the geographical orientation, taking into account the solar radiation through the day and through the year.

The sunlight creates a regional character, it renders and shapes *the place*, so often associated with architecture. Christian Norberg Schulz and Juhani Pallasmaa both advocate for the place, revolving around light as one of the factors creating the special character of a place. In this connection, Pallasmaa writes that modern buildings, such as airports and hospitals, have lost their anchor point to the site, and have become *indifferent containers* which may stand anywhere. Both authors also allege that Modernism and the International Style seem to lack these exact factors.

Evidence suggests that in order to restore the beneficial aspects of the architecture on the health, we need to restore the place, and the geographical orientation, which implies a break with the concept of *a cloudy sky*.

A showdown with the cloudy sky

In the Building Regulations, daylight factors beyond a certain level are generally recommended, subsequently often resulting in increased glass areas. However, in practice there seems to be no difference between these recommendations and the failed strategies and the open planning described earlier. These recommendations are primarily based on a goal of reducing the energy consumption for artificial lighting. However, as previously mentioned, the

daylight factor is problematic when it comes to light and health. For example, increased glass areas and daylight factors of 2% can create too much direct evening light to the west, where the sun is lower and shines more directly through the glass. The evening sun and the passive solar heating may healthwise turn out to be less appropriate. It may be necessary to refine this calculation within the planning of light, if a future sustainable architecture also entails a healthier architecture. Therefore, I would like to start with a retraction:

It is – not – cloudy all the time in Denmark!

It is only hypothetical, and for very brief moments, that a cloudy sky contributes with the same light in all four corners of the world. For the same reason the CIE also works with various degrees of a cloudy sky.

Yet, the planning of light often overlooks the direct light of the sun, instead, working with the measurable light, measured in lux and daylight factors. But the daylight factors are based on a cloudy sky[164] and excludes the direct sunlight.

A cloudy sky is per definition independent of the geographical orientation[165].

In this way the daylight factor neglects the time of day, which is an important part of the light when we talk about light and health. Furthermore it also neglects the seasonal differences in both daylight and sunlight – including the importance of the winter sun, the regional light and the regional weather.

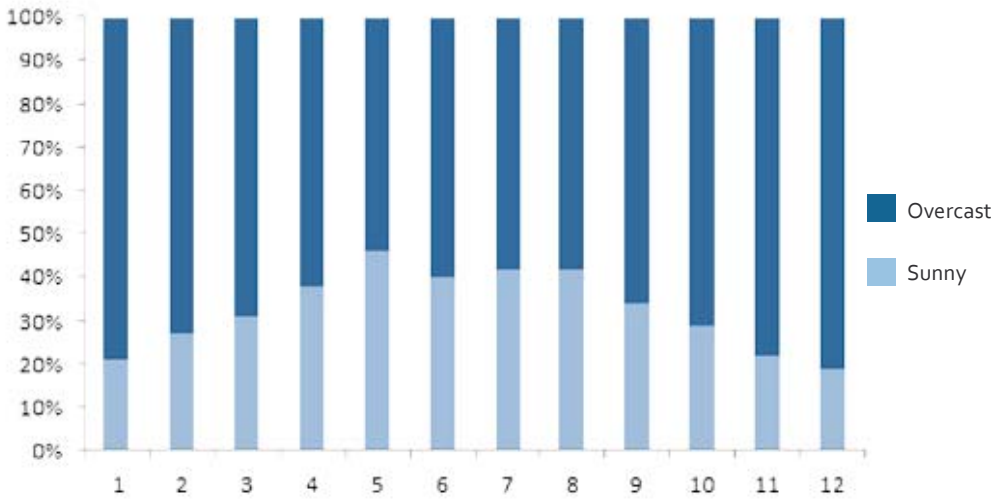
The Danish weather

As we have seen, glass has become increasingly complex as building material. Most solar protective glass types act as envelopes against the weather, balancing the solar light and the solar heat. Therefore, the Danish weather is an important key to light and health.

The Danish weather is quite diverse. This applies both in relation to the seasonal changes – the sun varies from up to 100,000 lux during the summer to 30,000 lux during the winter[166] – but it also applies in relation to the daily changes, due to weather conditions. In the summer, it is cloudy almost 60% of the time, while in the winter, it is cloudy approx. 75% of the time. The winter season is thus not only dark because of a lower intensity of the sun – caused by the lower solar height – it is also dark due to a more cloudy winter sky. These huge differences between the light of a cloudy sky and direct sunlight

164 Johnsen K, Christoffersen J. *SBI 219, Dagslys i rum og bygninger*, p. 103. SBI, 2008. The sunlight factor is an example of another method which seeks to account for the sunlight, however the method is rarely practiced.
165 Ibid. p. 76.
166 Ibid. p. 20.

In Denmark, the sun on average shines 1,496 hours a year, based on statistics from 1961-1990. The weather is cloudy approx. 66% of the time during a year, distributed with 57.7% in the summer period (April-September) and 75.2% in the winter period. Source Theilgaard J. Det danske vejr. Gyldendal, 2006, p.422



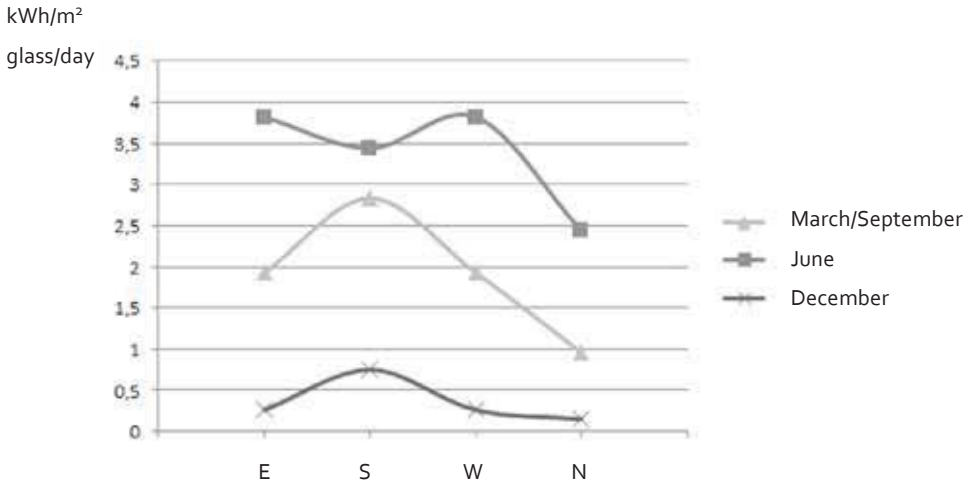
primarily manifest themselves in terms of intensity and color temperature. Along with the increased intensity, the sun also adds warmth to the colors and renders the environment different from a cloudy sky. However, the sun manifests itself in a more indirect way, namely by creating a direction and an *asymmetry* through a light opening in a room, with large variations over time. As opposed to the sky light, which manifests itself *symmetrically,* entering a light opening, similar to a *camera obscura* – with only little variations over time and place.

The cloudy sky traditionally plays a more important role than the sunlight in both the teaching[167] and in the recommendations[168] for the light-planning in architecture. In many ways, this is understandable, and this may also be a usable approach when we talk about the functional light in a room. However, when we talk about light and health, there is a huge difference between the light in a west-facing room and the light in an east-facing room. A difference which primarily manifests itself in the fact that the sunlight falls asymmetrically into the space creating a temporality, relating the light to the time of day.

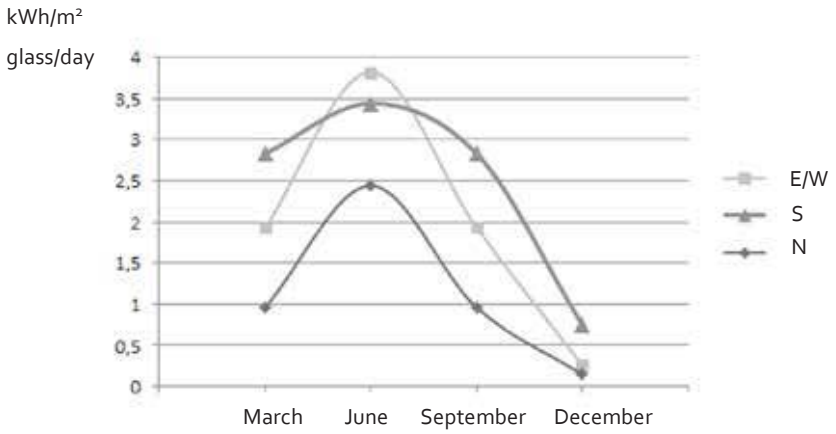
This asymmetry clearly manifests itself in the weather data, shown on the following pages. These statistical tables show a very varied distribution of the sunlight during the year, according to the compass.

If we study the incoming solar radiation, there is overall more sunlight during the month of May. Throughout the year, there is more solar radiation to the S and less solar radiation to the N. During the summer period, there is more radiation to the E and W caused by the early morning sun and the late evening sun. In the middle of winter, and at equinox, there is more radiation to the S. The variation in the radiation is highest to the E and to the W, less to the S, and least to the N throughout the year.

167 Sophus Frandsen et al.
168 In the recommendations of *SBI 219, Dagslys i rum og bygninger*, 2008.



The S-facing windows overall receive more radiation during the year



The E- and W-facing windows show the largest variation in solar radiation, while the N-facing windows show the least variation. Note that E and W have the greatest radiation during the summer, at time when the sun contributes the most with passive overheating

	June	March/September	December
S	40%	45%	15%
E/W	25%	20%	5%
N	0%	0%	0%

Duration of illuminance above 10,000 lux 08-18[169]

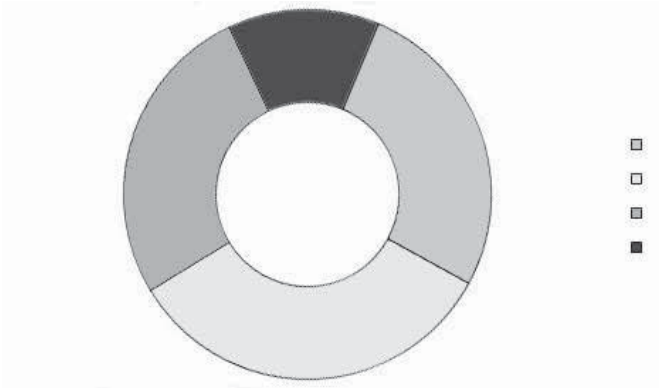
	June	March/September	December
S	25%	35%	10%
E/W	15%	15%	0%
N	0%	0%	0%

Duration of illuminance above 20,000 lux 08-18[170]

The statistics by numbers. Source: Monthly means of daily irradiation and transmitted energy through double glazing (In kWh/m2/day). European Passive Solar Handbook, 1986)

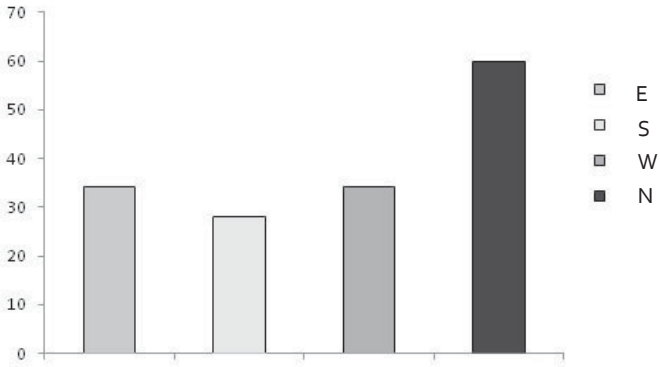
169 Source: SatelLight, 2007.
170 Ibid.

The differences in heat gain between E, S, W and N reflects the solar radiation. The relative sizes of the glass often determine the need for solar protective glass today. However, the new method provides the basis for determining the size of the glass areas and the light openings, in order to obtain clear glass and natural daylight



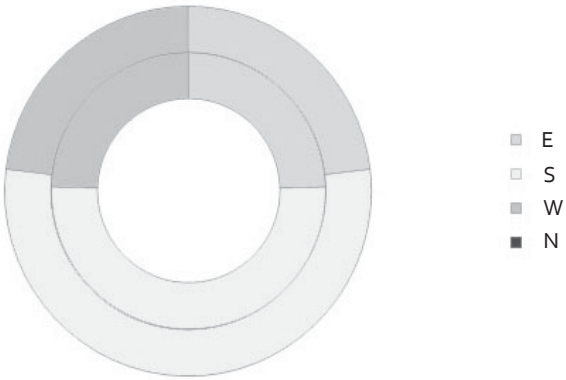
Radiance from the sun, average

The incoming radiation forms the basis, determining the glass area to the four corners of the world. The sizes of the glass areas are based on the differences in heat radiation between the S, E, W and N



Glass area

The duration of the illumination of the sunlight, respectively, above 10,000 lux (inner circle) and the duration of the illumination of the sunlight above 20,000 lux (outer circle). As shown, S has approx. twice as long time with illumination levels above 10,000 lux, compared to E and W, while N has no illumination levels above 10,000 lux



Distribution of sunlight

	March	June	September	December	Average
E	1,93	3,82	1,93	0,26	1,99
S	2,83	3,44	2,83	0,75	2,46
W	1,93	3,82	1,93	0,26	1,99
N	0,96	2,44	0,96	0,15	1,13

Fig. (Monthly means of daily irradiation and transmitted energy through double glazing (kWh/m^2 glass/day)[171]

171 Source: European Passive Solar Handbook, 1986.

Furthermore, the total curves for E, S, W and N and for March, June, September and December, show that the radiance in the spring and in the autumn are identical for E and W. These statistics document the large seasonal variations at the latitude of Denmark. N is the orientation which receives the least radiation and has the least light intensity, as it, throughout the year, receives very little sunlight.

The total number of hours of sunshine is distributed very unevenly between E, S, W and N, with twice as many hours of sunshine to the S as to the E and W and with no sunshine excessing 10,000 lux to the N. The figures also show that the relationship between the numbers of sunshine hours are by and large the same for E, S, W and N at 10,000 lux and 20,000 lux respectively.

All in all, statistics show that the geographical orientation creates large differences in both the light and the heat intensity, differences which, for good or bad, form the basis of the architecture. A healthier architecture may adapt to these geographical differences, balancing the sunlight during the day.

In its starting point, this balance – as we have seen – can be obtained through the orientation of the building and through the form of the building. However, where this is not possible, it can also be obtained by modifying and redistributing the windows and the glass areas of the building.

In order to base the architecture on clear glass, a differentiation between E, S, W and N is necessary. Otherwise, as mentioned earlier, these conditions are used to determine the degree of solar protective glass compared to the size of glass area. However, this is an approach which, all things being equal, reduces the natural daylight and impairs the previously mentioned health conditions, increasing the aforementioned *unhealthiness factor*.

Instead, the above mentioned weather and light conditions form the basis for a new method which can provide a healthier light in the form of the clear low-iron glass, and at the same time balancing the sunlight during the day and the year.

The circadian rhythm and the geographical orientation

Thus we can renounce the cloudy sky as a mathematical abstraction, which hardly exists in practice during a single day of the year. The morning light will basically create more light to the E, and the path of the sun will render the light different throughout the day and throughout the year, which is hardly surprising, considering that the direct sunlight exceeds 100,000 lux in the summer, while a blue sky, without direct sunlight, only provides approx. 12,000 lux[172]. The sun is, depending on the time of year and the weather, responsible for up to 88% of the total light.

172 Johnsen K, Christoffersen J. *SBI 219, Dagslys i rum og bygninger*, p. 20. SBI, 2008.

Let us therefore have a closer look at how the geographical orientation influences and supports the health and the circadian rhythm. A factor which is early on described by Florence Nightingale, who gives name to the hospital buildings where the pavilions[173] are oriented in order to benefit from the sunlight.

Nightingale has, based on experience, seen how wards without sunlight often have a higher mortality rate than wards with sunlight. For Florence Nightingale the seasonal variations play a particular role in the healing, which is why she recommends pavilions oriented to the S. South, as we have seen, is not only the orientation which makes the most of the sun, throughout the year, but also the orientation which provides most light during the dark winter period which – according to Nightingale – is critical for the mortality of the patients.

If we look at evidence based research, it seems that the geographical orientation is important when we talk about health and hospitalization. North facing wards may, with less light and less variation in the course of the day, be less suitable for patients. A survey[174], conducted over 4 years with a total of 600 patients admitted to an intensive coronary care unit, finds that a total of 39 die in the dark, north-facing side, while only 21 die on the sunny, south facing side. Also the hospitalizations are shortened on the sunny, south side, on average by one day.

As described earlier there is less light intensity to the N than to the other corners of the world. Likewise, there is approx. 60%[175] less UV light here, where the light of the sun barely enters – contributing to a lesser extent as an antiseptic agent on bacteria to the N. All in all circumstances which may explain the observations of Florence Nightingale on sunlight in relation to season. Moreover, to the N, there are least seasonal variations in light.

To the E and W the seasonal variations are significantly larger. In the summer, both receive much sunlight, respectively very early in the morning and very late at night – and very little sunlight during winter, where the sun rises in the SE and sets in the SW.

To the W, too much light and heat at nighttime immediately before the patients sleep can cause problems. During the summer, the sun sets in NW at PM. 21.00 solar time, which corresponds to PM. 22.00 summer time. At this time, light is not beneficial for the circadian rhythm and the formation of melatonin, which is only produced at low light intensities. Light at this time delays and impairs the sleep period and thus impairs the restitution, just as the heat of the sun causes problems – especially to the W in the summer, where overheating is a general problem in an already warm building.

As we have seen, E and W seem identical in many ways. However, from a health point of view, there are large differences between these two orientations. While the lack of sunlight to the W, results in no positive therapeutic

173 Nightingale F. *Notes on Nursing: What is and What is not.* London, Harrison. 1860.
174 Beauchemin KM, Hayes P. *Dying in the Dark*, p. 352-354. Journal of the Royal Society of Medicine, 1998.
175 Wulff HC, et al.

effects in the morning, the sunlight to the E, seems to have beneficial effects on the health, strengthening and supporting the circadian rhythm in the morning, advancing and improving the sleep period – which, incidentally, is particularly important at hospitals where sleep is often notoriously poor.

On the other hand, E does not have the same heat problems as W. To the E, the sun heats up both the room and the body in the morning, at a time when the temperatures of both the body[176] and the building are low. The light and the heat from the sun does not cause the same problems here to the E, as compared to the W, where both the light and the heat may cause problems, impairing sleep. Especially if solar protective glass is not used.

The geographical orientation all in all creates differences in the light, differences which affect us bodily and mentally. The *circadian light clock* shows the bodily rhythm, relating the light of the sun – or rather the rotation of the earth around itself – to the circadian rhythm of the body. The sun is in the N at nighttime and in the S at noon, solar time. This circadian light clock is based on the sunlight, and the differences[177] in the sunlight which support the circadian rhythm of the body, both during the day and during the year.

Fundamentally, light works differently depending on the time of day. While light in the morning has a positive therapeutic effect, until a certain time of day, approx. PM. 14, light after PM. 14 no longer works therapeutically. Actually, light in the evening time becomes counterproductive to e.g. sleep, shifting and reducing the production of melatonin after PM. 18.

In this context, it is essential to understand that the time, at which we receive the light, is of great importance. As can be seen, the sun rises very early in the summer in the NE, in fact, immediately after the deepest sleep, at AM. 04.37 in what is termed *summer east*. As we have seen, the early morning light varies a lot at the latitude of Denmark, as the angle of the morning sun and the evening sun varies by up to 90 ° – from *summer east* in NE to *winter east* in SE. In the evening hours, at PM. 19, the highest body temperature is observed, this is a time when the body is – as opposed to in the morning – trying to get rid of heat, especially during the summer. This means that the sun, coming in from W, makes a warm building even warmer, which is why W often creates heat problems during the summer.

North varies – together with S – very little throughout the year, the light to the N is very stable through the day, and creates no differences, that may support the circadian rhythm. To the N, the lower intensity of the light, caused by the lack of direct sunlight, does not support the production of serotonin – and thus is not conducive to the production of melatonin at night[178]. The fact

176 The body temperature varies approx. 0.6° C during the day, it is warmest approx. PM. 19.00. See *the circadian light clock*, p. 101.
177 Large differences, due to the fact, that up to 88% of the light comes directly from the sun, affecting e.g. serotonin, according a Finnish study. Partonen T. *Vitamin D and serotonin in winter*. Medical Hypothesis, 1998 september 51(3).
178 Op. cit. In the chapter light and disease, p.48.

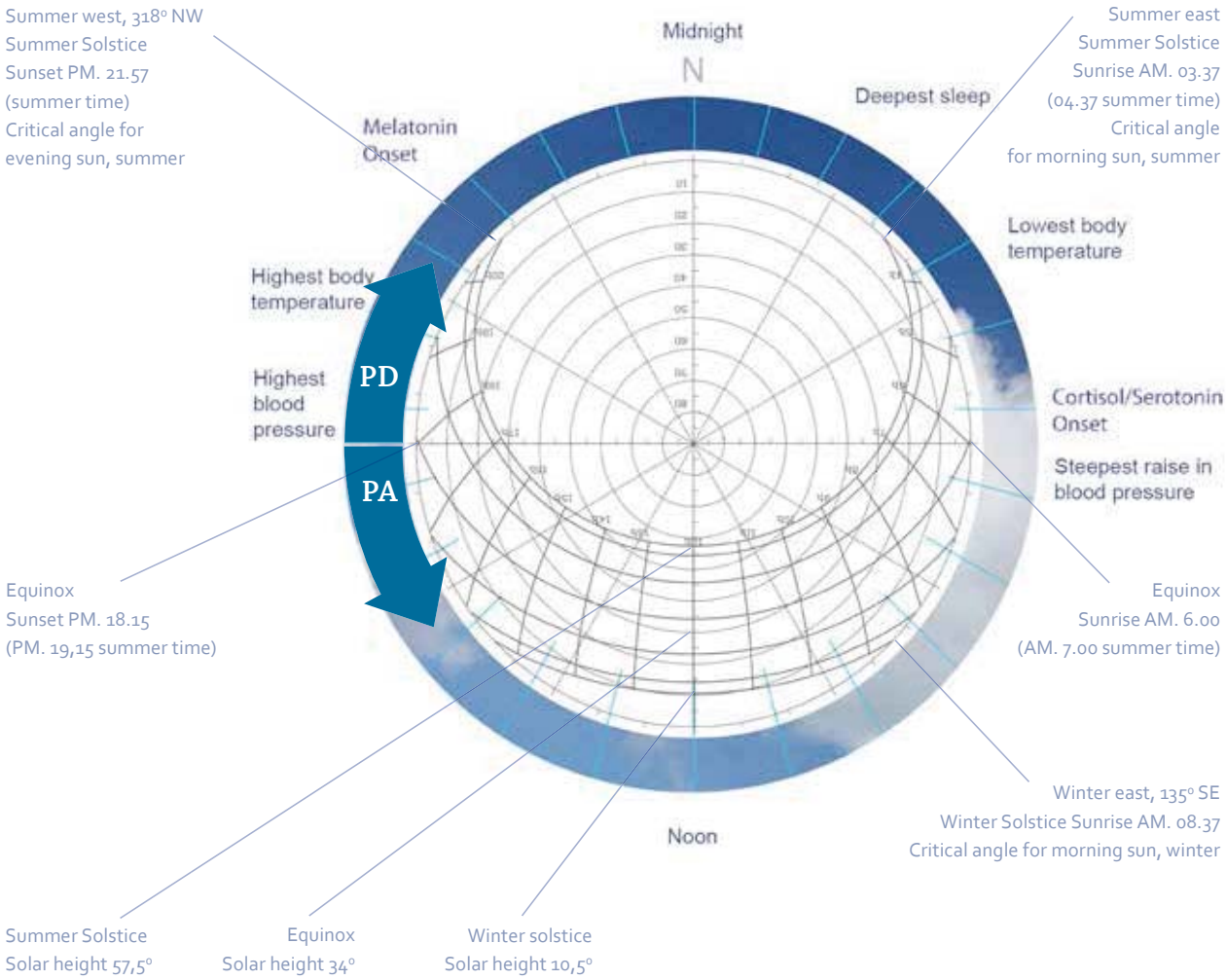
that the S varies very little means that both the biological night and noon time can be kept fairly constant throughout the year. An orientation to the S, in this context, not only means that the room receives more sunlight during the day, it also means that too much sunlight too late in the afternoon and in the evening can be avoided, which can, healthwise, be appropriate.

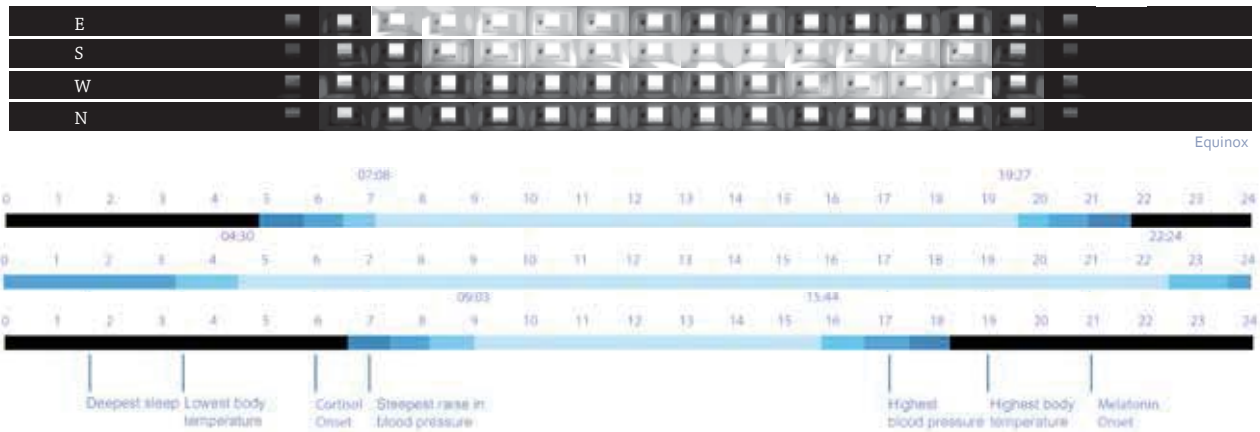
By contrast, the planning of the light in E and W present a greater challenge, when talking about light and health, and much suggests that they are determinative of whether a building is rightly or wrongly oriented, seen from a health perspective. Especially the morning light is essential. However, the therapeutic benefits of light, vary during the year and may, in a room facing due E, become directly counterproductive during the summer time, when the sunlight enters too early in the morning.

As shown on the opposite page, equinox perfectly balances the periods of light and darkness with the circadian rhythm and the serotonin levels. However, the seasonal changes, as shown on *the circadian light clock*, challenge this balance. On the basis of the earlier section, *light and disease*, and the discovery of *the missing piece in the lighting puzzle*, it is no wonder that we get tired and more sluggish during the dark winter period and more excited and active during the bright summer period.

All in all, our body rhythm seems to be adapted around the equinox – the median of the lighting conditions – which corresponds to the completely fixed light-dark ratio around the equator. Originally, we may actually have evolved to this rhythm – in the equatorial regions – where the light varies very little during the year. The varying light levels e.g. in Denmark challenge the way we plan the architecture and the daylight, simply because the large differences between summer solstice and winter solstice challenge our circadian rhythm and thus both our physical and mental health.

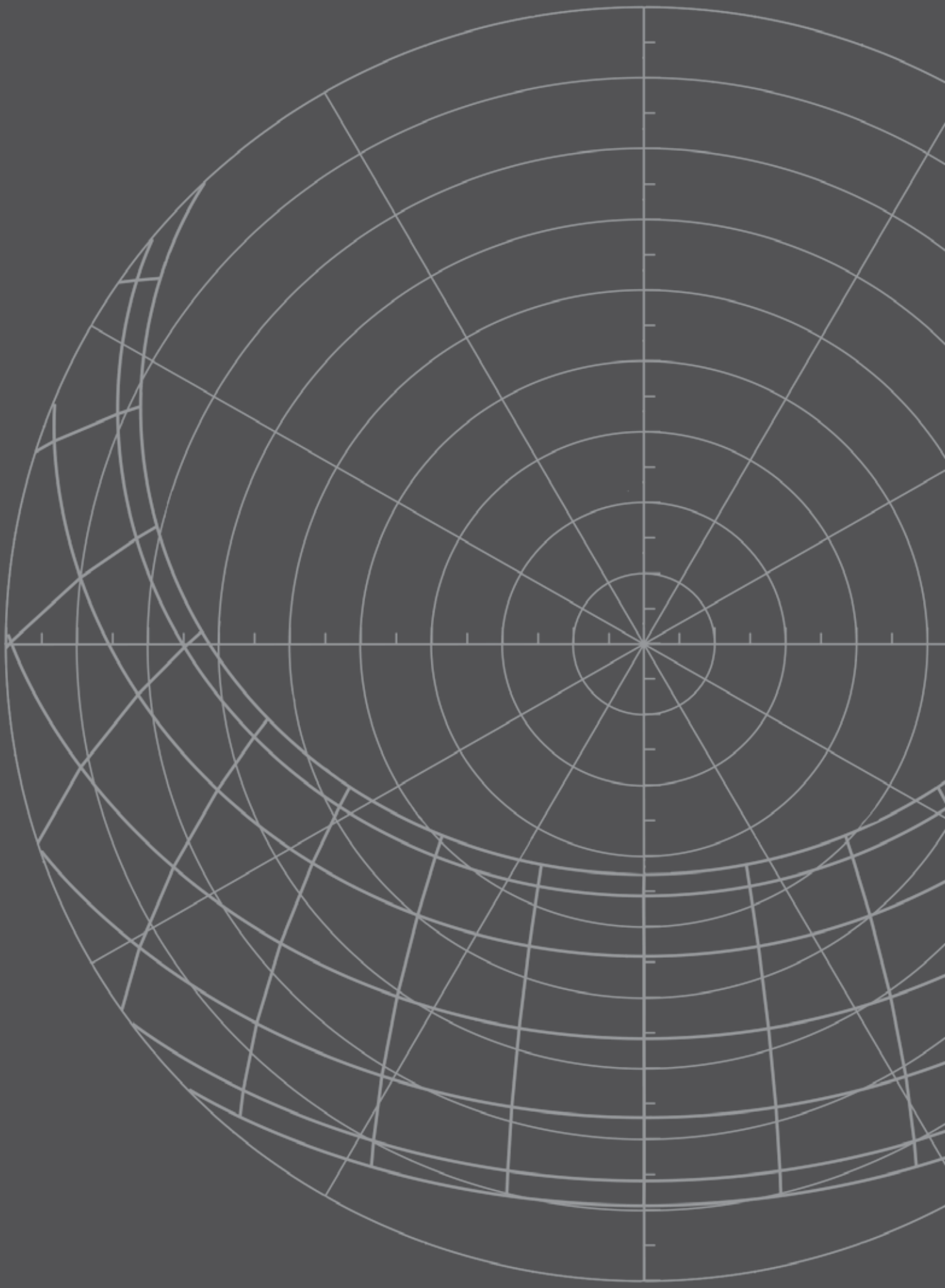
Against this background, it is no coincidence that Alvar Aalto blocks out the evening sun, which heats through the window until PM. 22.30 at 60° N. latitude, where the darkness and the cold of the winter must be balanced with the sunlight and the heat of the summer.

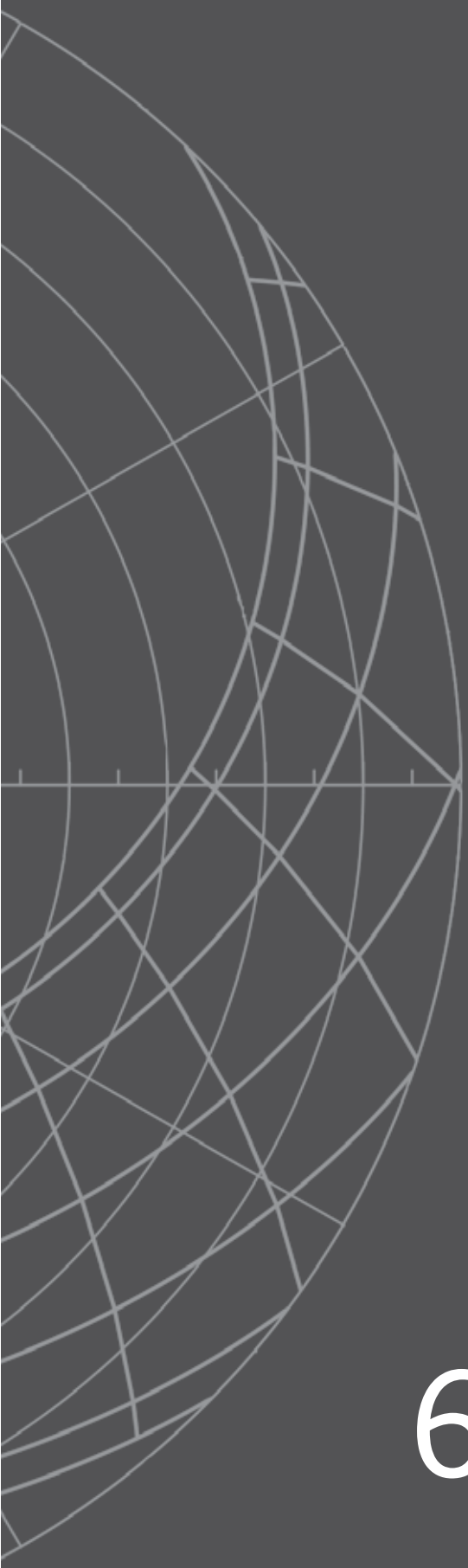




Top: A new tool: *The circadian light clock*, relating light, darkness and the geographical orientation to the circadian rhythm of the body, partly during the day, partly during the year. As shown, the shifts in the seasons at our latitude challenge the circadian rhythm, thereby challenging the architecture and its geographical orientation. For example, the sun rises in NE approx. 3 hours earlier than the serotonin onset, during summer. The formation of melatonin, as shown, culminates approx. PM. 21 – but actually already starts PM. 18. The late evening sun to the W therefore challenges sleep and the circadian rhythm in the summer

Bottom: Simultaneous-time-lapse-photography of the control rooms at equinox. The facades, oriented strict E, S, W and N, as shown, support the circadian rhythm at equinox. But at northern latitudes, this strict EW-orientated axis is challenged during the year; in the winter period the morning sun is shifted and delayed, E receiving less and later morning sun, and in the summer period E receives more and too early sun – at times when we have the deepest sleep. The evening sun shifts in the same way to the W, where the solar light and the solar heat during the summer may cause problems





6 THE PRACTICAL LIGHT EXPERIMENTS

6. THE PRACTICAL LIGHT EXPERIMENTS

The practical light experiments – method

Of the elements of a room, the window is the most marvelous. The great American poet Wallace Stevens prodded the architect, asking "What slice of the sun does your building have?" To paraphrase: What slice of sun enters your room? What range of mood does the light offer from morning to night, from day to day, from season to season and all through the years?[179].

Louis I. Kahn

Louis Kahn may, like Paul Scheerbart, describe the light through the eyes of beauty and poetry. But in this context I often miss more specific studies of the variation in the sun over time and place and through the year. Such a study is therefore what I will embark on, a study which, based on different rooms[180], studies the light in the different orientations, from day to day and from season to season, using a new method of representation.

In terms of research, the method relies on an active gathering of information, i.e. information that is not gathered passively, but produced actively, in this case, the form of architectural scale models of rooms. The experimental procedure is based on test and control trials, using test- and control-rooms with similar total glass areas. While the glass area in the test-rooms is divided *asymmetrically*, according to the geographical orientation and the weather- and lighting-conditions, described earlier, the glass area in the control-rooms remains uniform and *symmetrical*, regardless of the geographical orientation. The purpose of this experimental setup is to explore the differences in light caused by the geographical differences and to explore a healthier architectural balance between these differences in light.

All the light experiments are carried out on the roof of The State Hospital in Copenhagen in the period 2011 - 2013. Here, approx. 70 m above the ground, there is an unobstructed view to all four corners of the world. A prototype *light station* is installed and mounted, consisting of a total of 8 rooms. All 8 scale-rooms are based on *the good ward*[181]. All the rooms are basically single-bed wards and serve as light laboratories in the light experiments.

The experimental procedure of the light experiments is based on *similar conditions*, i.e. in controlled experiments in which test and control experiments are compared under similar conditions. *The control experiment* consists of 4 identical, undifferentiated rooms, while *the test experiment* consists of 4 modeled and differentiated rooms. Both test and control groups consist of a room for each

179 Kahn, LI. *The Room, the Street, and the Human Agreement*, 1971.
180 All in all 8 rooms, in the scale 1:17, based on a 18 m² single bed ward and produced using a 3D print in plaster, with glass having a light transmittance corresponding to the clear, low-iron diamond glass.
181 Made by Vejle County, 2003.

of the four corners of the world. The test rooms are modeled in relation to the knowledge that has been gathered earlier, and the light is deliberately planned according to the described differences in light, both in terms of the geogra- phical orientation and the weather, and in terms of health-related issues.

The function af a light modulator is to catch, reflect and modulate light. A flat surface does not modulate, it only reflects light. But any object with combined concave-convex or wrinkled surfaces may be considered a light modulator since it reflects light with varied intensity, depending on its substance and the way its surfaces are turned towards the light source[182].

The method consists of two parts, an analytical part, which examines and observes the geographical orientation and its influence on the light, and an architectural part, which examines the influence of the architecture on the light, as *a response* to the differences in light and the differences in the body's circadian rhythm. So firstly, this is about comparing the influence of the geographical orientation on the light, and secondly, to compare various architectural interventions and their impact on the light in relation to health.

The method is based on studies of the actual daylight, as portrayed through the day and through the year. The light of the sun and the weather become subjects to careful studies during the day and during the year. All the test rooms are based on the clear, low-iron glass which, in the first light experiment, has been found to be the healthiest. The openings are dimensioned and adapted to incoming sunlight, in order to use the clear, low-iron glass. In the control rooms, the symmetrical, undifferentiated and uniform architecture makes it impossible to use the clear, low-iron glass, simply because it creates too much exposure to solar light and solar heat, as we have seen earlier in field studies.

Also the artificial lighting is planned differently. All the illuminance levels are equal in all rooms, equivalent to 50 lux measured at floor level, the artificial lighting is *symmetrical* in the control rooms, while the artificial lighting in the test rooms is *asymmetrical*, see also p. 109.

Representation of light

The experiments are represented through photography. Although photography is not an objective mediator of light, and though photography, as a neutral form of representation is questionable, the fascination with light and openness perhaps finds its clearest expression in the photograph. Instead of being experienced on the site, the architecture is up through Modernism represented by photography. One might actually ask whether the international style would have been possible without the photograph? Alvar Aalto and Le Corbusier, amongst many other architects, are inspired by the often black and white publications, inclu-

182 László Moholy-Nagy. *Experiment in totality*. 1950.

ding the architecture of *Josef Hoffman* and *Adolf Loos*. However, Le Corbusier describes the discrepancy between the photography and the reality, as exemplified by the works of Josef Hoffman[183], Le Corbusier early on sees that photography is not just a passive intermediary, but an active and very powerful interpreter of reality[184]. In the early days, Le Corbusier dislikes the photograph and is very reluctant to use it, until he later – through a learning process – is able to master it and use it himself.

This learning process *László Moholy-Nagy*[185] calls *the education of the eye*[186]. Nagy considers this education a necessity at The Bauhaus School where he teaches. Nagy indeed describes those who remain unaware of the power of photography as the illiterates of the future. For the photograph not only reproduces reality passively, it also creates reality. We see it in movies and on TV, which often set the agenda for our perception of reality, mediums which interact with reality, but also go far beyond reality. We see it in 3D visualizations which, without an anchoring point in the perception, create buildings and set lights that very often manipulate us.

In this way photography overemphasizes the visual world, in what David Michael Levin describes as *the hegemony of vision*[187] and what Juhan Pallasmaa calls *an ocular-centric paradigm*[188]. Pallasmaa believes that we lose our unconscious peripheral vision and other senses in the attempt to capture the world only with the central vision of the eye. Therefore, we are not, in fact, stimulated to a more embodied experience, but merely held in passive observation.

However, architecture is not about creating images, it is about creating buildings, buildings in which people feel comfortable and when we talk about light, photography is so obvious and yet so far away. Obvious because the photograph reproduces and represents forms and shapes very accurately. But far away, because the photograph depicts light quite differently than our eyes conceive it and as a consequence doesn't reproduce the light as it is in reality. Although the photograph is – as the name suggests – *drawn with light*, it paradoxically tells very little about how the light is experienced in reality. The photograph is a very crude and primitive record of differences in light. The reason why it is so alluring and can fool us, is the fact that it detects *differences in the light* in a similar way as the eye and brain do when we see.

Simultaneous-time-lapse-photography

Despite these limitations in photography as representation, I have decided to portray and maintain the geographical differences in the light between the dif-

183 Colomina B. *The Split Wall, Domestic Voyeurism.* Princeton Architectural Press, 1992.
184 Ibid. Among other things, Le Corbusier writes about the disappointment when seeing the architecture of Joseph Hoffman in reality, Le Corbusier preferring it as a photograph.
185 Schildt G. *Alvar Aalto – his life,* p. 313. Alvar Aalto Museum, 2007. László Moholy-Nagy, Hungarian multi-artist, working with photography and film as teacher at the Bauhaus school. He early on inspires Alvar Aalto a.o.
186 Moholy-Nagy László. *New Vision*. 1938.
187 Levin DM. *Decline and fall – occularism in Heideggers reading of the history of metaphysics*, p. 205. 1993
188 Pallasmaa J. *The eyes of the skin*, p. 16. 2005.

ferent rooms, using photography. The photograph is used as *a fallible method of representation* in the light experiments and not without challenging it as a form of representation and in this regard, I have developed a new method of representation, a method that I call *simultaneous-time-lapse-photography*.

The method is, very briefly, based on photo-recordings of all rooms, recorded *at the same time – simultaneously*. Light is known to be a volatile quantity, ever changing and never constant. To develop a method which can at the same time catch and represent the light, is essential to portray the light and to maintain the differences in light over time and place. Simultaneous-time-lapse-photography depicts all the rooms *in the same light*. The method thus provides the opportunity to study all the different rooms and the different orientations, under the same lighting conditions – under *similar conditions*.

The photo-recordings are made in a complex setup, using 8 radio controlled SLR-cameras to capture photos from each of the 8 different rooms, every 2 minute. All recordings are made over a total period of 24 hours at summer solstice, winter solstice and equinox, respectively.

The intention of this complex setup is to get behind the weakness of the photograph. The practical light studies shall all in all be seen as a new form of representation of light, that seeks to eliminate the self-resonance of both the photographer and the photograph in favor of an overall strategy aimed at soberly to portray *the differences in light* over time, differences, which not only manifest themselves over time, but also over space, between the different geographical orientations N, S, E and W.

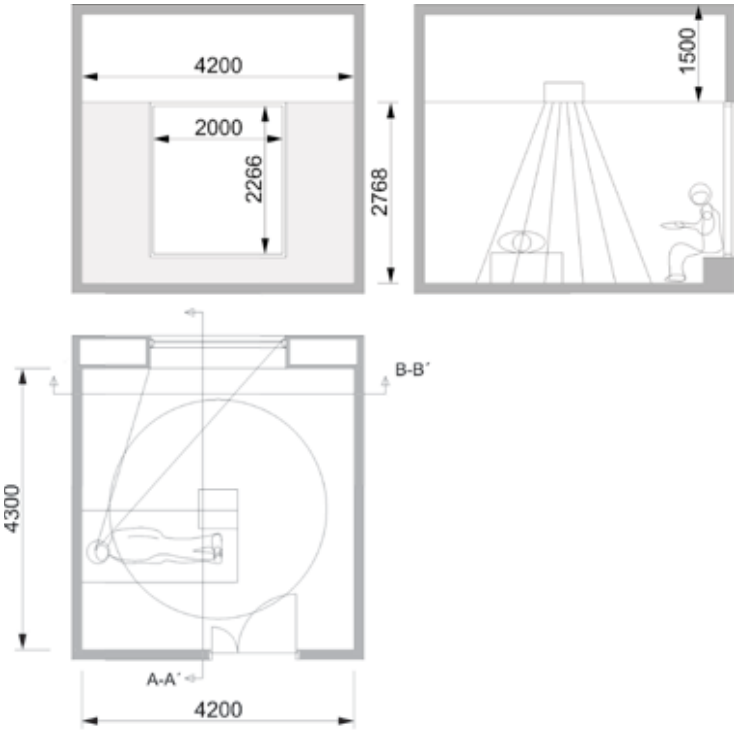
All simultaneous-time-lapse-recordings are shot with fixed aperture and varying shutter speed (0-30 seconds). In this way the recordings seek to represent the light as perceived, i.e. as a result of the adaption of the eye. In other words, the recordings represent how the rooms are *experienced*, and not how *the measurable light* actually is.

This approach may be discussed, and in this context, *the measurable light* and *the non-measurable light* are two very different methods which can quickly create a discussion. Therefore, at the end of the experiment, a measurement of the light in the 8 different rooms is also performed. Experimentally, this takes place in a quite simple way, by setting all 8 cameras at fixed shutter speed and fixed aperture. Based on an anchor point in the form of a reference measurement in lux, both the horizontal and the vertical illumination are recorded over time.

Previously, studies[189] have been conducted based on photo representations of windows and rooms. In one study independent subjects rate pictures on a scale from 1-5. Their assessments are subsequently divided into 3 groups; 1.0-2.2: bad, 2.3-3.2: neutral, 3.3-5.0: good. 105 are rated as poor, 100 as neutral and 129 as good, and although the spread between the responses is relatively high (0.79), the results are scientifically acceptable. Several similar studies[190] may be men-

189 Veitch JA, Aries MBC, Newsham GR. *Windows, view and office characteristics predict physical and psychological discomfort*. 2010.
190 Verderber. *Dimensions of person-window transactions in the hospital*. 1986.

The good ward, a single bed ward, with a total of 18 m², acts as the control room in the practical light experiments



tioned, and common to them is their use of unbiased test subjects to assess the photographs. In another study[191], different scale rooms are observed at different times, again making assessments of the quality of the light, e.g. the influence of glass on colors, textures and shapes in the rooms. Again, the results are scientifically acceptable.

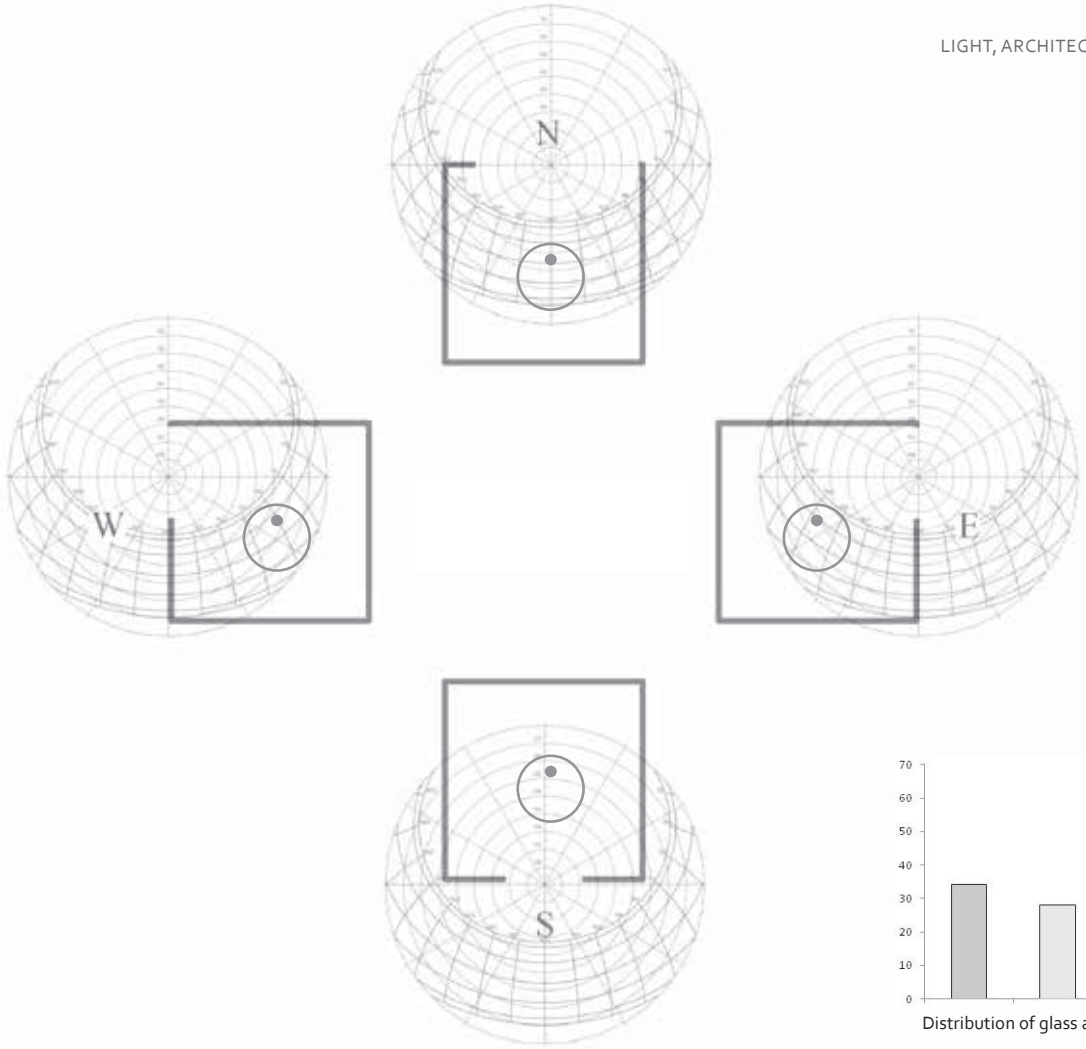
I have chosen to use scale rooms, but choose not to use volunteers. This is based on the desire to contribute to a more academically reasoned assessment, based on the general health considerations of light and health described earlier.

The ward as a light laboratorium

The same feeling of nowhere is also encountered in the interior of the dwellings. A neutral, flat surface has substituted the articulate ceilings of the past and the window is reduced to a standard device which lets in a measureable amount of air and light...( ) What range of moods does the light offer from morning to night, from day to day, from season to season, and all through the years?[192]

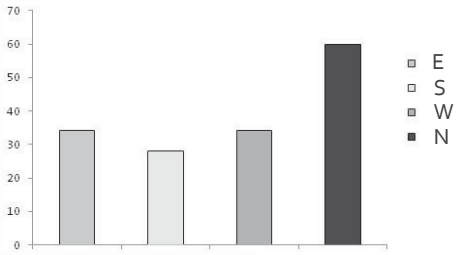
The light experiments are based on *the good ward*[193]. The good ward describes accessibility, size, patient requirements and personnel requirements as well as functional considerations related to the hospital ward, in order to form a rational

191 Johnsen K, Dubois MC, Cantin F. *The effect of coated glazing on visual perception: A pilot study using scale models.* Lighting Research and Technology, 39 - 3, s. 283-304. 2007.
192 Noberg-Schulz C. *Genius Loci*, 1979, p.190.
193 By Vejle County, January 2003

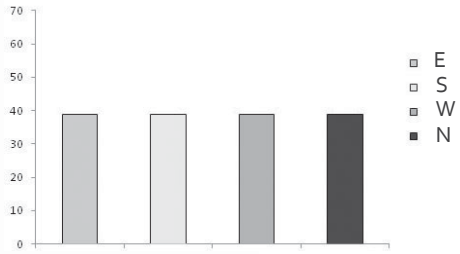


The test rooms. Consisting of four rooms with *asymmetrical* planning and placement of the light openings. A planning that reflects the solar light, the solar heat gain and the direction of the sun. In this way, the quality of the glass is optimized to achieve a healthier daylight

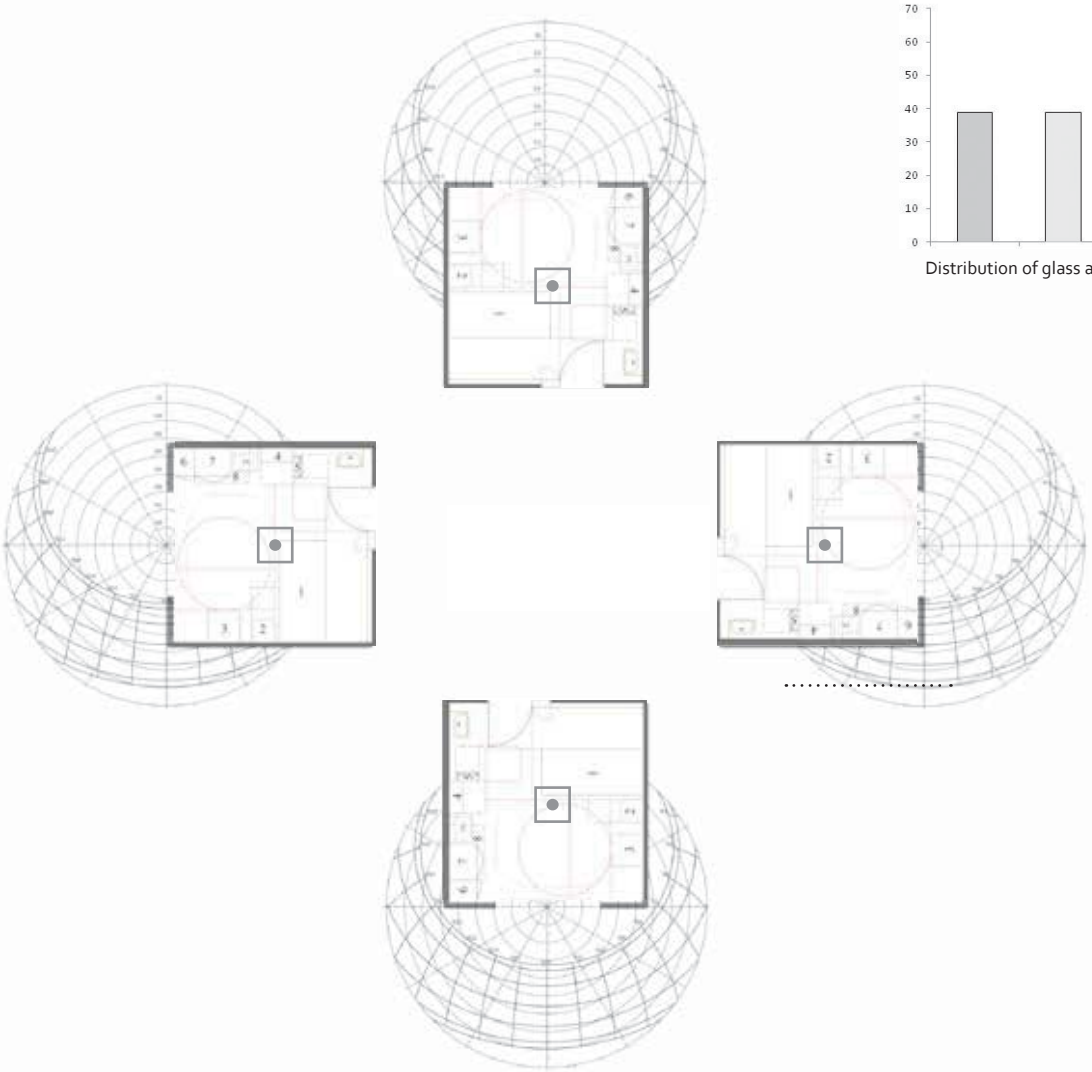
The artificial lighting is located centrally in the room and has an *asymmetrical* light distribution



Distribution of glass area: 34%, 28%, 34%, 60%



Distribution of glass area: 39%, 39%, 39%, 39%



The control rooms. Consisting of four identical rooms. Completely *symmetrical* planning and placement of the glass areas in every room. A planning which does not take into account the solar light or heat gain, and which in fact requires asymmetrical use of solar protective glass in relation to E, S, W and N.

The artificial lighting is placed centrally in the room and has a *symmetrical* light distribution. PS. The total glass area for test and control rooms is equal

framework for the future hospitals in Denmark. But in doing so, the geographical orientation is completely omitted, and light is only described based on intentions of a functional nature.

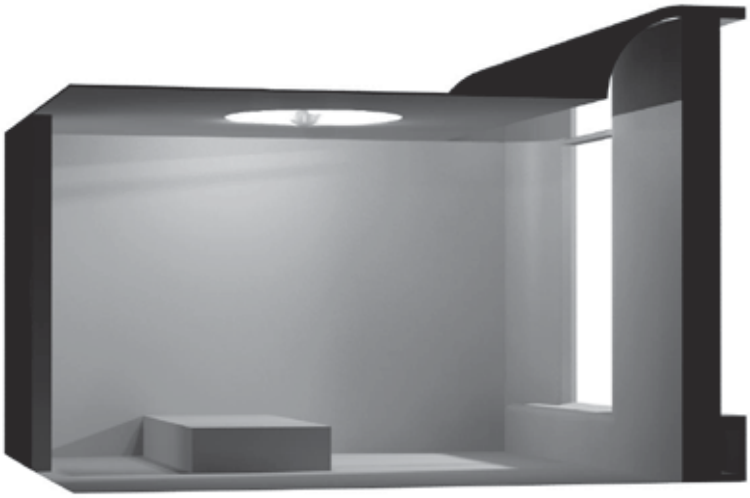
As we have seen, undifferentiated and symmetrical buildings exclude the clear, low-iron glass, so to speak, just as they do not differentiate the pros and cons of the evening sun and the morning sun, depending on the geographical orientation and the time of day and year. Architecturally, the good ward is therefore a good example of architecture which has lost its anchor point to the place, as described by Christian Norberg-Schulz[194]. Not only this, it has also lost its importance to the health.

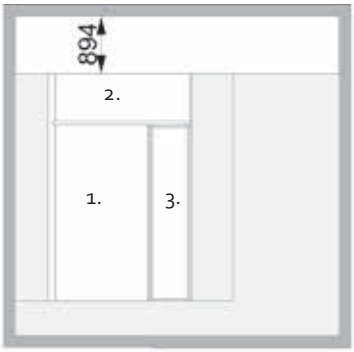
As I described earlier, a building may be seen as a response to the light of the sun. The architecture responds to the sun by adapting to the geographical orientation. But how does this adaption take place, and how can the architecture be differentiated according to the geographical orientation? How is the light planned? And how is the darkness planned? In this context, these are relevant issues. Through modeling the light opening and the facade, it is the intention that the test rooms will supply the answers to these questions, depicting how light and darkness may be balanced, in order to better cater for the health aspects of the sunlight.

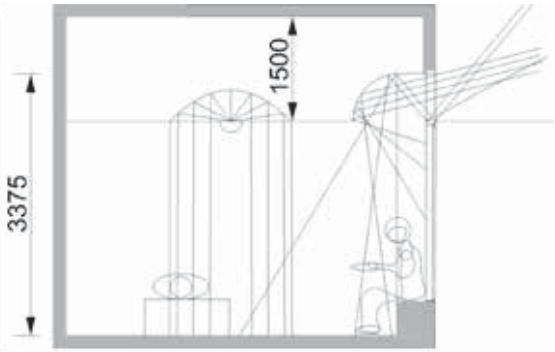
The overall grip in the practical light experiments, involves, as shown on the following pages, the creation of an asymmetrical architecture, which better takes account of the asymmetrical light of the sun. In the test rooms this is done by opening up to the N, where both the solar light and the solar heat gain are less. This may create more light on *the dark side* of the building, compared to the other rooms. In the same way to the E and W. Here, both the solar light and the solar gain is higher and as a response, the window openings here become smaller. To the E the light opening is positioned so that the morning sun shines on the bed area, where the patient is located. To the W, the light opening is positioned so that the evening sun is shielded by moving the light opening away from the bed area; in this way, the patient is protected from the evening sun. To the S the light opening is smallest. Here, the solar light and the heat radiation – together with the UV radiation – are highest. In order to balance these factors, it is necessary to rearrange –and reduce – the light opening to the S. Unlike all the other orientations, there is no canopy in the S-facing test room. The canopy will – to the E, W and N – increase the ceiling height, and provide access to the healthy sky light deeper into the room. However, to the S, a canopy may be counterproductive to the health, since a canopy will let more solar heat and UV light in at noon, at a time when the UV radiation is highest.

All in all, this architectural method creates different responses to the differences in daylight. The bar charts, p. 109, show the distribution of the window openings, and their different sizes and positions in the test- and control-rooms.

194 Norberg-Schulz C. *Intentions in Architecture*. MIT Press, Cambridge, Mass., 1965.



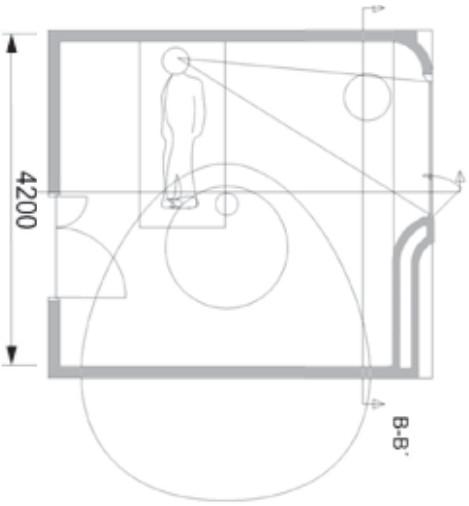




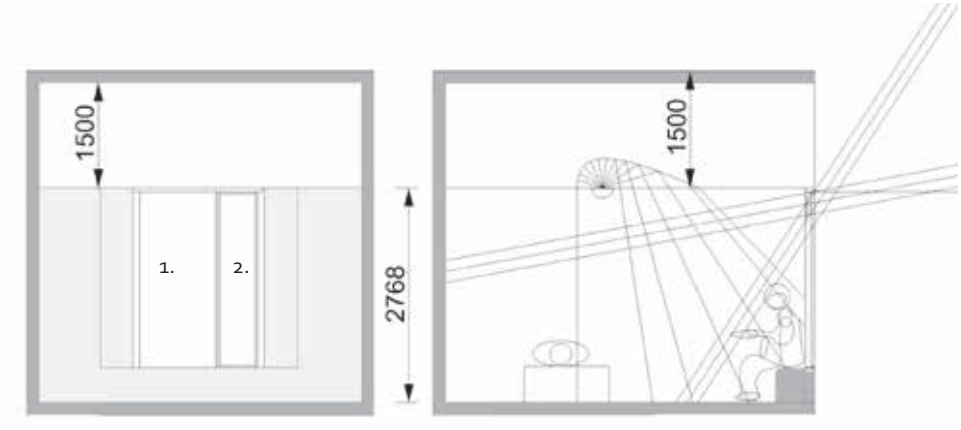
E-facing test room. The window is placed asymmetrically in the room so the sunlight hits the adjacent side-wall. In this way, the light is reflected into the room, while the bed area is exposed to the morning sun. The window is divided into three parts:

1. View opening
2. Daylight opening
3. Fresh air opening

The light opening is modeled to increase both the view and the light. The canopy spreads and diffuses the morning sun near the window. The windowsill is designed ergonomically so that it is possible to sit in it. The artificial lighting is asymmetrical, indirect and glare-free LED lighting, directed in the opposite direction of the light opening



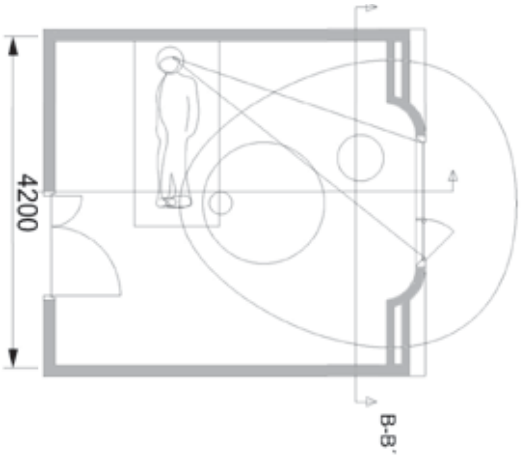
E



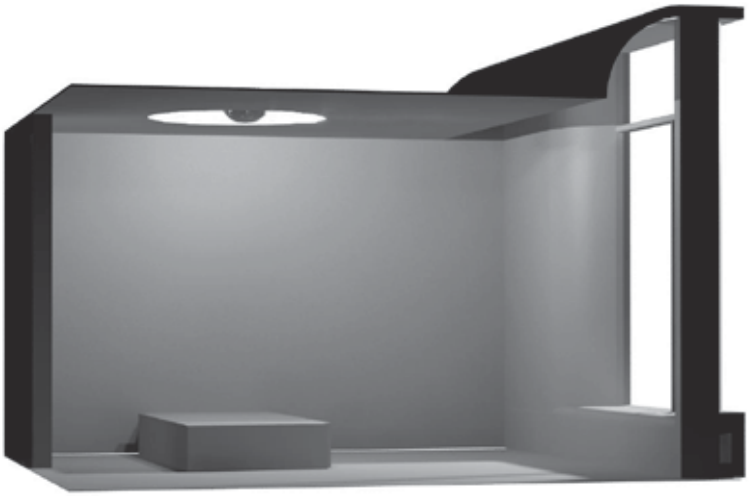
S-facing test room. The window is, exceptionally, placed symmetrically in the room. The window is only divided into two parts:

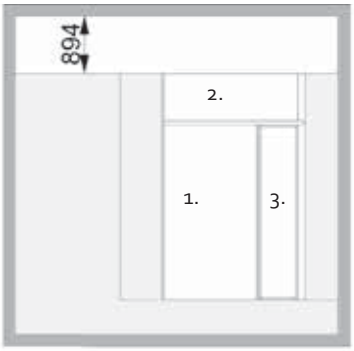
1. View opening
2. Fresh air opening

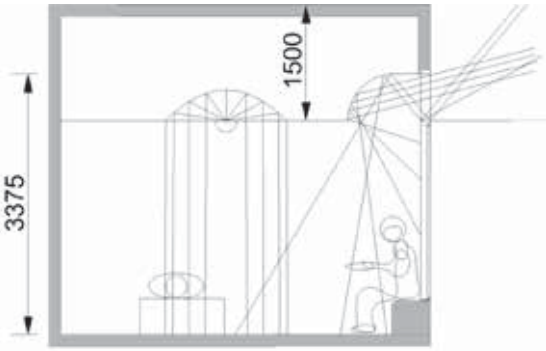
The light opening is modeled to increase both the view and the light. The canopy has been removed and this lowers the ceiling height, in order to protect the patients from the noon sun and its high UV radiation. The asymmetrical, artificial lighting is directed to the facade, since the light opening here is small, the facade can better reflect the artificial lighting back into the room, compared to the other test rooms

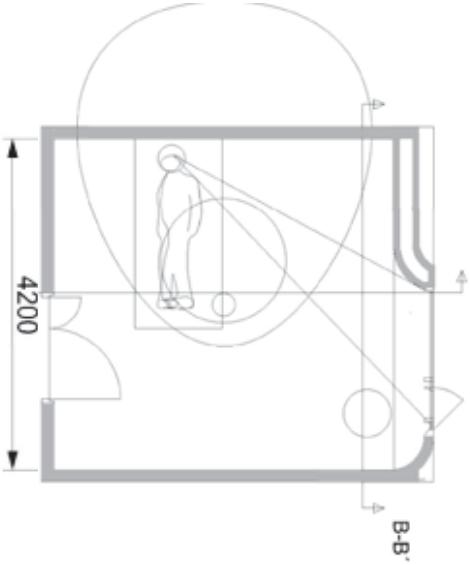


S







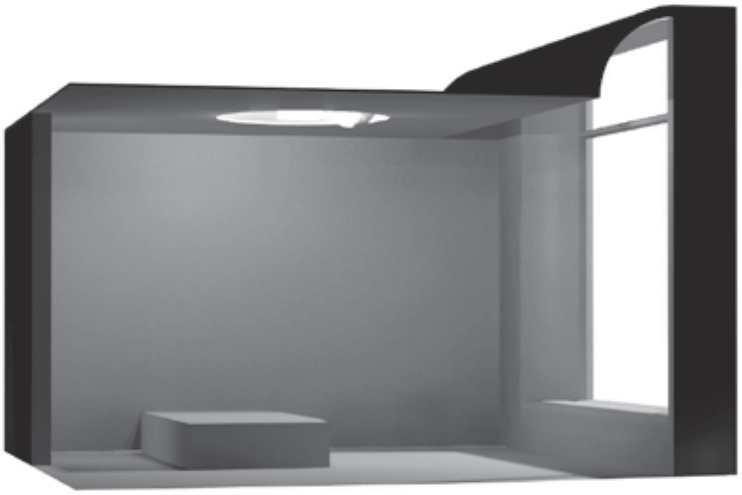


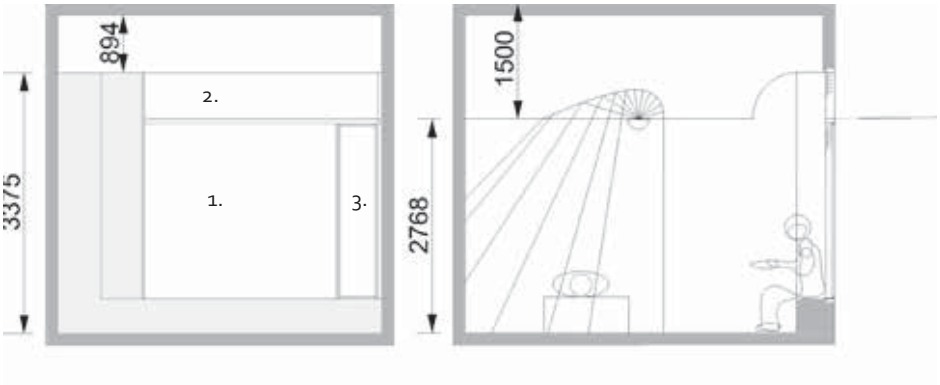
W-facing test room. The window is placed asymmetrically in the room, so the sunlight hits the adjacent side-wall. In this way, the light is reflected into the room, while the bed area is protected against the evening sun. The window is divided into three parts:

1. View opening
2. Daylight opening
3. Fresh air opening

The light opening is modeled to increase both view and light. The canopy spreads and diffuses the evening sun down into the bay window. The artificial lighting is asymmetrical, and directed in the opposite direction of the light opening

W

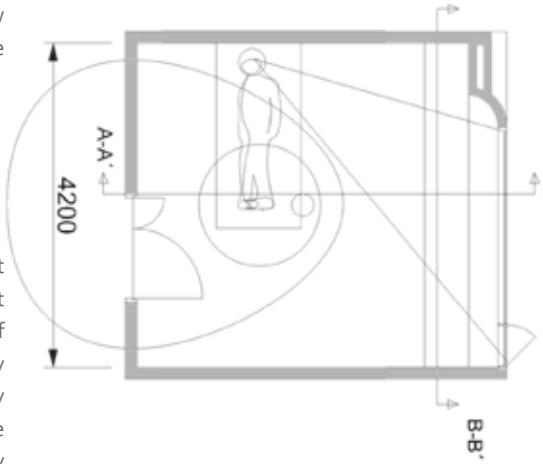




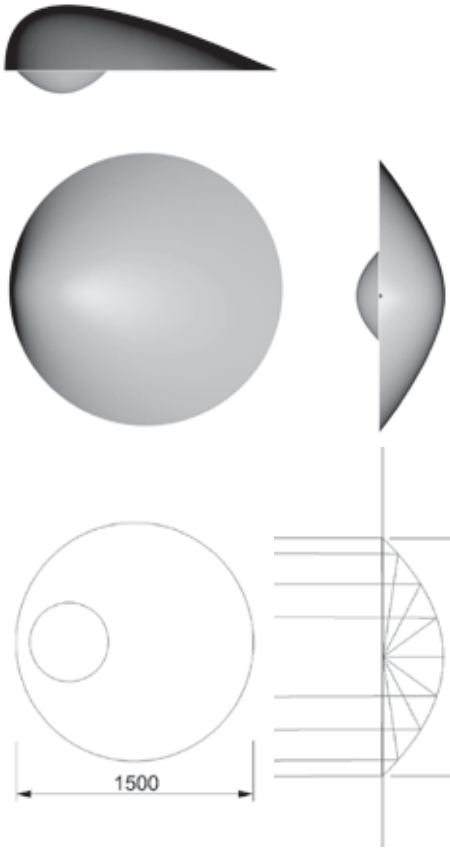
N-facing test room. The window is placed asymmetrically in the room. The window is again divided into three parts:

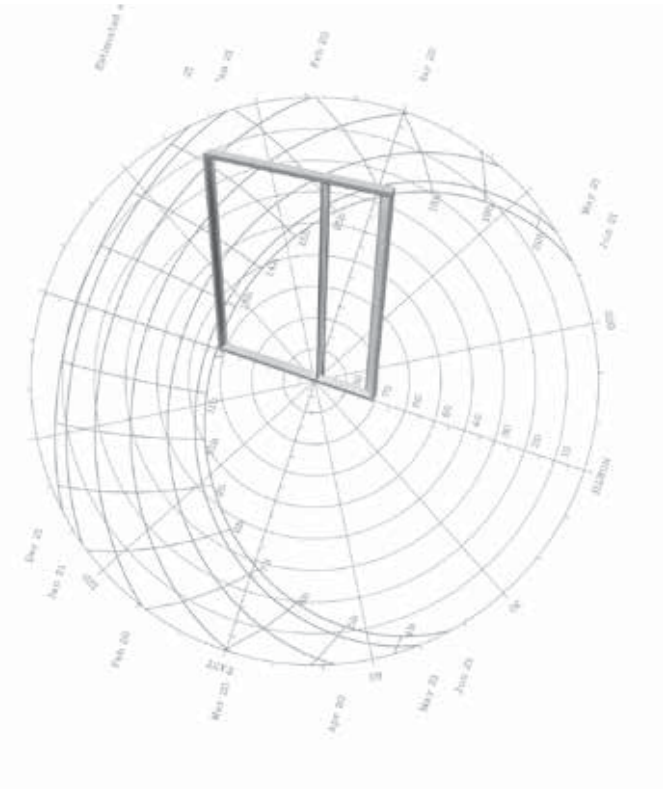
1. View opening
2. Daylight opening
3. Fresh air opening

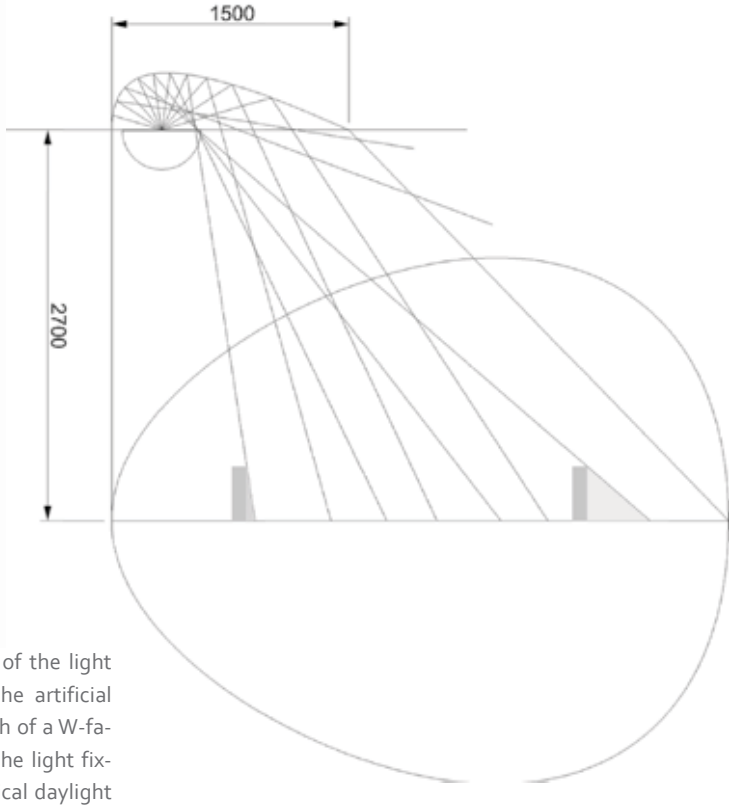
The light opening is largest here to the N, where the light intensity and the amount of sunlight is less. The canopy reflects and diffuses the sky light into the room, and the windowsill is ergonomically designed in order to sit in the light. The artificial lighting is directed away from the window, away from the large glass area, and toward the back wall



N







In the test room, not only the placement and the size of the light openings are asymmetrical. So are the windowsills, the artificial lighting and the windows, as seen here in an early sketch of a W-facing window – yet without the daylight opening. Also the light fixtures are asymmetrical, as a response to the asymmetrical daylight in the test rooms. However, the asymmetrical light fixtures also – as shown – create a more varied shadow-rendering in the room, from a sharp shadow-rendering and better detail rendering in the bed area, to a softer shadow-rendering and a better spatial rendering further away from the light fixtures

The practical light experiments – results

In the following, the light experiments are presented as *a light story*, which tell how the light and the darkness affect the architecture and the space during the day and throughout the year. However, it also tells us how the light and darkness affect our health, and how the architecture may respond to the light, facilitating and supporting the health. The light story is told under light and weather conditions characteristic to Denmark. That is, during the course of days[195], with both cloudy weather and sunshine. The story focuses on several key stages of the day, which are interesting seen from a health perspective. All captured and portrayed through *simultaneous-time-lapse-photography*. Here are the following six key stages of the day.

AM. 6.00	The morning light – the first light
AM. 8.45	The morning light – winter east
PM. 12.15	The noon light – the last morning light
PM. 15.45	The winter west
PM. 19.00	The evening light – the last light
PM. 21.45	The night – the first darkness

The light story may be read as *a comparative study* of light, showing the differences in light. Each of the stages consist of 8 simultaneous-time-lapse-photographs depicting the different rooms at the same time and *in the same light*, partly in the test rooms (top) and partly in the control rooms (bottom). The key stages are presented in chronological order, first in relation to E, S, W and N, and then in relation to the seasons, respectively equinox, summer solstice and winter solstice. At each stage the differences in light are related to health, and the advantages and disadvantages during the day and year are discussed and clarified.

On the opposite page, an overview of the graphic form of representation is shown, depicting the layout of the 8 cameras in simultaneous-time-lapse-photography. Top and bottom each magnify one of the recordings of the test and the control rooms respectively. For each page, the time of day and the geographical orientation of the rooms is indicated. In the depictions of the differences throughout the year, the recordings are also magnified, depicting equinox, summer solstice and winter solstice respectively.

Each page may work as an individual study. In this context I would ask the reader to feel free to explore, sense and experience the differences in light and architecture, during the day and during the year – be it in chronological or in random order.

195 On 28th June, 2012, 13th September, 2012 and 13 December, 2012. All recordings are made over 24 h on these three dates.

1-4

1

2

3

4

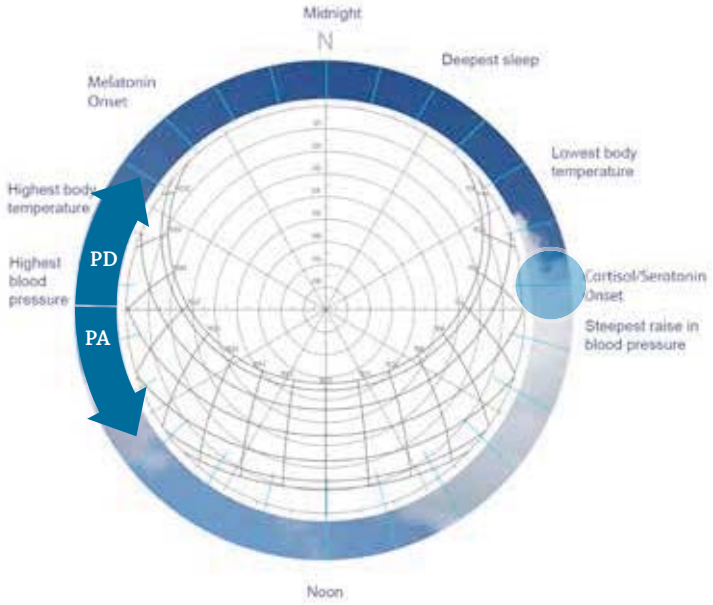
5

6

7

8

5-8



THE MORNING LIGHT – THE FIRST LIGHT

Equinox AM 6.00

The light is distributed differently, because of the geographical differences. The E-and N-facing rooms have more light in the early morning.

The daylight is asymmetrical. In the control room facing E, the right wall receives more light, while to the N the left wall receives more light.

In the test rooms, the size of the light opening is decisive for the amount of light in the room. At this time, there´s mainly skylight and no direct sun, therefore the light opening serves as a *camera obscura*; the larger the window, the greater the reflection of light and environment becomes in the room.

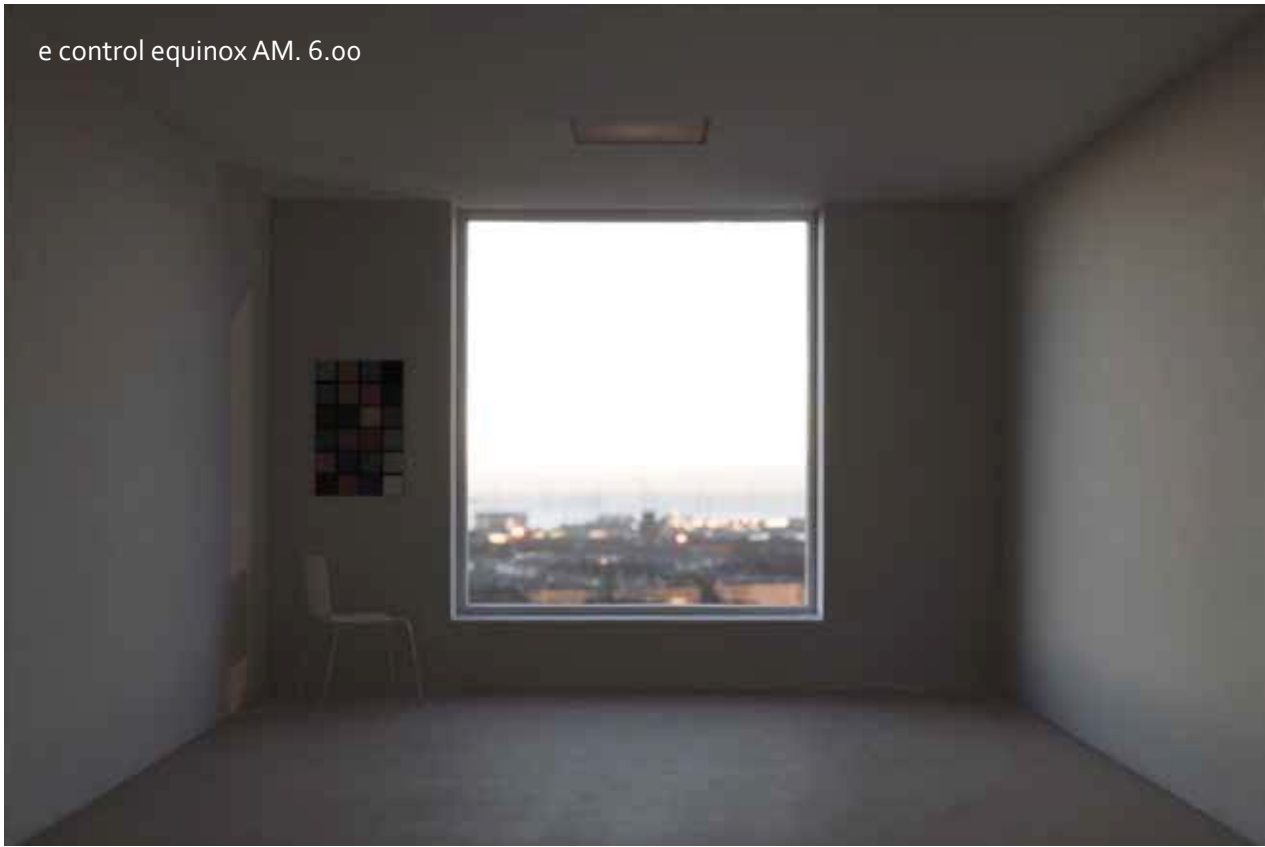
Making the window opening larger, to the N results in more light in the test room than in the control room, by moving the light opening to the left, towards the E, the test room becomes brighter, and the asymmetrical daylight is distributed more uniformly, compared to the control room. In the test room to the E the light in the room is distributed more symmetrically, despite a more asymmetrical planning and placement of the light opening.

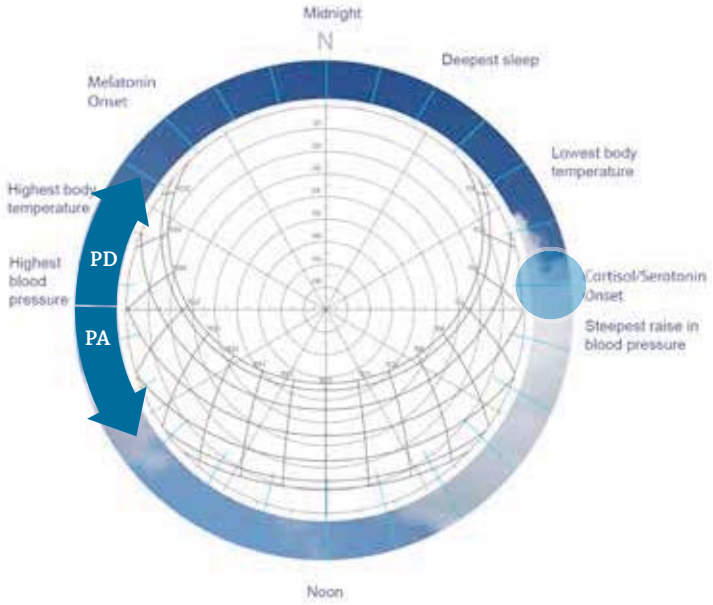
To the E and N, the canopy not only creates an increased window height, allowing more skylight deeper in the room, it also reflects the sunlight, which lights up the facade wall, which, in comparison, is experienced as darker and more contrasted in the control room.

At equinox, the light supports the circadian rhythm and the production of serotonin, as seen above. The sun rises at a time when serotonin and the stress hormone cortisol are being formed and it sets at a time when the sleep hormone melatonin is being formed.


e test equinox AM. 6.00
55°66´N, 12°60´W, kl 6.00


e
s
w
n


e control equinox AM. 6.00



THE MORNING LIGHT – THE FIRST LIGHT

Summer solstice AM. 6.00

The morning light varies according to the season, the morning light in the summer is very different from the morning light at equinox.

There are large geographical differences in the morning light, between E, S, W and N. The W-facing room appears darker compared to E. The difference in morning light throughout the year occur primarily in the E-facing rooms which vary, while the W-facing rooms are more stable.

As at equinox, there is more light to the E and to the N here, when the sun rises in NE.

To the S the test room is brighter than the control room, due to the modeling of the light opening creating more skylight. The test room – inspite of a smaller aperture – appears brighter than the control room. The N-facing test room is significantly brighter than the control room.

In the test rooms, the canopy creates more light on the facade wall, compared to the S, where there is no canopy, together with a symmetrical position of the light opening – creating a darker facade.

The sunlight enters very early to the E, in summer, and the sun has at this time been shining into the room for approx. one and a half hour.

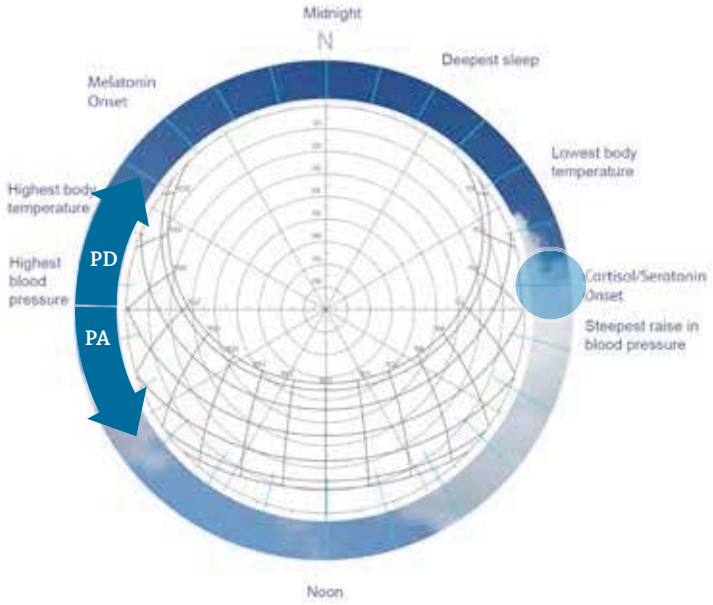
From a health perspective, light too early in the morning is not appropriate. At summer solstice, the sun rises at 4.37, at a time when we are sleeping deeply, disturbing the circadian rhythm and arousing us too early. Therefore, the light should be shielded.

Although the test room to the E shelters from the early morning sun, the sunlight creates too much – and too early – sun to the E, here at these due EW-oriented facades in this experimental setup.


e test summer solstice AM. 6.00
55°66´N, 12°60´W, kl 6.00


e
s
w
n


e control summer solstice AM. 6.00



THE MORNING LIGHT – THE FIRST LIGHT

Summer solstice, equinox and winter solstice AM. 6.00

The morning light varies significantly through the season. In the morning there is too little sunlight in the winter and too much sunlight in summer.

The seasonal differences in light at our northern latitudes challenge the planning of light, making it difficult to balance the morning sun throughout the year.

But asymmetry in the position of the light opening in the E-facing test room shelters the bed area from early morning sun, during the summer; it is not reflected into the room to the same extent as in the control room.

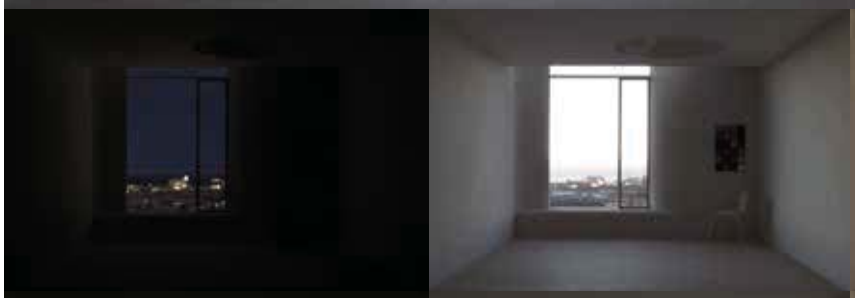
Seen from a health perspective, the light is balanced better in the test rooms during the summer in this manner.

However, the overall, strict EW-orientation of the rooms does not balance the seasonal variations well, exposing us to too much – and too early – morning sun, throughout the summer.

As can be seen above, the strict E-facing facade means that the sunlight – depending on environment – enters the room AM. 4.37 in the morning in the summer time, and very late in the winter. While it seems that this EW-orientation supports the circadian rhythm at the equinoxes, it challenges the health in the summer and does not balance the morning sun in winter, when sun rises further south and much later; AM. 08.37.

e test equinox AM. 6.00

55°66´N, 12°60´W, kl 6.00

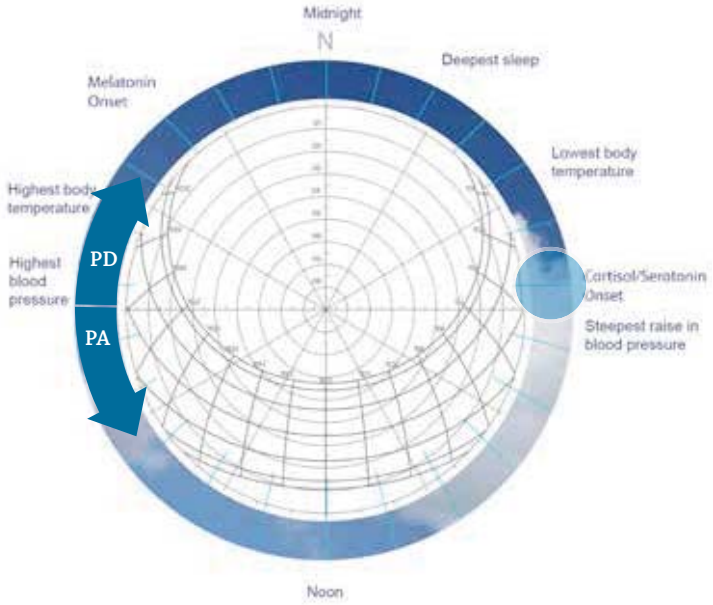


winter solstice

equinox

summer solstice

e control equinox AM. 6.00



THE MORNING LIGHT – THE FIRST LIGHT

Summer solstice, equinox and winter solstice in artificial lighting AM. 6.00
The large seasonal variations emphasize a particular need for good artificial light in the morning hours.

The experience of the artificial lighting varies in relation to the seasons; from intense white in the winter darkness, to a weak, more yellowish light during the summer. The artificial lighting also creates a bluish rendering of the daylight outside, compared to the same time without artificial lighting.
Although the illuminance is identical in all rooms, the test rooms appear brighter, and the asymmetrical artificial lighting increases the depth of the rooms, creating larger differences between light and darkness, enhancing the experience of light, at the same time creating a better representation of the space, with softer shadows around the chair.
The asymmetrical light distribution creates more space for the interplay with daylight in the often long, characteristic transitions between light and darkness in Denmark. In the control rooms, on the other hand, a more uniform shadow-rendering with less difference in the light, creates a more flat light, with less depth in the room, without variation, leaving no space for the interplay between daylight and artificial lighting.

Seen from a health perspective, good artificial lighting is important here early in the morning, especially during the winter period, to support activity and serotonin levels at a time when we, as seen above, may rather prefer to sleep.

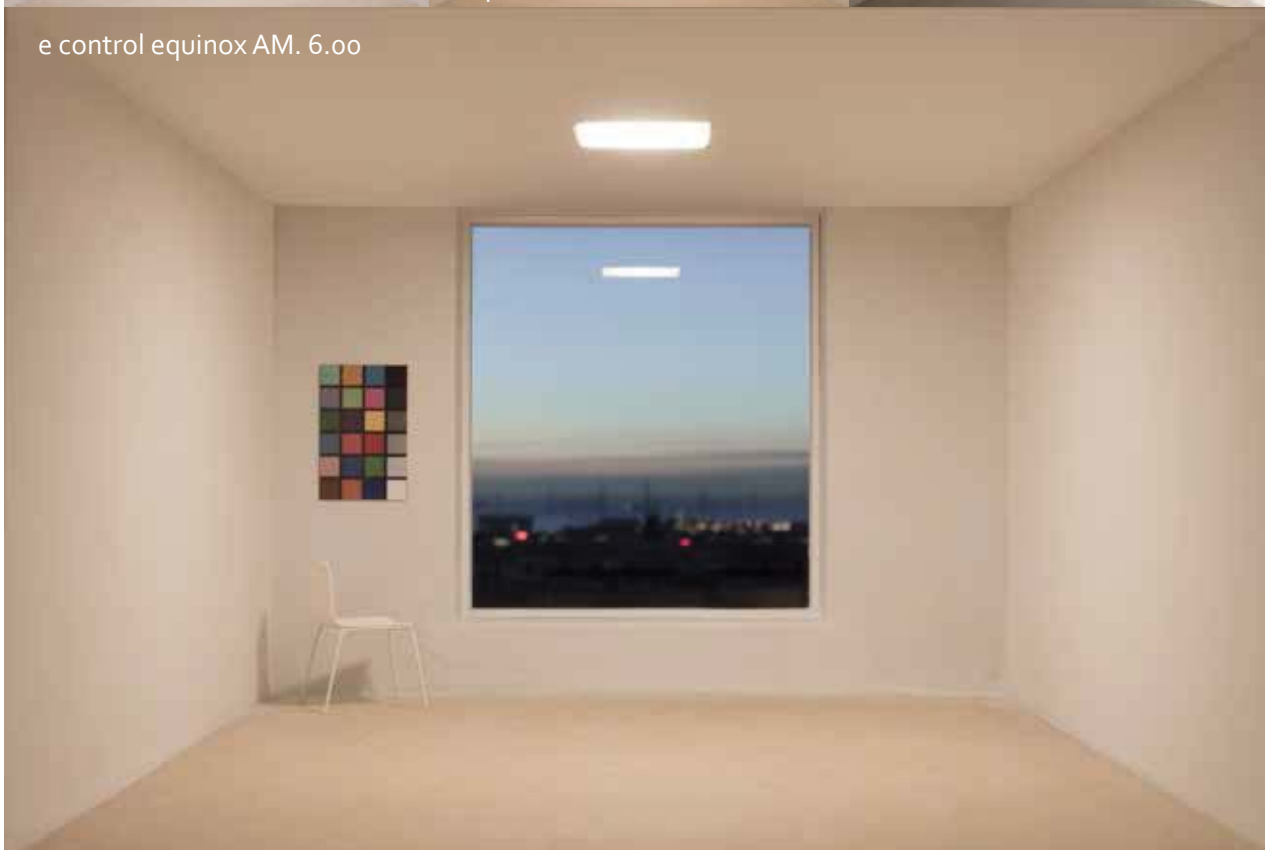
Artificial lighting overall renders a room very different than daylight does. In broad daylight, during the summer, the space becomes tall, the canopy providing daylight and light on the facades, while the room, at the same time during the winter, appears low-ceilinged and cave-like in artificial lighting.

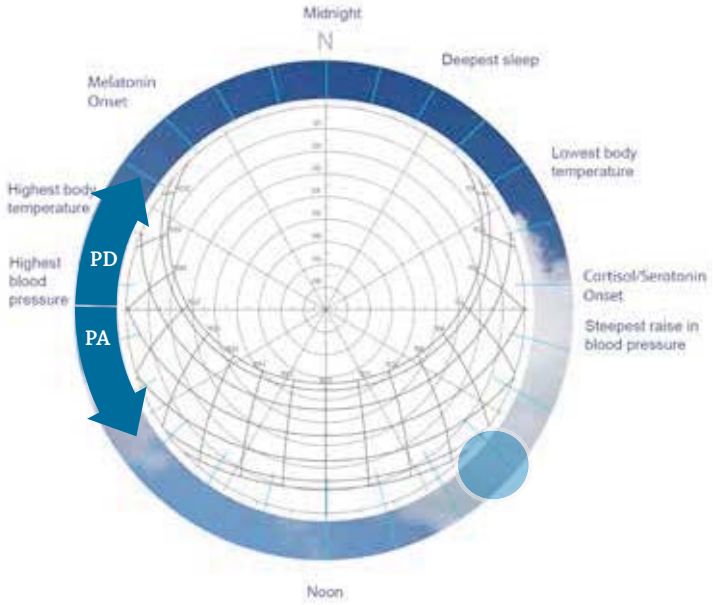

e test equinox AM. 6.00
55°66´N, 12°60´W, kl 6.00


winter solstice


equinox


summer solstice


e control equinox AM. 6.00



THE MORNING LIGHT – WINTER EAST

Winter solstice AM. 8.40
At winter solstice, the sun rises in what is termed the winter east. It happens AM. 8.37 and relates to the SE, which corresponds to 135°.

During the winter it is often cloudy, together with a generally weaker intensity from the sun, reduces the differences between E, S, W and N. However, geographical differences in light are observed, for example, to the E, where the sunlight is more intense.
To the E, the asymmetrical placement of the window in the test room creates more morning light, and the increased light opening to the N again creates more light than in the control room. To the W the right side wall and the canopy, reflect the skylight into the room creating a softer light – which, incidentally, is the hallmark of all test rooms with an asymmetrical placement of the light opening.

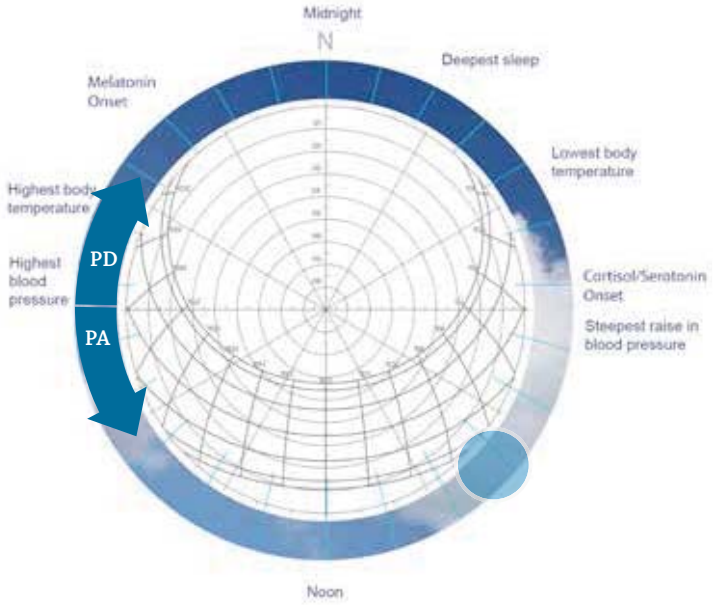
Outside there is snow, and it creates more reflected light upon the ceiling, which gives less direction in the light. This soft light highlights the modeling of the light opening in all test rooms, resulting in the windows being experienced as larger in the test rooms. In all control rooms the facade walls appear more uniform and dark, in stark contrast to the window, the facade wall receives only internally reflected light from the space.

Healthwise the morning light is not utilized very well here at the winter solstice, as shown above, when the sun rises in the SE, in winter east. This means that the strict EW-orientation provides less morning light to the E during the dark winter period, as the sun only briefly enters, before disappearing to the S.
An orientation more to the SE, to the winter east, would create more morning light in the winter – as it would indeed reduce the early morning sun in the summer, see p. 125.


e test winter solstice AM. 8.40
55°66´N, 12°60´W, kl 8.40


e
s
w
n


e control winter solstice AM. 8.40



THE MORNING LIGHT – WINTER EAST

Summer solstice AM. 8.40

Again the morning light varies a lot, depending on the geographical orientation, here at same time of the day as before, but in the summer.

While E, at winter solstice, at this time receives the first rays from the sun, it receives significantly more – and earlier – sunlight during the summer. The sun has already been up for 4 hours and is located high in the sky to the E.

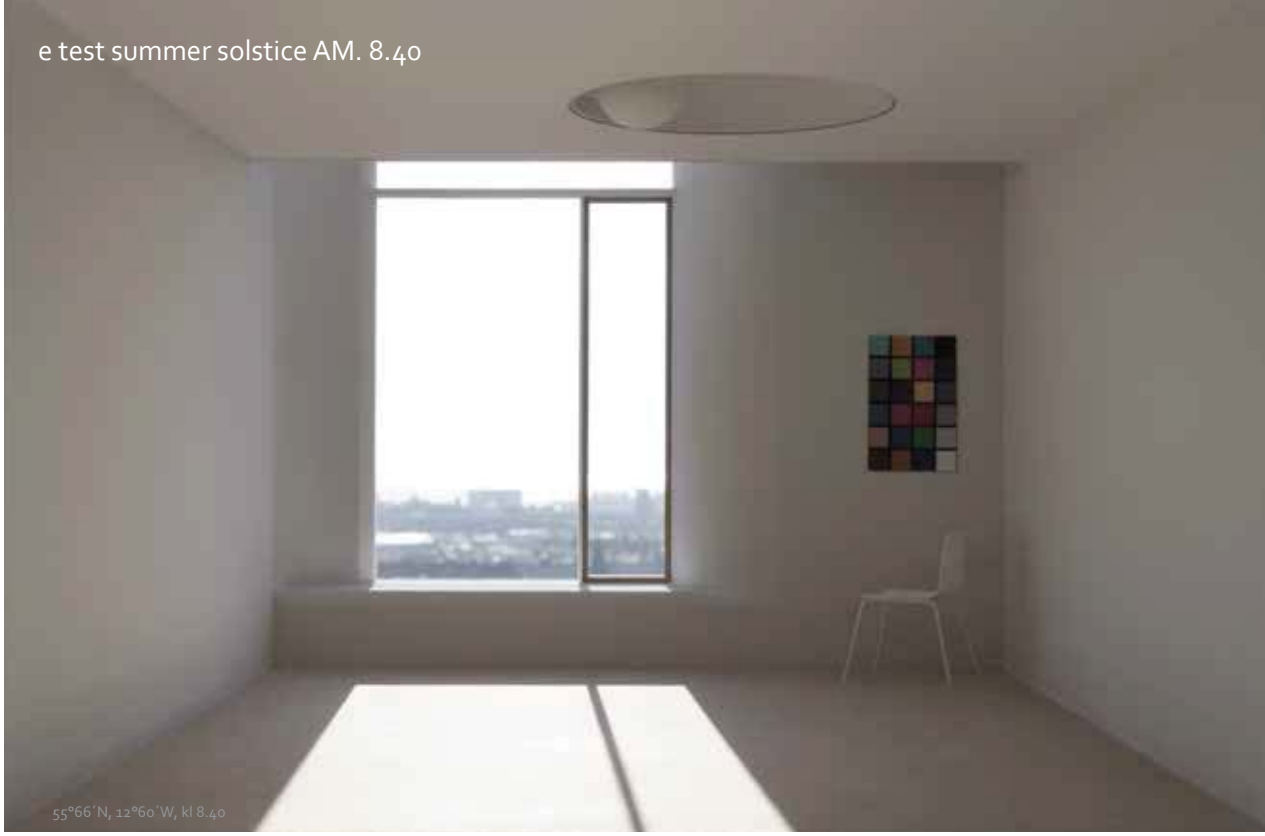
The W-facing rooms again vary less in the morning compared to the E-facing rooms, they appear darker and more contrasted, because there is no sunlight here. The W-facing test room, however, is brighter because of the asymmetrical placement of the window. The test room also provides more skylight than the control room, primarily due to the increased height of the window and the canopy, reflecting the light.

The test room, facing N, again appears brighter in the morning than the control room.

As seen, the modeling not only increases the size of the light opening and the amount of skylight, it also extends the sunlight in the test rooms, here to the N, where the sunlight hits the wall, which acts as a light source, creating more morning light in the test room – over a longer period of time – compared to the control room.

N only receives the sunlight in the summer months, as shown above, from equinox to equinox; a modeling of the light opening may help to utilize the sunlight better in the morning.

Healthwise, the morning sun rises early during the summer, rising already AM. 4.37 giving too much – and too early – light to the E. The strict EW-facing orientation of the facades opens up too much to the morning sun, which is already high by this time, during the summer. Reversely, in winter – as we saw on the previous page – it does not open up enough to the morning sun.


e test summer solstice AM. 8.40
55°66´N, 12°60´W, kl 8.40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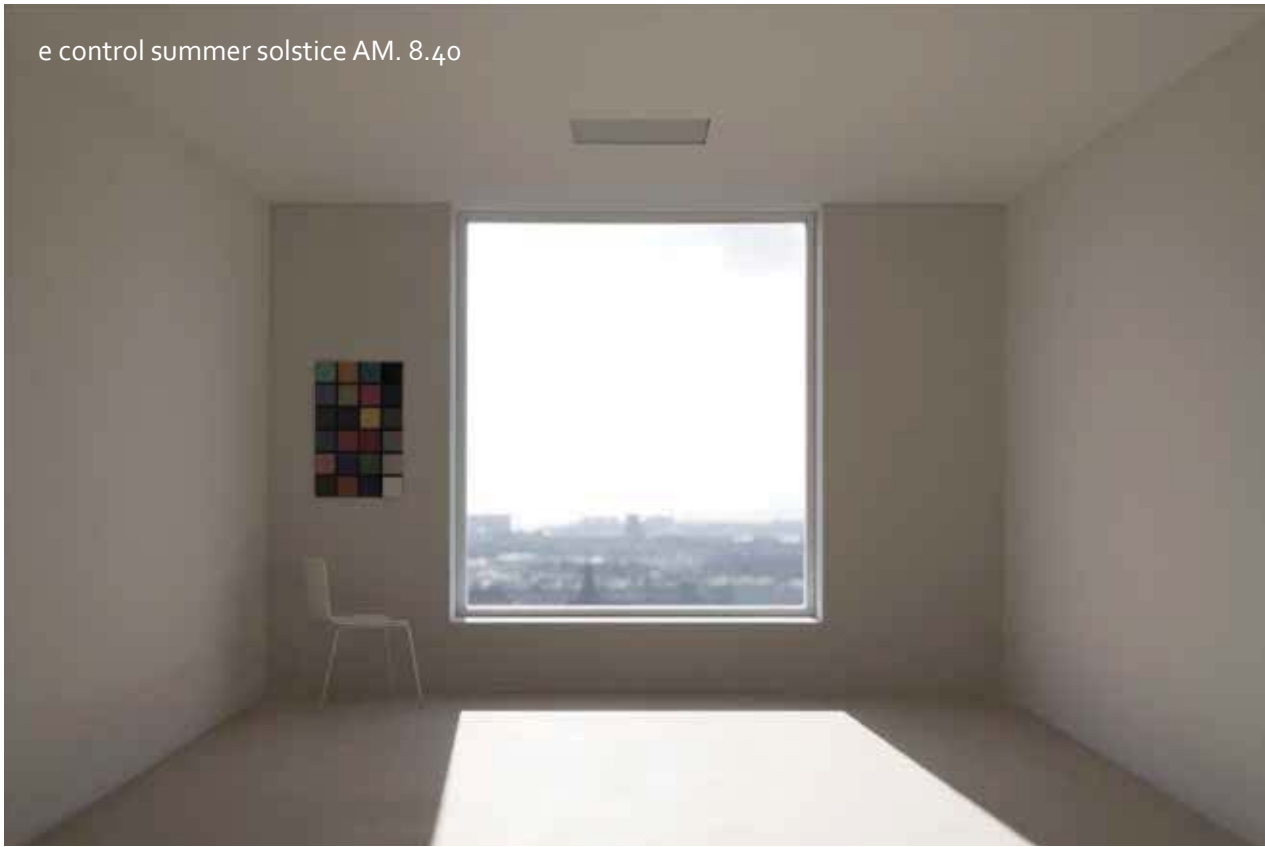
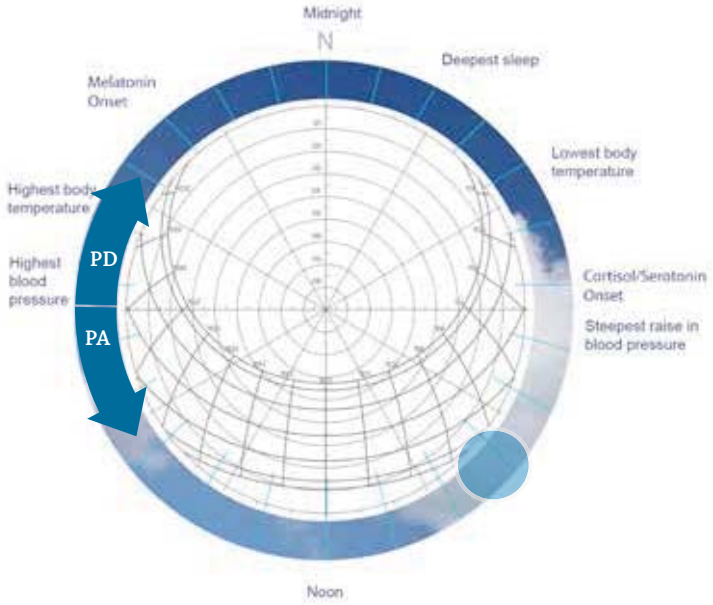

e control summer solstice AM. 8.40



THE MORNING LIGHT – WINTER EAST

Summer solstice, equinox and winter solstice AM. 8.40

By now, we have seen how the morning light varies throughout the year, but later in the day, the seasonal differences become smaller than they were AM. 6.00.

As can be seen, the sun has in the summer, moved due S, while it has only just risen in SE in the winter. So this is the earliest time of day when it is bright all year round, summer and winter.

All test rooms appear bright at this time compared to the control rooms, although the light opening, in e.g. the E-facing test room is smaller. This is again due to the asymmetrical placement of the windows, that better cater to the asymmetrical sunlight, together with the tall windows, better utilizing the healthy skylight.

Especially the morning light varies a lot throughout the year. Both light- and healthwise, this creates challenges, especially in a strict EW-facing building as this, challenges which can be lessened – but not solved – by asymmetrical planning of the light opening.

Instead, they may be solved by altering the main orientation of the building, towards the winter sun, that is towards SE, or winter east. This would shield the early morning sun in the summer, while at the same time utilizing the morning sun better during the winter.

As shown, the E-facing room is darkest during the winter, when the sun rises in SE and disappears to the S. A main orientation towards SE would provide more light and extend the hours with sunlight in the morning. Just as it also would mean that there would be less light – less early – in the E-facing rooms during the summer.

e test equinox AM. 8.40

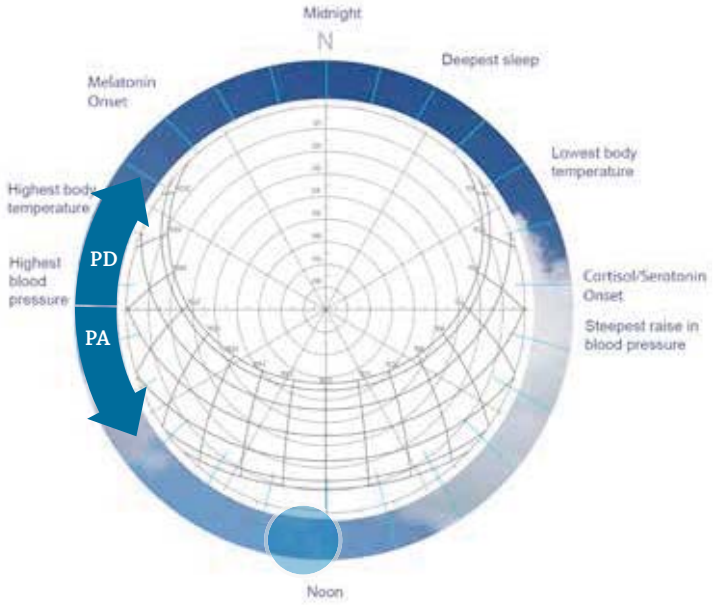
55°66´N, 12°60´W, kl 8.40

winter solstice

equinox

summer solstice

e control equinox AM. 8.40



THE NOON LIGHT – THE LAST MORNING LIGHT

Equinox PM. 12.15
Due to the summer time, and because of the geographical shifts, the sun is due S at PM. 13.15 local time in Copenhagen.

While we, previously, have seen that the first morning light varies a lot, the noon light is more stable, and the geographical differences in light between E, S, W and N seem less.

The E-facing test room is again markedly brighter than the control room, and the asymmetrically positioned light opening reflects more light into the room, rendering the test rooms in a softer light without sharp shadows around the chairs and with fewer contrasts compared to the control rooms.

Only the S-facing control room receives sun, while both the E- and S-facing test rooms receive sunlight. Again, the modeling of the light opening extends the sunlight – here in the E-facing test room.

The south-facing test room differs from the other test rooms, not having a canopy and this is due to two factors.
Firstly, the southern midday sun has the highest light and heat intensity, and, overall, most hours of sunshine.
Secondly, the UV radiation is highest in the middle of the day, when the sun is at its zenith in the sky – seen from a health perspective, the midday sun must hence be balanced.
Apart from this protection against the UV light of the sun, there are healthwise no special considerations to be taken at this time, here in the middle of the day.
The noon light is not just more stable than the morning light, throughout the year and in relation to E, S, W and N. It is also more neutral in relation to the circadian rhythm of the body, than the morning light. In other words, architecturally speaking, the noon light is easier to plan throughout the year than the morning light.


e test equinox PM. 12.15
55°66´N, 12°60´W, kl 12.15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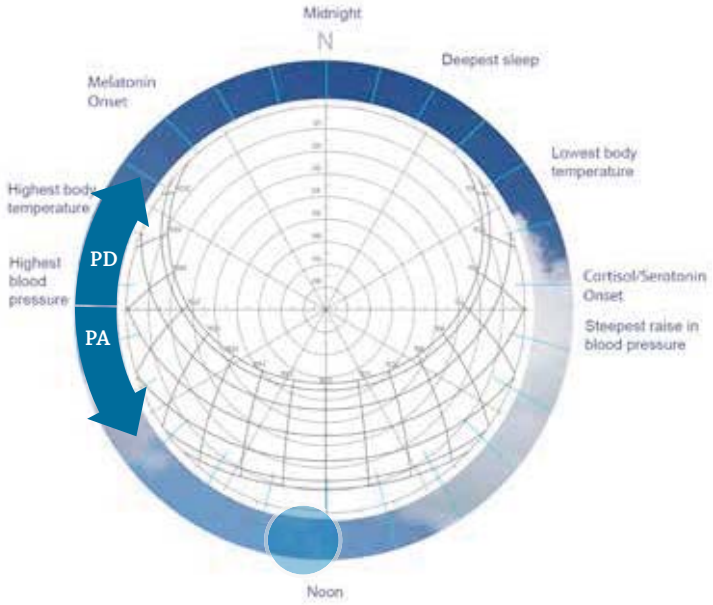
e control equinox PM. 12.15



THE NOON LIGHT – THE LAST MORNING LIGHT

Winter solstice PM. 12.15
Again the noon light is more stable than the morning light, here shown to the E, S, W and N.
However there are geographical differences in the light, caused by the asymmetry of the daylight. E.g. in the E-facing rooms which receive more light on the left side.

The N-facing test room is again significantly brighter than the control room. However, it only receives skylight, as there is simply no direct sunlight throughout the winter season.
The differences between the four corners of the world in the control rooms are generally leveled out by the asymmetrical architecture in the test rooms. This is confirmed in the S-facing test room, which, with its symmetrical placement of the window, does not seem to utilize the asymmetrical daylight as efficiently – appearing darkest, though there is actually more light here to the S.

In a sense, one can say that the architecture – by being asymmetrical and by being based on the asymmetrical light of the sun – balances and distributes the differences in daylight more equally between E, S, W and N. The test rooms generally create more light on the side walls and deep into the space, as the canopy lights up facade walls and vertical surfaces, also providing more skylight in the test rooms.

Healthwise, the light sensitive ganglia cells in the eye, are best stimulated by light coming from above and from the side. Vertical surfaces are, in this context, important and support the circadian rhythm and the daily activity. In general the canopy lets in more of the healthy skylight from above. Conversely in the control rooms, the vertical facade walls and side walls appear darker, as the healthy skylight does not enter due to the height of the window, which is lower than in the test rooms.


e test winter solstice PM. 12.15
55°66´N, 12°60´W, kl 12.15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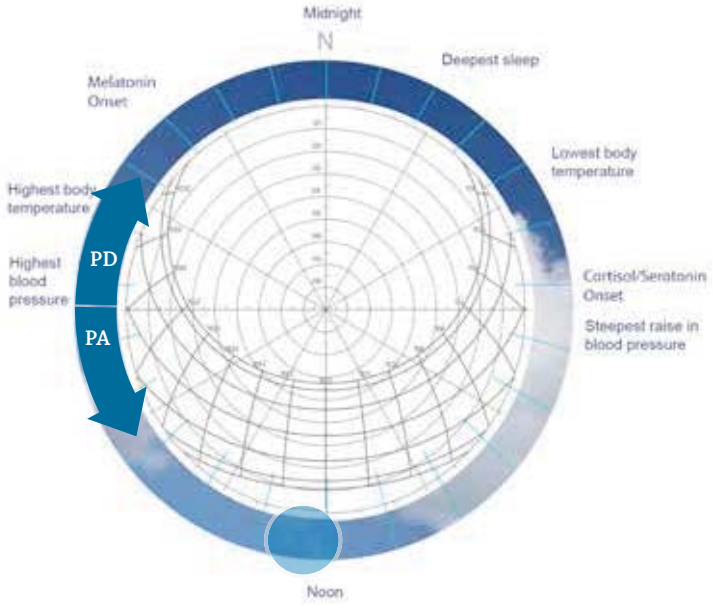
e control winter solstice PM. 12.15



THE NOON LIGHT – THE LAST MORNING LIGHT

Summer solstice, equinox and winter solstice PM. 12.17

While the morning light varies in relation to the season, the noon light is more stable, both in terms of the geographical orientation and – as seen here – in relation to the seasons.

Here to the S, the variations are primarily created by the solar altitude which varies with 47.5° from summer to winter, creating differences in light and heat radiation, also creating the UV winter. As seen here, the intensity of the daylight is revealed through the artificial lighting; the stronger the daylight, the weaker and more yellowish the artificial lighting.
As shown, there´s more light in the S-facing rooms at the equinoxes than at summer solstice, due to the lower height of the sun at equinox, which results in the light coming deeper into the room.
In its starting point, S provides both plenty of summer and winter sun. However healthwise, a strict EW-orientation constitutes one problem; it often creates a N-side.

Seen from a health perspective, the N-facing rooms can create problems, with less intensity and variation during the day, and less UV light, which is further aggravated during the winter, where N does not receive any sunlight – from equinox to equinox.

Healthwise, the form of the building may take this into account – along with the sun – by being asymmetrical in this way, a due N-side may to some extent be avoided.
However, again, a geographical main orientation towards the SE, that is winter east, will mean that the dark N-side can be avoided throughout the dark winter period – at the same time balancing the morning and evening sun better.

s test summer solstice PM. 12.17

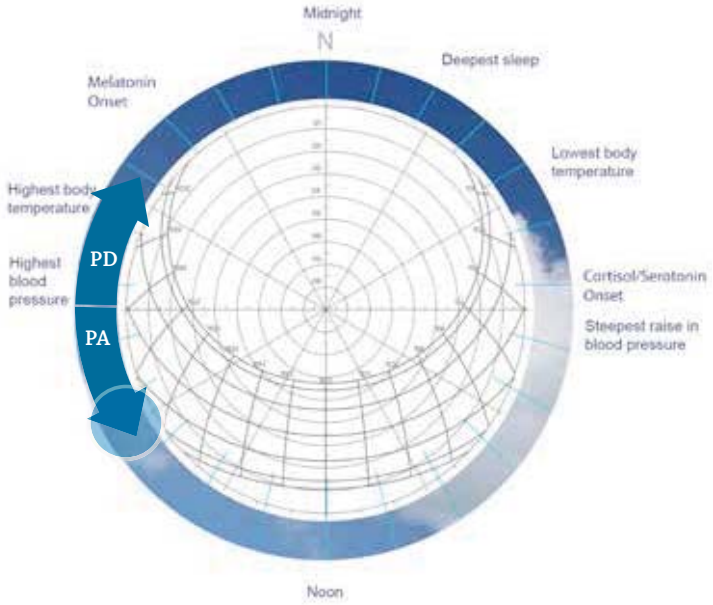
55°66´N, 12°60´W, kl 12.17

winter solstice

equinox

summer solstice

s control summer solstice PM. 12.17



THE AFTERNOON LIGHT – THE FIRST EVENING LIGHT

Equinox PM. 15.45

From this point and on, the light does not have the same therapeutic effect as the morning light. All in all, the balance that supports the circadian rhythm and the health starts to change character – the morning light is gone.

Instead, a hot building – and body – now demands more protection from the sun.

As shown, the W- and S-facing rooms receive more of the first evening light, while the E-facing rooms now appear dark, just as dark as N or W earlier in the day.

The test rooms again appear significantly brighter than the control rooms, especially E and N. In the test room to the S, the narrow but tall light opening results in the sunlight hitting the bed area in a relatively shorter period of time than in the control room. The portrait window may then, through its design and slim, tall form, help to protect against the sunlight here in the late afternoon. The opposite of what we actually have seen earlier, where the design of the window, through modeling and canopy, could extend the morning sun in the room.

In the S-facing test room, the missing canopy results in a lower window height, which, in the same manner, provides protection against the heat and intense light from the sun during the afternoon.

Again, there is generally less difference between the test rooms relative to E, S, W and N, than there is among the control rooms. Again the architectural asymmetry and differentiation create a more equal distribution of the asymmetrical daylight.

Healthwise, the light remains neutral, in the sense that it does not affect the circadian rhythm to the same extent as we have seen earlier, during the morning hours.


s test equinox PM. 15.45
55°66´N, 12°60´W, kl 15.45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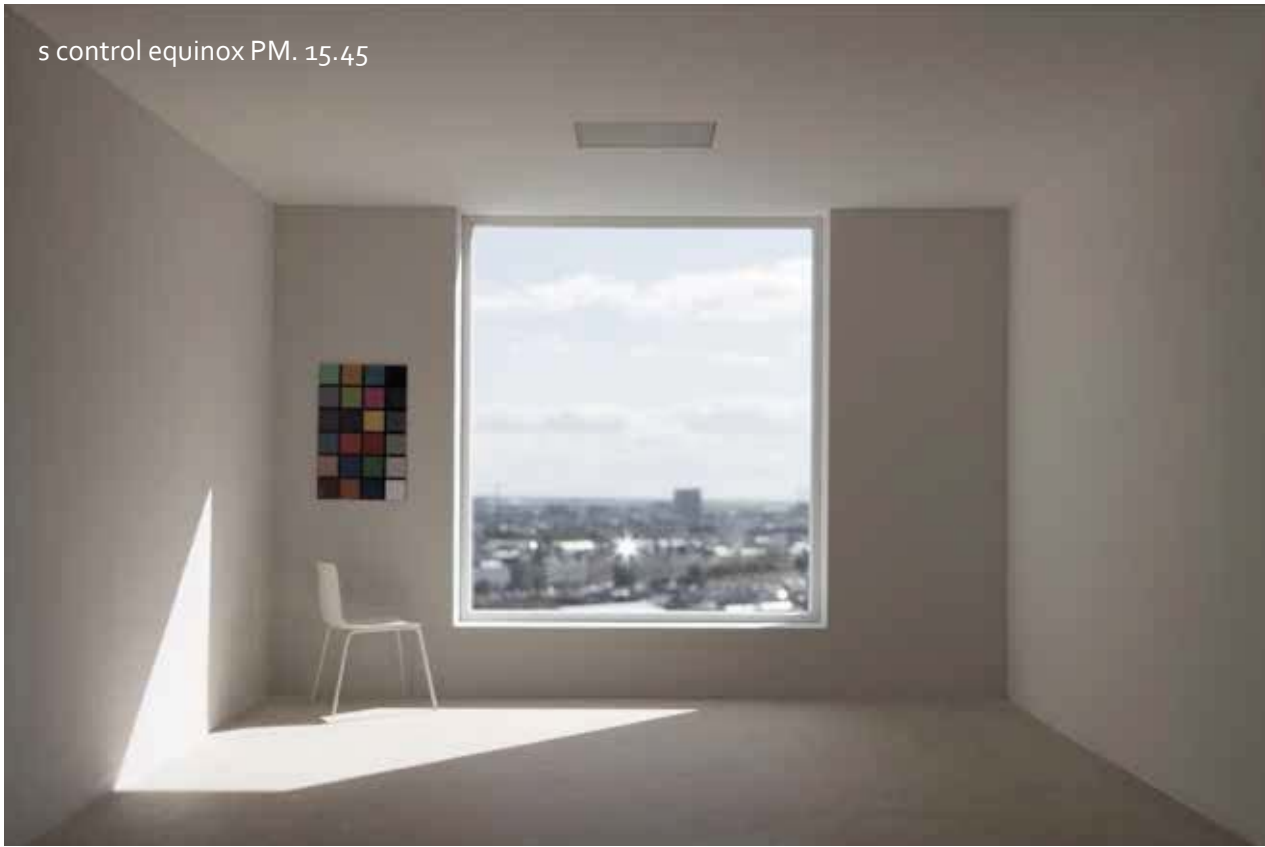
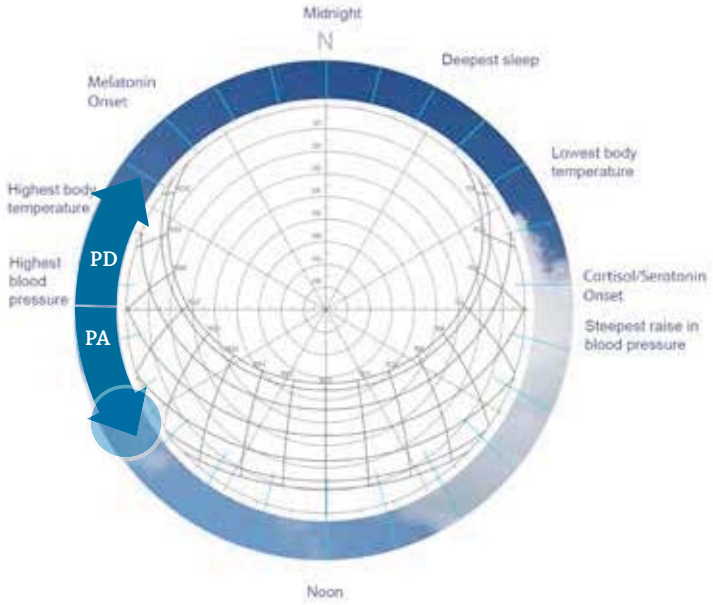

s control equinox PM. 15.45



THE AFTERNOON LIGHT – THE FIRST EVENING LIGHT

Winter solstice PM. 15.45
At winter solstice, the sun is sets in what is termed winter west. It happens at PM. 15.49, and relates to the SW, corresponding to 235°, see above.

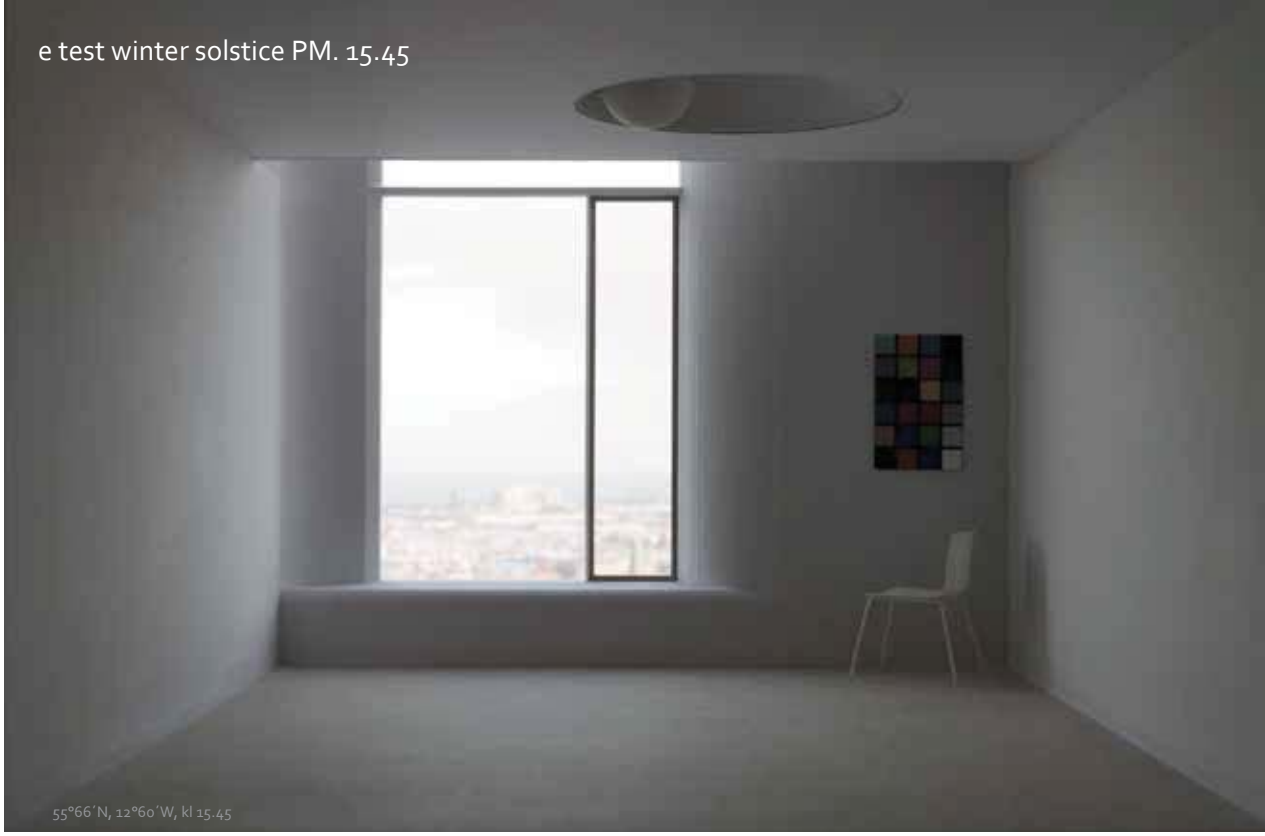
Compared to the S-facing test room without a canopy, the influence of the canopy in the utilization of the low sun and the morning and evening light is obvious, especially to the E and here, to the W.
At this time of day, the light has lost its therapeutic effect. The E-facing rooms, which earlier supported the formation of serotonin by being brighter, now remain dark, similar to the W-facing rooms earlier in the day.

During the winter period the evening sun provides both light and heat in the little time that it is there. Again, modeling the light opening in the test rooms prolongs the morning and afternoon sun.

To the N the large light opening compensates for the dark side – in the dark season. During this period, the N-facing rooms have not seen the sun since last equinox and it will be another three months before it happens, in a strictly EW-oriented building.

Like all the previous times, the N-facing room appears constant, without any large variations in the light throughout the day – or for that matter throughout the year.

In the test rooms, again, the light is more equally distributed, and the asymmetrical planning of the daylight overall seems to create a more even distribution of light throughout the year, compared to the uniform control rooms – which, with similar and symmetrically placed light openings, generally appear more different throughout the year.


e test winter solstice PM. 15.45
55°66´N, 12°60´W, kl 15.45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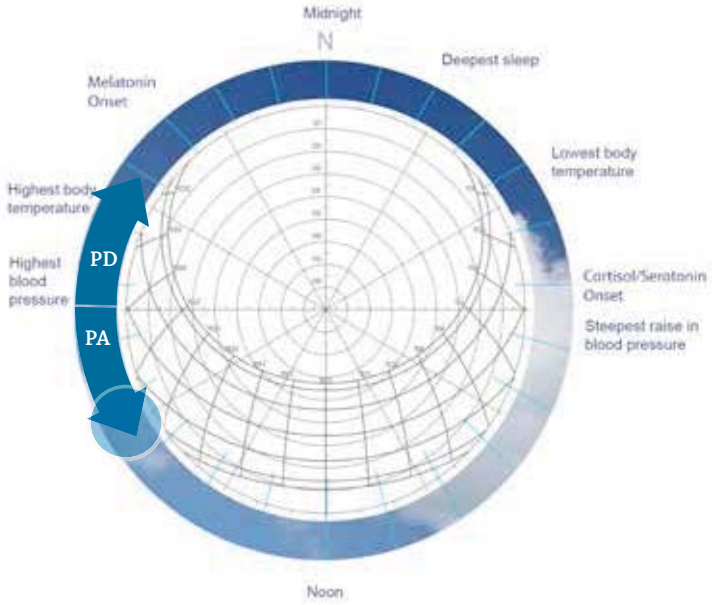
e control winter solstice PM. 15.45



THE AFTERNOON LIGHT – THE FIRST EVENING LIGHT

Summer solstice, equinox and winter solstice PM. 15.45

What may rightly be termed *the first evening light* is, at winter solstice, in fact the last evening light.

This specific time of day corresponds to the latest time of day, at which there is daylight all year round – at our northern latitude it says a lot about the characteristics of the light existing here. As shown, the sun creates large differences in color temperature throughout the year. At this time differences begin to show again between the otherwise completely identical control rooms, depending on season and geographical orientation.

Again, the bay windows extend the sunlight, and the asymmetrical placement of the window to the W creates more light in the test rooms. As mentioned earlier, the canopy reflects the low height of the sun – in the winter. In the dark season, when the canopy lights up the facade wall. In the bright season, in the summer, the canopy on the other hand opens up to the skylight.

As previously described, the noon light varies less than the morning light, both in relation to E, S, W and N, and in relation to the seasons.

Seen from a health perspective, the light does not challenge the circadian rhythm, as mentioned, there is light all day – both at summer solstice, equinox and winter solstice.

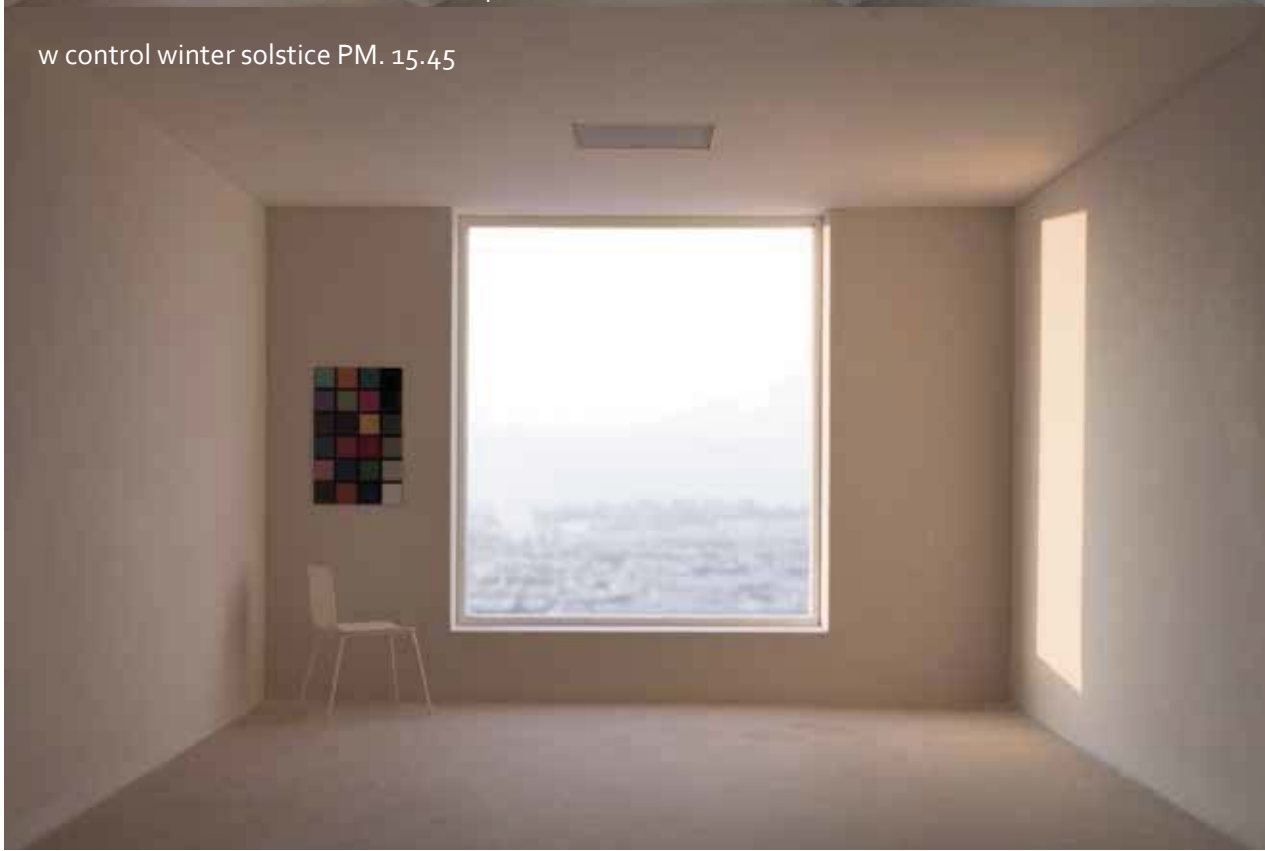
In many ways, *winter west* is far different from *winter east*. While the morning sun in the winter affects the production of serotonin and the mood, supporting the circadian rhythm, the afternoon sun does not have the same therapeutic effects – besides substantiating activity and a generally higher blood pressure, as seen above. Light is generally more neutral at this time of day, in the middle of the day.

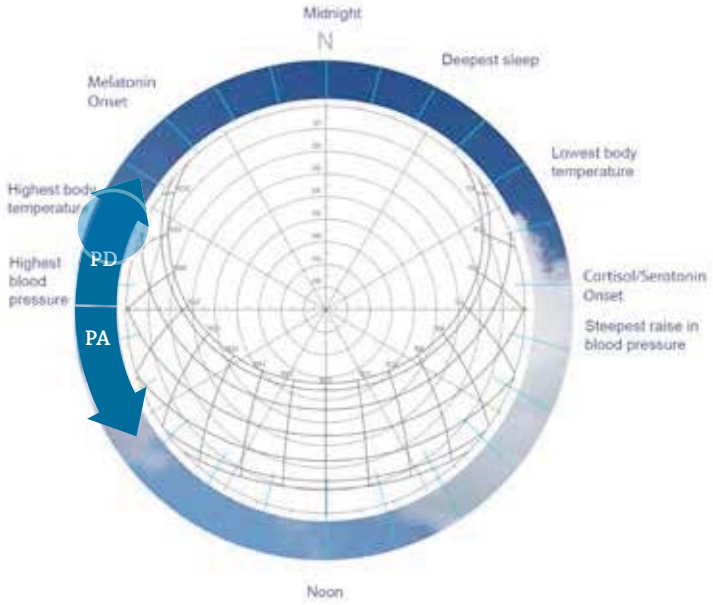

w test winter solstice PM. 15.45
55°66´N, 12°60´W, kl 15.45


winter solstice


equinox


summer solstice


w control winter solstice PM. 15.45



THE EVENING LIGHT – THE LAST LIGHT

Summer solstice PM. 19.00
Later than approx. PM. 18.00 the natural formation of the sleep hormone *melatonin* starts. At this time, light is reducing the production of melatonin – and may delay and impair sleep.

Another health condition, which has now changed, is that our body temperature, as seen above, is highest during the evening[196]. Direct sunlight may now result in excessive heating, causing the body to use extra energy to cool itself. Also the temperature in a building is higher at this time of day, especially during summer, when the sunlight can create differences in temperature from 19° C in the shade to 35° C in the sun[197].
Both excessive heat and too much light disturb and degrade the sleep at night – in other words, a shielding and a protection against the sunlight may with good reason be planned.
As shown, the W-facing test room protects against the evening sun at this time. Again, this is due to the asymmetrical location of the window, aided by the tall, narrow portrait window. As seen, the bed area – to the left in all rooms – receives less sunlight in the test room compared to the control room.

Again, the differences between E, S, W and N are smaller in test rooms, compared to the control rooms. The asymmetrical light openings balance and distribute the light during the day and the year, in a balance, which is at this time about protection against the sunlight – rather than exposure to the sunlight.
Again, the general, strict EW-orientation is challenged, especially here in the summer to the W – where the evening sun creates too much, and too late, light and heat.

196 The normal body temperature 36.5° C varies during the day in *a circadian cycle* approx. 0.6° C, being lowest in the morning and highest in the evening. Source: The great Danish, Gyldendals Open Encyclopedia, 2013.
197 In comparison, the morning sun only creates a difference of 11° C, from 19° C to 30° C, according to measurements taken on 06/21/2013.


s test summer solstice PM. 19.00
55°66´N, 12°60´W, kl 19.00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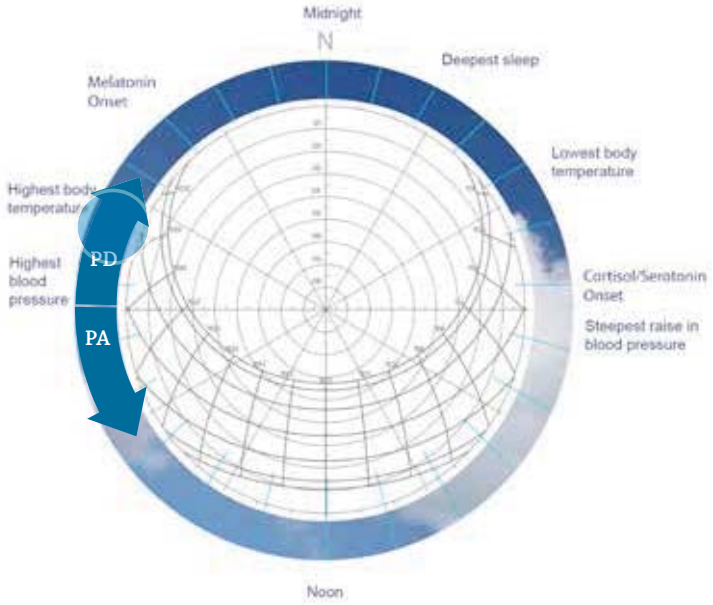
s control summer solstice PM. 19.00



THE EVENING LIGHT – THE LAST LIGHT

Equinox PM. 19.00
Here, right before sunset, there is more light to the W – which is also reflected in the artificial lighting, which here appears to be weakest.

In the test room facing W, the tall, vertical light opening again protects better against sunlight in the bed area during the evening.
The canopy, again, reflects the light from the low sun on to the facade wall. A low evening sun, which can otherwise often create contrasts and glare, resulting in a dark, gloomy room – as seen in the control room, which appears significantly darker.

In the S-facing test room, the modeling of the light opening reduces the contrasts between inside and outside. However, at the same time, it creates an area, a room, for a stay in the sun – finally also creating more skylight in the room.

As mentioned earlier, the EW-orientation only supports the circadian rhythm of the body at equinox, when the sun rises and sets at times which do not challenge the circadian rhythm in the same way as at summer solstice and winter solstice, see above.

In many ways equinox is similar to an *equatorial orientation*, i.e. an orientation where either the morning sun or the evening sun is predisposed. A strictly EW-facing building supports the health, as long as the sun rises due E and sets due W.
However, at 56^0 N. latitude, *the last light* at equinox does not correspond to the last light during the summer and the winter. A strict EW-orientation, causes problems with late – and early – sun during summer. The N-facing rooms will also be without direct sunlight, and with little variation during the day, for 6 months during the dark winter period.


w test equinox PM. 19.00
55°66´N, 12°60´W, kl 19.00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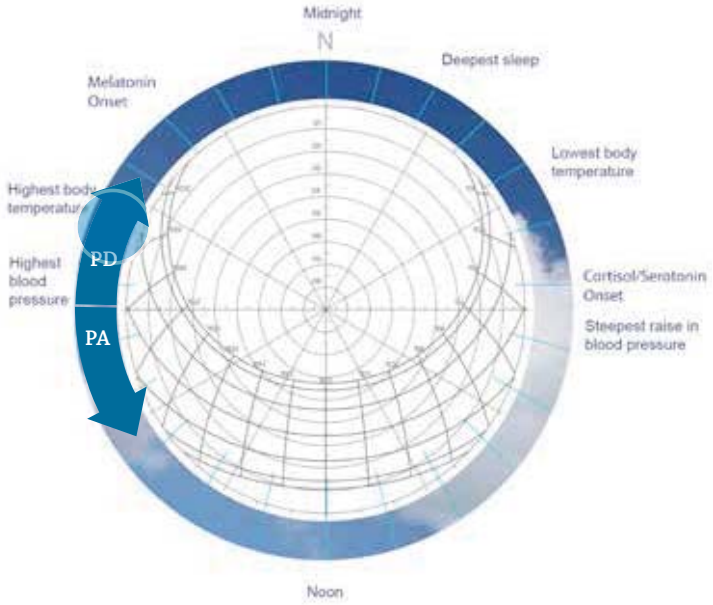
w control equinox PM. 19.00



THE EVENING LIGHT – THE LAST LIGHT

Summer solstice, equinox and winter solstice PM. 19.00

The evening light varies – just as the morning light – a lot to the season. Again, major differences are challenging the planning of the light. Especially to the W where too much – and too late – evening sun interferes with and impairs the circadian rhythm and sleep in the summer.

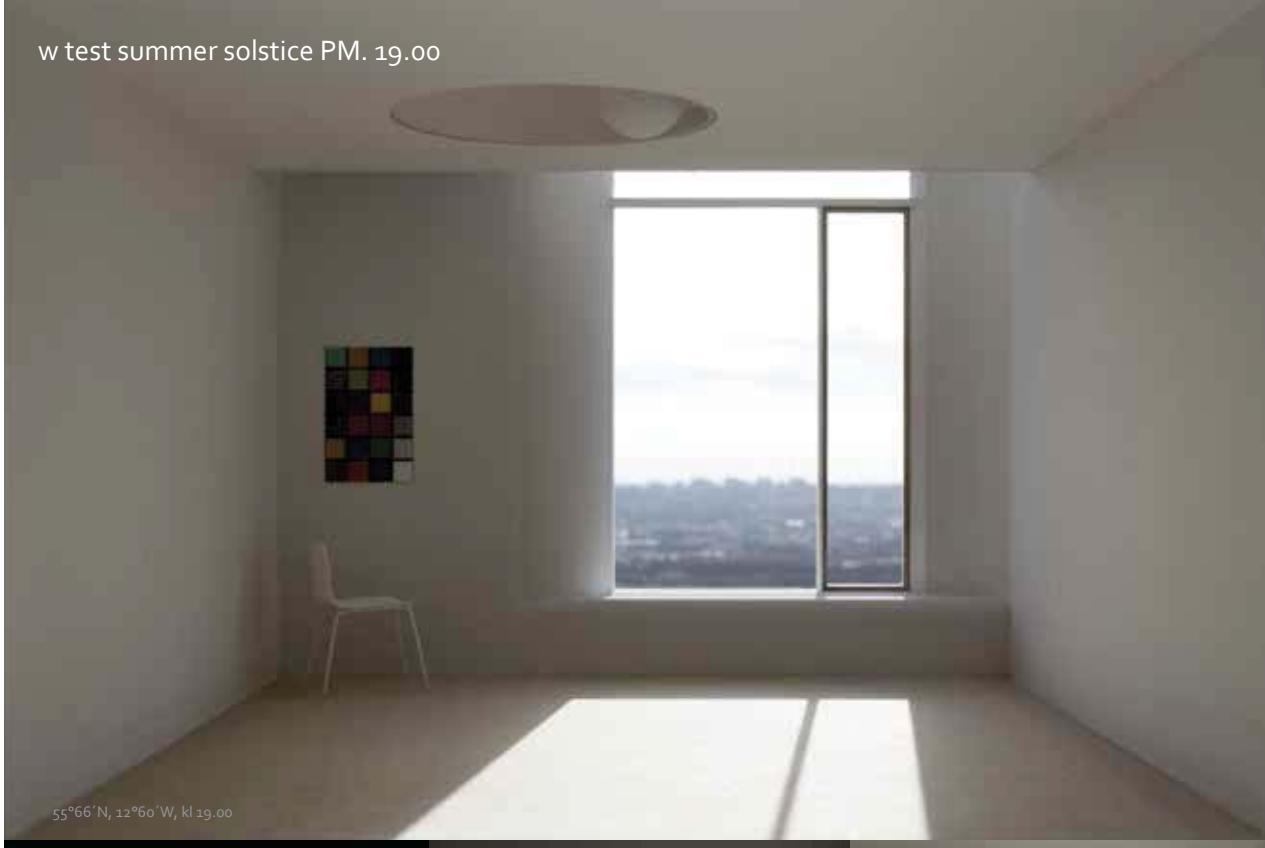
As shown above, the light at this time begins to delay and impair the nocturnal sleep (PD), which can be an issue, when it comes to good health.

The balance may – like the morning light – seem hard to find. However, the asymmetrical placement of the window creates several advantages; partly it shields the sun and the heat in the bed area, partly the asymmetrical position – up against the side wall – increases the amount of indirectly reflected light in the room.

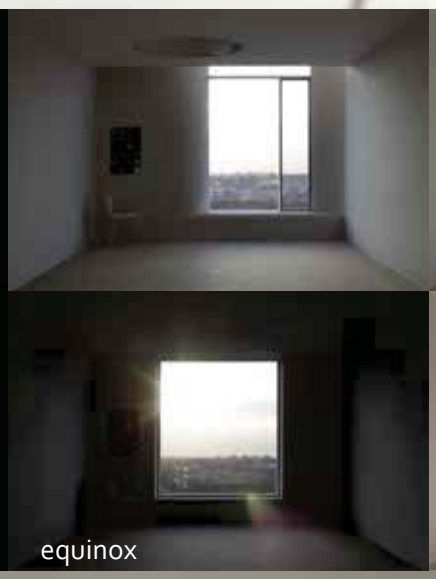
This protects the test room from the sun, without shielding the reflected light too much. For these reasons the W-facing test room appears brighter than the control room, at the same time shielding more against the sunlight.

In this way, the light is balanced, however only at equinox, as shown. This will not succeed at summer solstice, when the sun enters much later, and causes problems, both with too much light and too much heat – at a time when the building, and the body, are already warm.

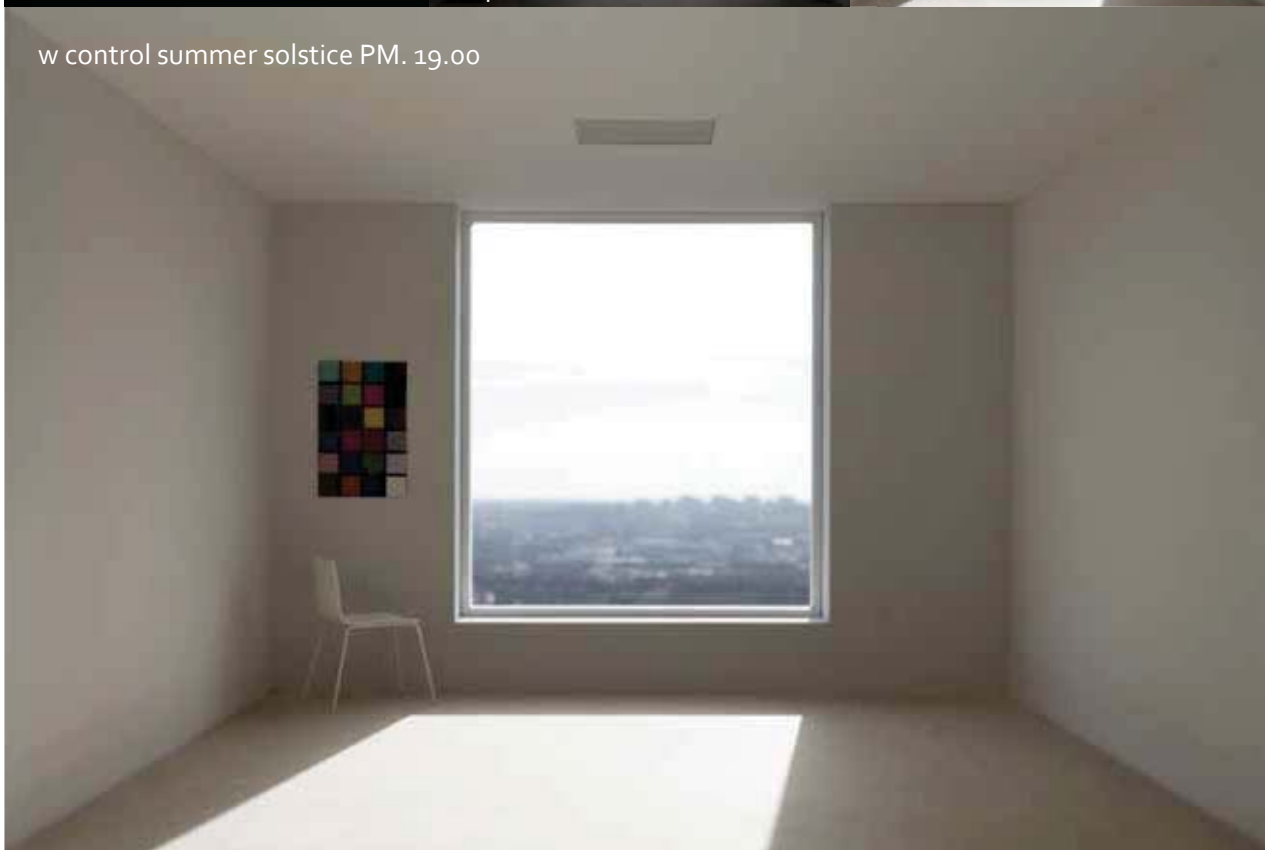
Healthwise, it may again seem like the strict EW-facing building facade is questionable and that the main orientation of the building and the room instead may be turned to a more SE-facing orientation, partly to balance the morning sun during summer and winter and partly to prevent the evening sun from overheating the W-facing room, from noon until sunset PM. 21.57.

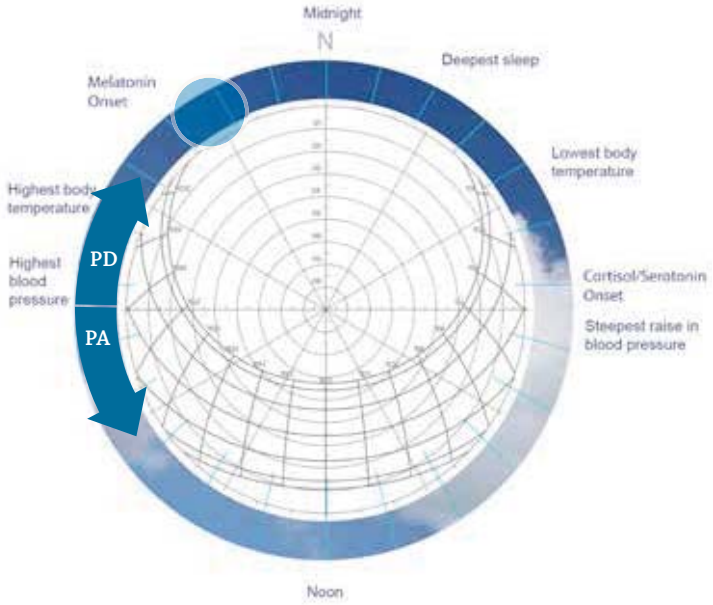

w test summer solstice PM. 19.00
55°66´N, 12°60´W, kl 19.00


winter solstice


equinox


summer solstice


w control summer solstice PM. 19.00



THE NIGHT – THE FIRST DARKNESS

Summer solstice PM. 21.45
During the summer, the sun sets in the designated summer west PM. 21.57, summer time, corresponding to NW 318°, see above.

As shown, W and N appear to be brightest here late at night and the test room facing W fails to block out the evening sun, albeit the smaller window size. The tall, slim portrait format, per se, shields more of the sunlight than the control room. Overheating from the sun – at this, the warmest time of year – is, if not resolved, at least reduced.

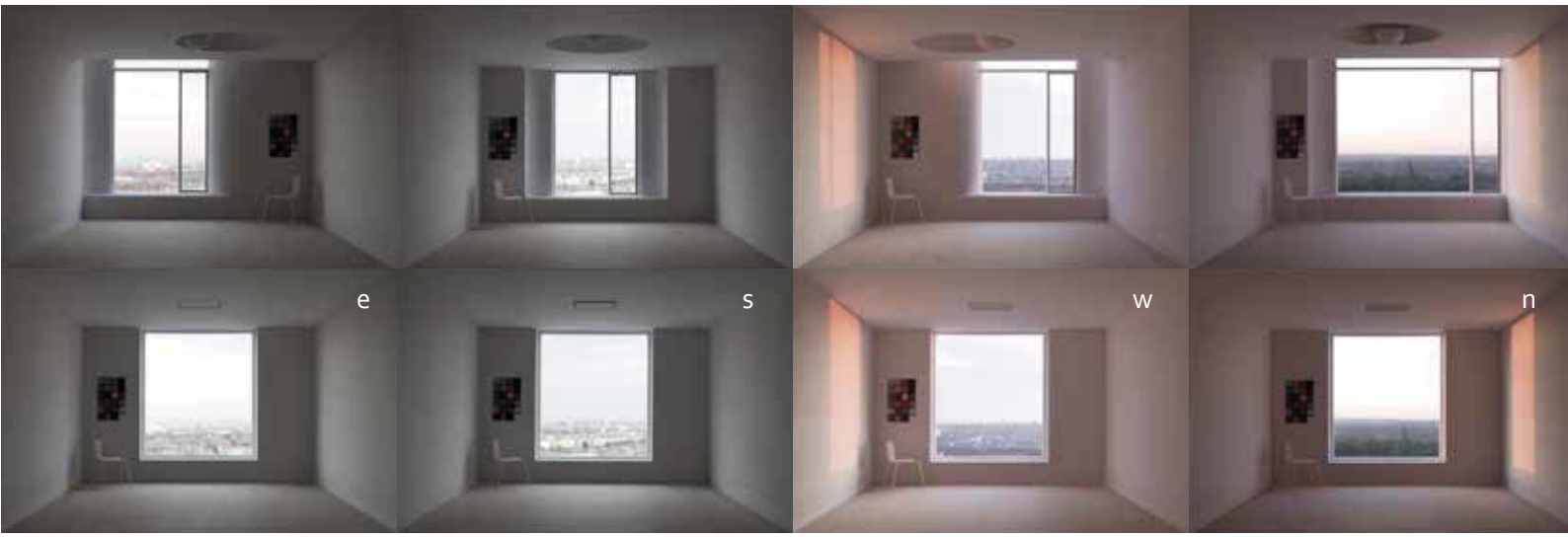
Again, the asymmetrical placement of the light openings creates more reflected light in the test rooms.

Here, towards the evening, the differences in light are starting to even out again between E, S, W and N – just like we have seen earlier in the morning.

In general, N receives very little sunlight during the year and during the day. However, when N – as here – finally receives sunlight, it is healthwise often at inappropriate times, such as very early in the morning or very late at night.

An orientation due EW results in a N-side and an S-side which are very different and which do not balance the seasonal variations in light; while S receives sunlight throughout the year, N only receives sunlight through half of the year.
It also creates a W-side with too much light and heat in the evening through the summer period. Again, it seems that an orientation towards NW will reduce the overheating at the end of the day, resulting in the sun entering approx. 3 hours later, see above. This not only eliminates the dark N-side, it also enables the use of the clear – and healthy – glass to the W, where overheating otherwise often results in solar protective glass.


n test summer solstice PM. 21.45
55°66´N, 12°60´W, kl 21.45


e
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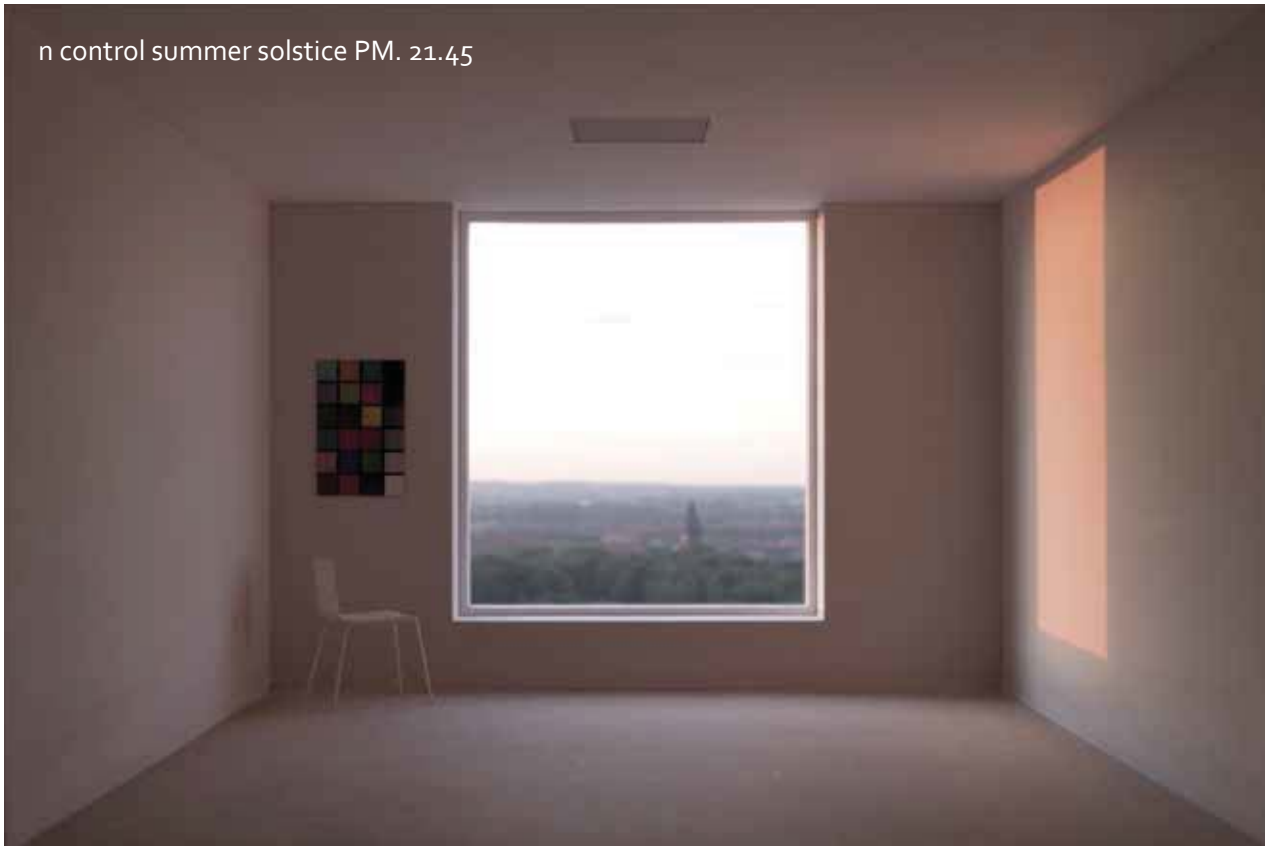
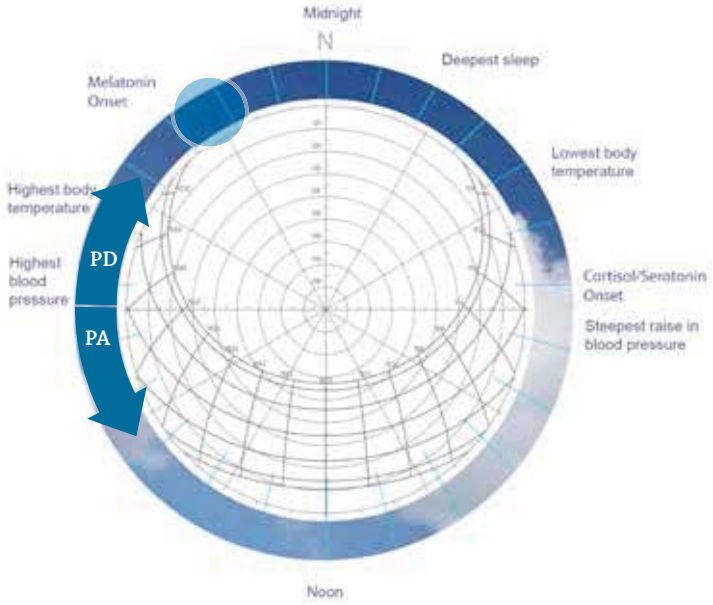

n control summer solstice PM. 21.45



THE NIGHT – THE FIRST DARKNESS

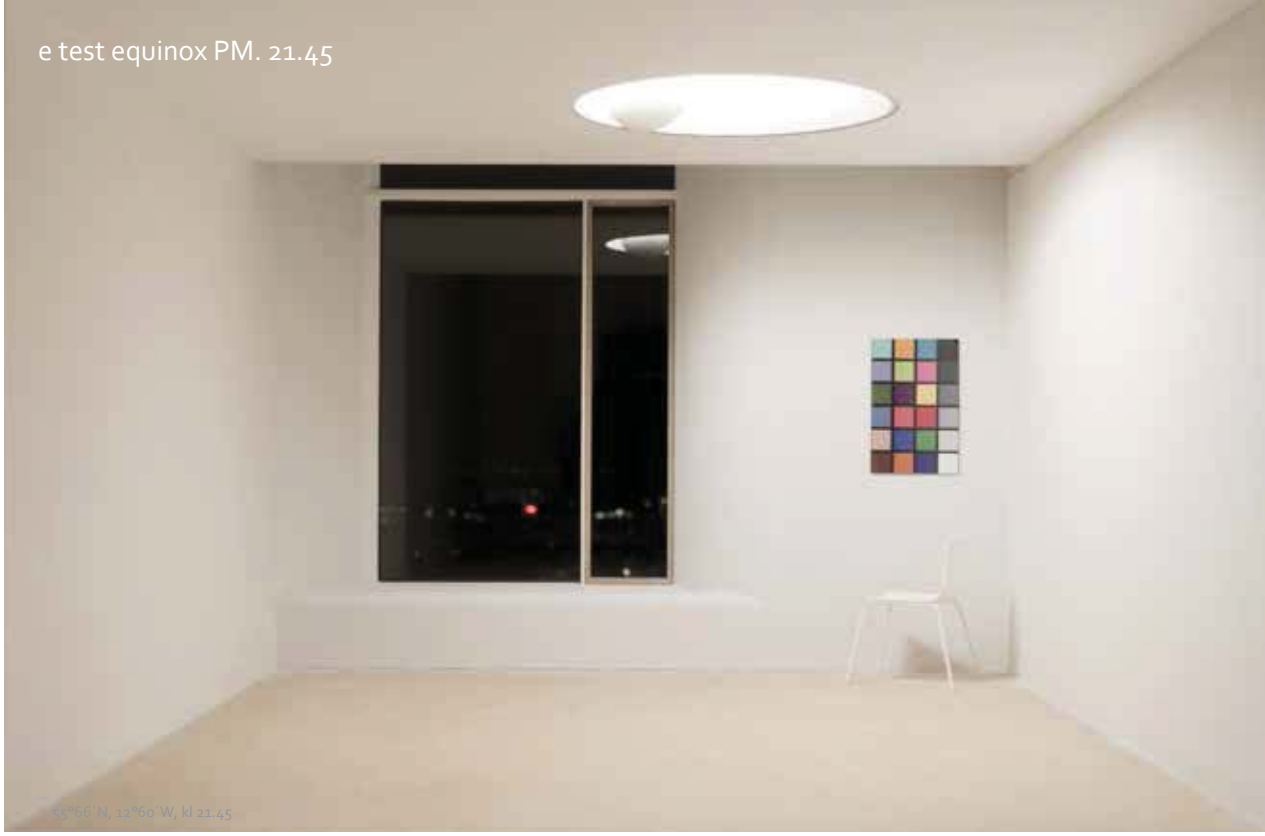
Equinox PM. 21.45 artificial lighting
All geographical differences gradually fade and eventually disappear when the sun sets. Everything becomes equal and the artificial lighting achieves autonomy.
However, the asymmetrical artificial lighting in the test rooms creates *an after-image* of the daylight, creating differences between E, S, W and N.
All the light sources, in all rooms, are centrally located in the middle of the ceiling. However, the asymmetrical fixtures are oriented differently in the test rooms. This gives rise to large differences. As shown, the artificial lighting to the E and W is directed away from the daylight-side of the room. To the S the artificial light is turned right towards the light opening and the facade wall – the latter being the largest, therefore reflecting more artificial light back into the room. To the N, the artificial lighting is turned away from the large glass area – which would only result in loss of light in the room.

The asymmetrical, artificial lighting also creates different shadows; from a soft space-rendering near the chairs to a sharp detail-rendering in the bed area, all in all providing a more varied spatial representation of the test rooms, compared to the control rooms. At a hospital the need for plenty of light often collides with the need for variation and good shadow-rendering. However, shadows and shadow-rendering may amplify the light; indeed, they are inseparable parts of the light itself.

Shadow inhales and illumination exhales light[198]

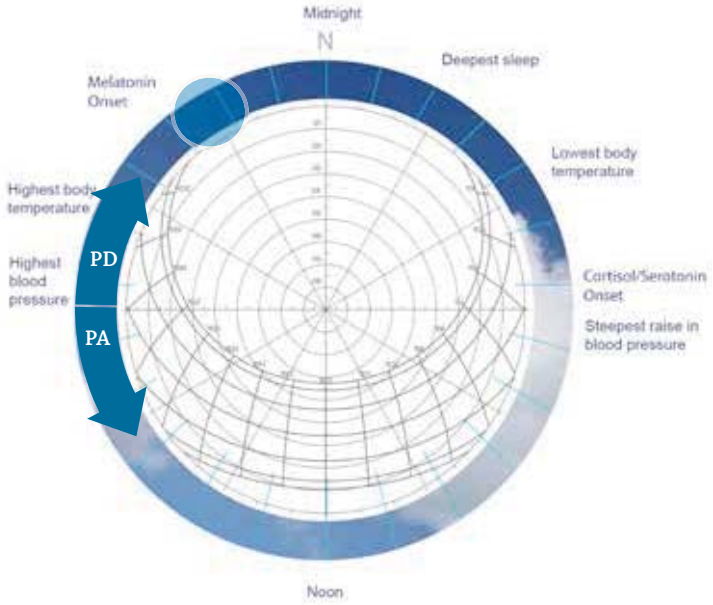
Also, the artificial lighting adds a warmer character to the room which is different from the cool daylight. The artificial lighting creates glow and depth in both colors and shapes and unites the room, while daylight, on the other hand, spreads and dissolves the room.

198 Pallasmaa J. The eyes of the skin, 2005, p .19.


e test equinox PM. 21.45
55°66´N, 12°60´W, kl 21.45


e
s
w
n


e control equinox PM. 21.45



THE NIGHT – THE FIRST DARKNESS

Summer solstice, equinox and winter solstice PM. 21.45

The evening light – like the morning light – varies a lot during the year due to the variations in the sunlight at our latitudes.

These seasonally related differences challenge us, both when it comes to light and health, as they challenge the architecture.

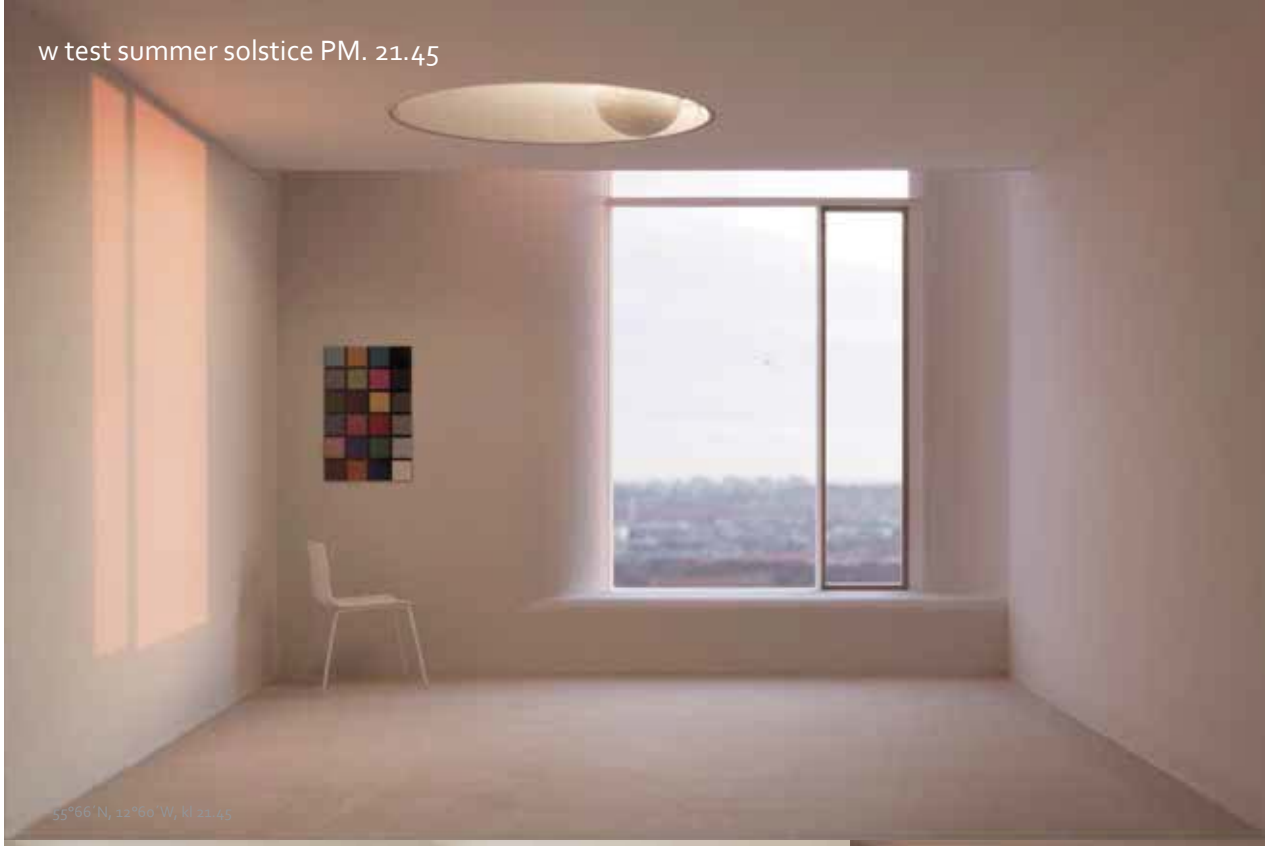
The test room to the W fails, as shown, to shield from the sun in the bed area, the sun coming in from NW at a time when neither light nor heat is appropriate.

As we have seen, there are no problems at this time at equinox. In other words, it is the latitude and the shifts in sunlight, which cause these challenges to light and health.

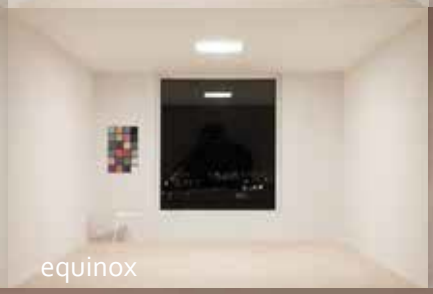
The strict EW-orientation creates problems with too early – and too late – light during the summer and too little sun early in the morning during the winter, problems which can to some extent be solved through an asymmetric differentiation of the facade. However, the geographical orientation seems to play the most important role.

A predisposition of SE seems to balance the morning and evening sun better healthwise throughout the year. Partly because the morning sun is better utilized in the winter – simply because the facade is oriented towards the sunrise, and partly because such a SE-facing facade better shields the early morning sun during summer – at the same time preventing the evening sun from creating heat problems later during the day.

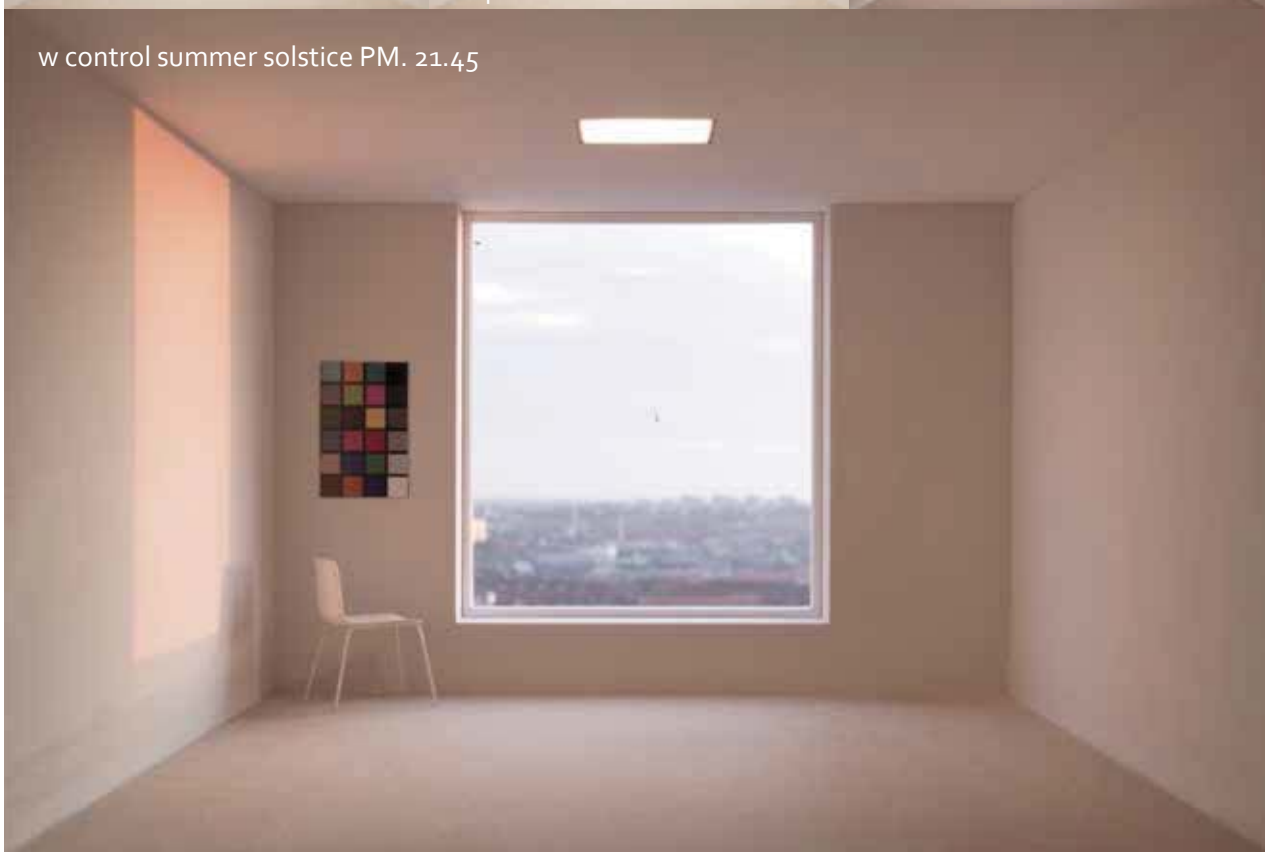
Finally, as mentioned earlier, the dark, north-facing facade can be avoided, a facade, which, according to the literature study, can create problems for a good health. In this way, the sun is better balanced in all the rooms – throughout most of the year.

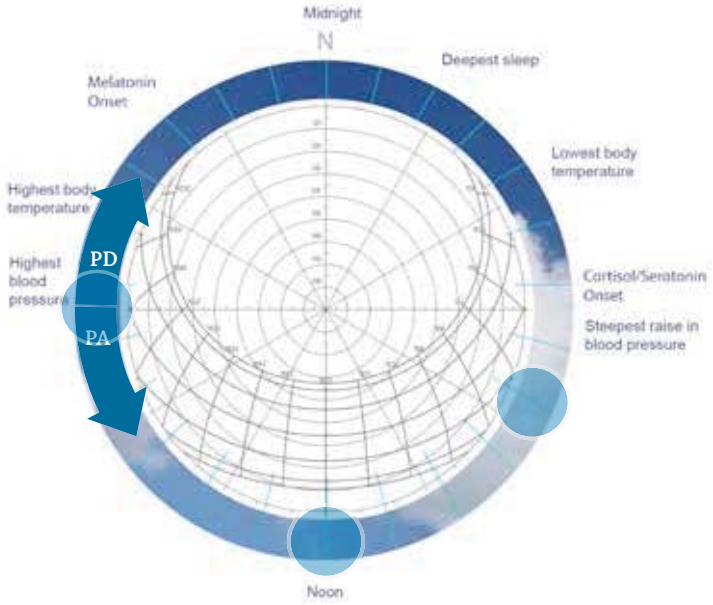

w test summer solstice PM. 21.45
55°66´N, 12°60´W, kl 21.45


winter solstice


equinox


summer solstice


w control summer solstice PM. 21.45



SUMMARY – THE MEASURABLE LIGHT

Equinox, the measurable light to the E, S, W and N

Finally, to conclude this light story, the differences in light, measured in lux, are here depicted during a day – from AM. 8.00 until PM. 18.00, at equinox.

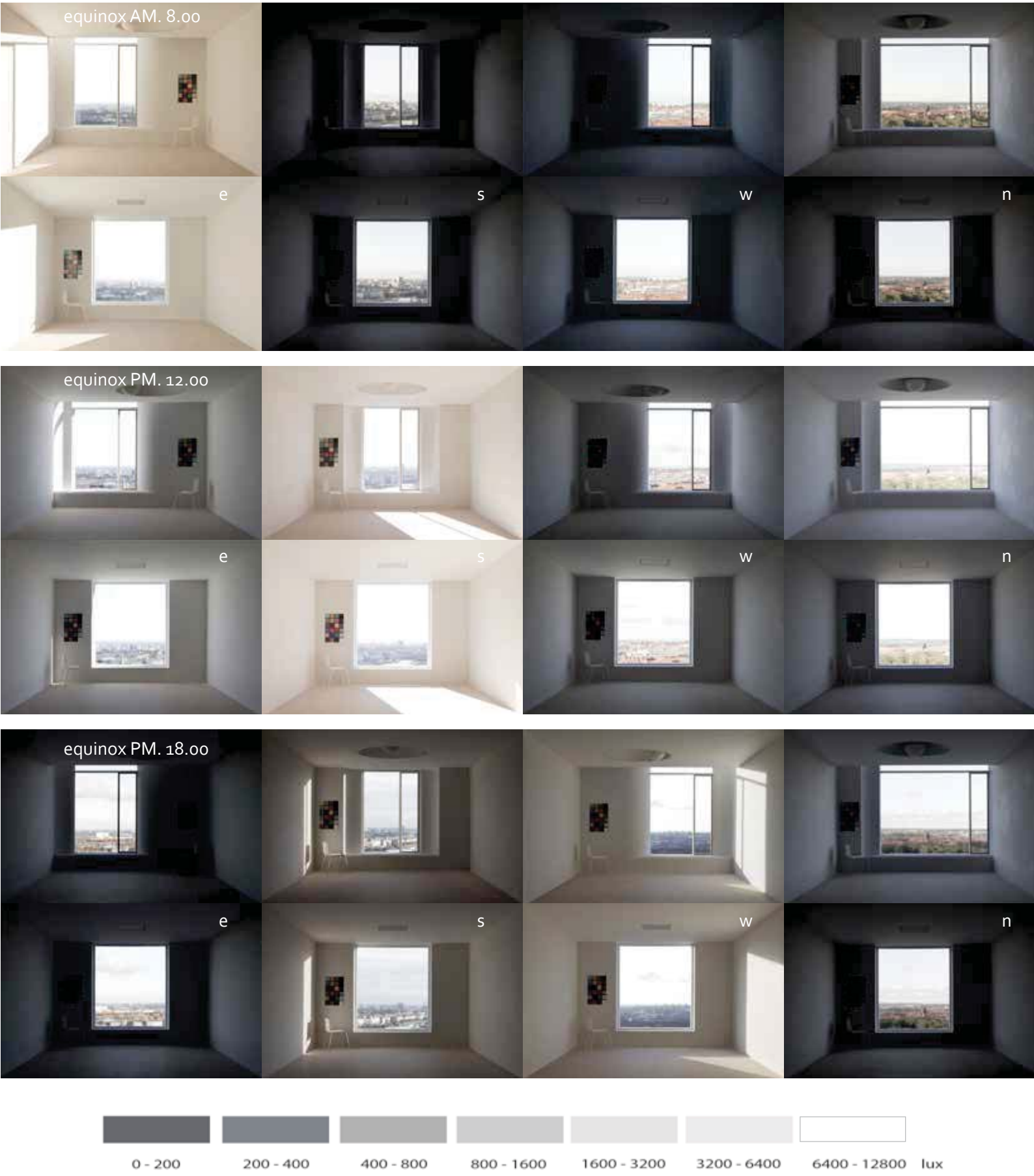
The recordings reveal huge differences in the light between E, S, W and N. Differences, which far exceed 10,000 lux, and which initially appear to be important in the balance between the varying, therapeutic morning light, the stable, neutral noon light and the varying, warm evening light.

At equinox, the light supports the circadian rhythm in all rooms. However, as we have seen, the health is challenged by a strict EW-orientation as we move away from the equinox; at summer solstice by too early morning light and too late evening light, and at winter solstice by too little morning light and a too dark N-side.

While the EW-oriented facades balance the morning and the evening light here at equinox, they create too large variations in the morning and evening light during summer and winter at our northern latitudes.

On the whole, it seems as if this strict EW-orientation is based at equinox, and overlooks our northern latitudes and the specific variations that exist here, overlooking the importance of the northern winter sun. Instead, this study suggests that a comprehensive main orientation which utilizes the winter sun, with facades facing the winter east, better balance and distribute the morning sun and the evening sun throughout the year.

Finally, the light experiments show that an asymmetrical planning of building form, light openings and facades, as a method, can help balance these large variations in the morning and the evening light better throughout the year.


equinox AM. 8.00
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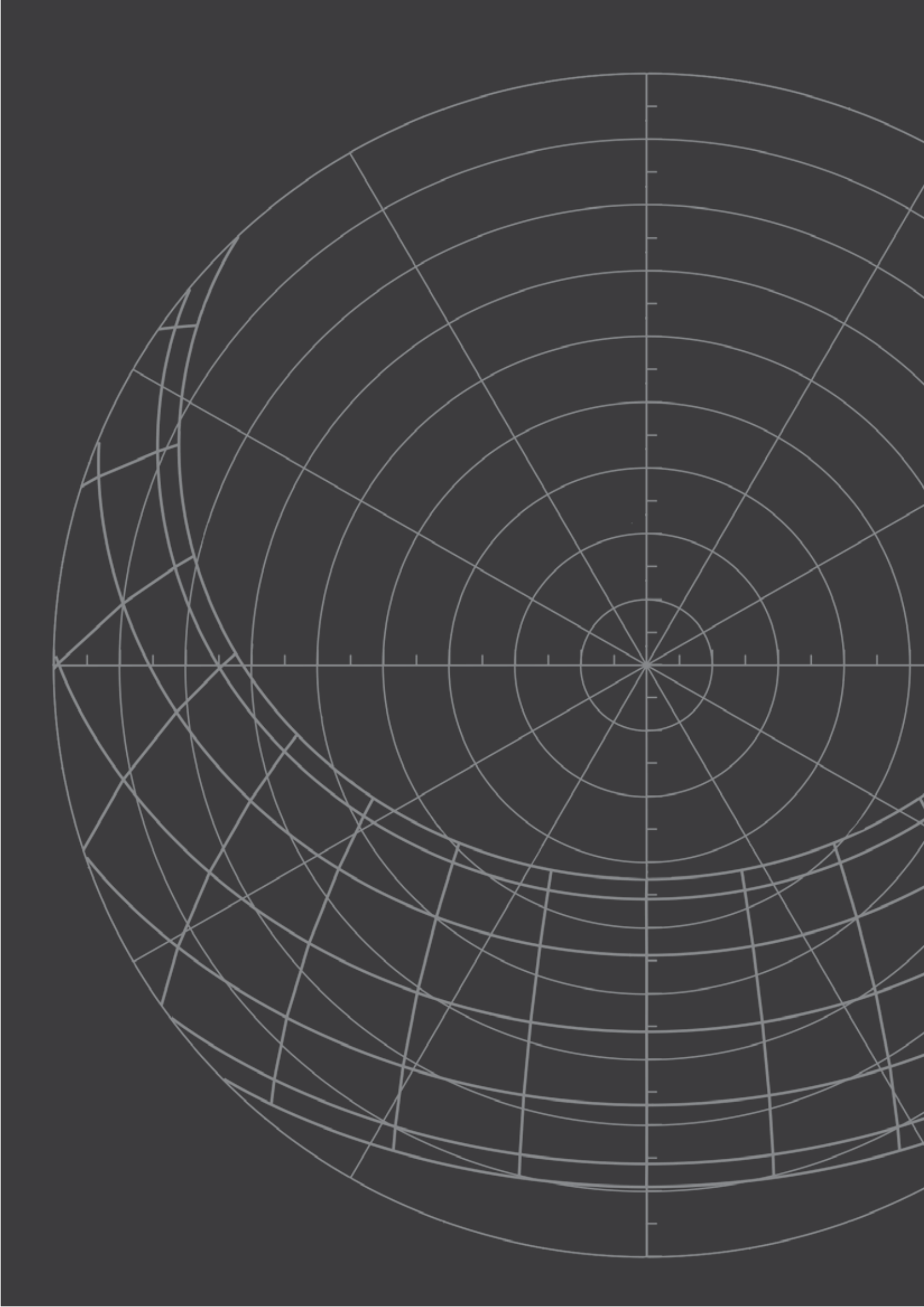
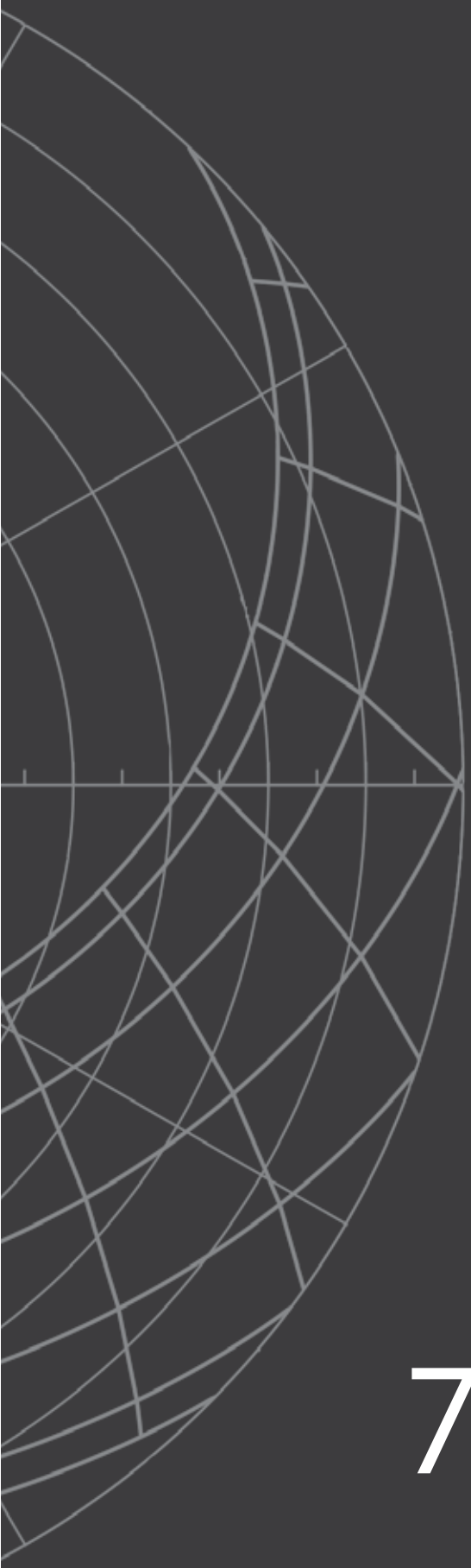




7 APPLICATION OF THE NEW METHOD

7. APPLICATION OF THE NEW METHOD

The practical light experiments document the importance of the geographical orientation to the light, as it generates varying differences in the light, differences exceeding 10,000 lux depending on the E, S, W and N. The method thus, balances the pros and cons of the varying, healthy morning and the varying, warm evening light, both during the day and during the year, based on the geographical orientation. *A circadian light clock* is developed as a tool in the light experiments providing a method linking together light, the geographical orientation and the bodily rhythm, taking into account all these factors in the planning of a healthier light and a healthier architecture. The method also indicates how the planning of the light can be based on clear – and healthier – glass.

As mentioned earlier, the method works on several levels, partly in the planning of the basic orientation of a building, partly in the planning of the shape of the building relative to the sunlight, as a response to the asymmetrical light of the sun, and partly in the planning of the light openings and facades, again in the form of an asymmetrical planning which distinguishes between the morning light and the evening light.

In the following, I will describe how the method is applied in practice as a strategy in the planning of The New Herlev Hospital, planned and built using this method.

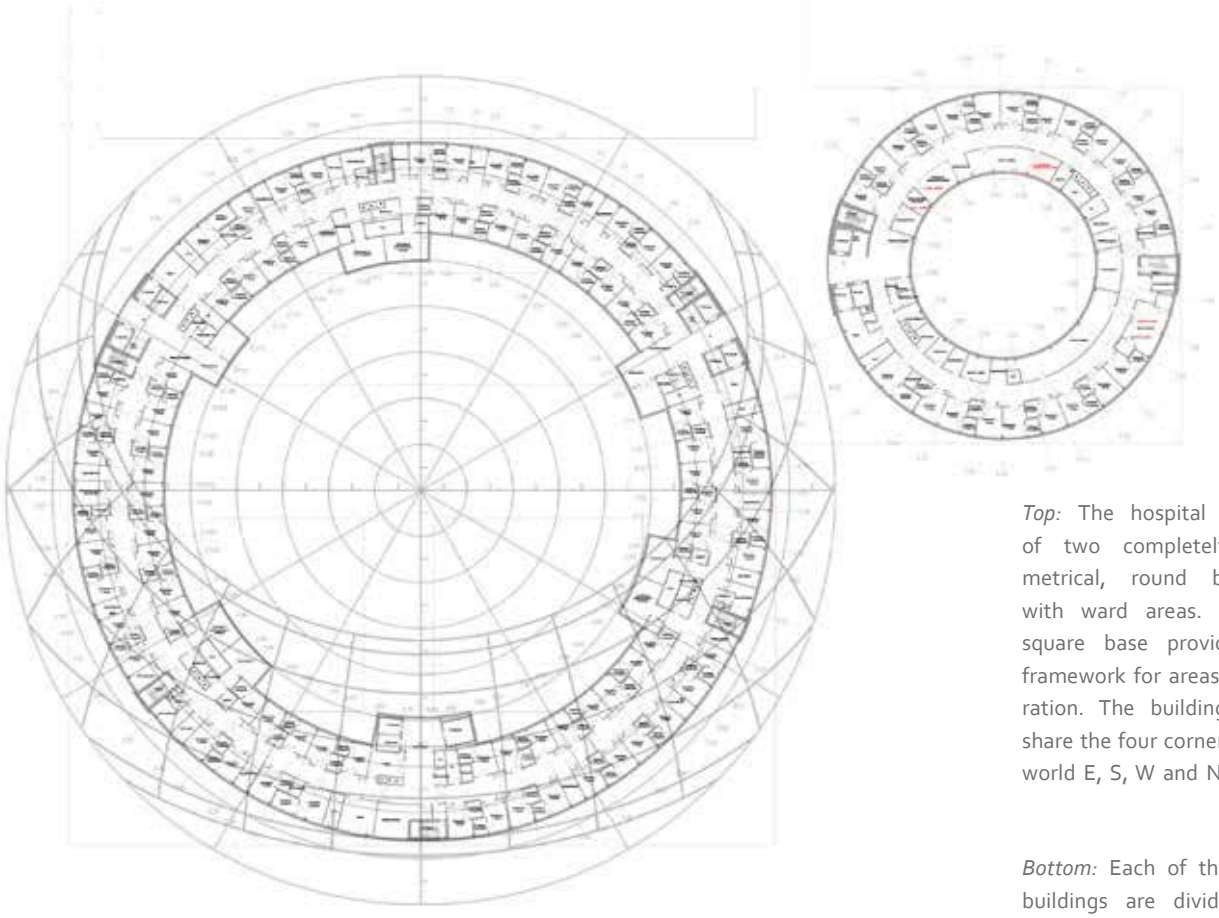
However, the method may also be used in other contexts. Through a brief study, the geographical orientation and its significance to the differences in light and color in relation to the time of day, is studied, and finally, the method is applied in an experiment, using different types of shielding, created in generative architecture, in an attempt to shield off the evening sun to the W in an alternative way.

The New Herlev Hospital

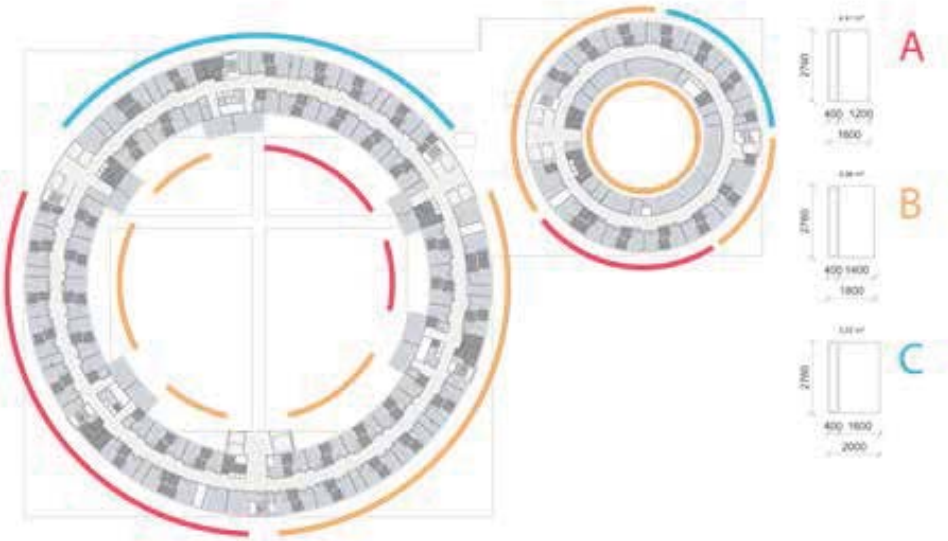
These years, several new hospitals are being built in Denmark[199]. One of those hospitals is The New Herlev Hospital, a hospital building with a total of 54,000 m^2.

In April 2011, a consortium, consisting of Henning Larsen Architects, Friis & Moltke Architects, Orbicon, Norconsult, NNE Pharmaplan, Brunsgaard & Laursen and SLA Architects, wins the architectural competition for a new hospital, commissioned by the Capital Region. The hospital consists of two symmetrical, round building forms. Forms which are in many ways comparable to the symmetrical buildings, studied earlier on, such as *Skolen ved Sundet*.

199 In total, the new hospitals amount to approx. 40 billion DKK, including the superhospitals in Aarhus, Odense, Aalborg, Gjødstrup and Copenhagen.



Top: The hospital consists of two completely symmetrical, round buildings with ward areas. A large square base provides the framework for areas of operation. The building forms share the four corners of the world E, S, W and N equally



Bottom: Each of the round buildings are divided into three identical main sections facing in different directions according to the compass. Architecturally and light-wise these sections are formed differently, using the method; a north, a south-east and a south-west facing section. To the north fewer patient wards are planned

The method is used to differentiate the size of the windows asymmetrically, in relation to the radiation of the sun. Not only in terms of E, S, W and N, but also in relation to the environment and the exisiting buildings. E.g. the W-facing windows are larger, where the main building shields the direct sunlight

The method is applied at The New Herlev Hospital at a time when the basic form of the building is already defined. However, the facades and the planning of the daylight, is yet not determined.

At this time, the original drawings describe an *open planning*, similar to what we have seen earlier in several of the previous field studies. A full glass solution – based on a strategy to optimize the daylight, partly based on high *daylight autonomy*[200] – and a desire to maximize the number of hours during the year when the daylight alone can create 200 lux, equivalent to a daylight factor of 2% at 10,000 lux. All in all a strategy which does not differ from the previously described strategies, as promoted by RIBA in the 1930s – also in an attempt to optimize the daylight.

However, as we have seen, this kind of open planning is not appropriate because it does not distinguish between the morning light and the evening light, or between the body´s different needs for light during the day, for that matter. Finally, it also, in practice, makes it impossible to use the clear and healthy glass.

Instead, the method specified here is applied in the planning of The New Herlev Hospital. On the basis of the test rooms in the practical light experiments, the facades of the buildings are differentiated in relation to E, S, W and N. The method thereby transforms *a symmetrical* building form to *an asymmetrical* building form on the facade level.

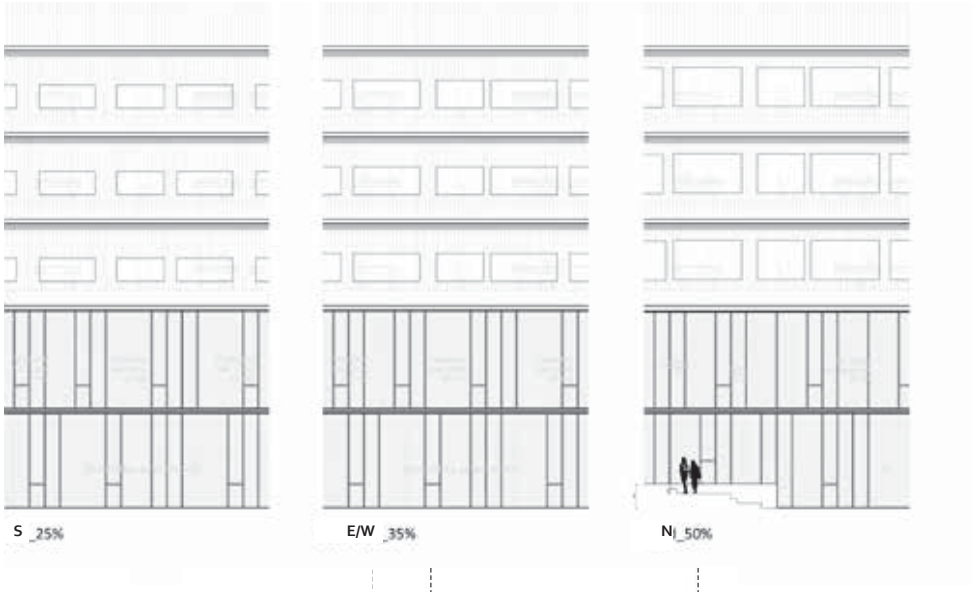
Where the shielding against the sun originally consisted of adjustable, physical screens and solar protective glass, the shield now instead becomes integrated in the architectural form, by reducing and differentiating the light openings in the facades relative to E, S, W and N, so that the facades respond to the asymmetrical light of the sun, using the distribution described on p. 109.

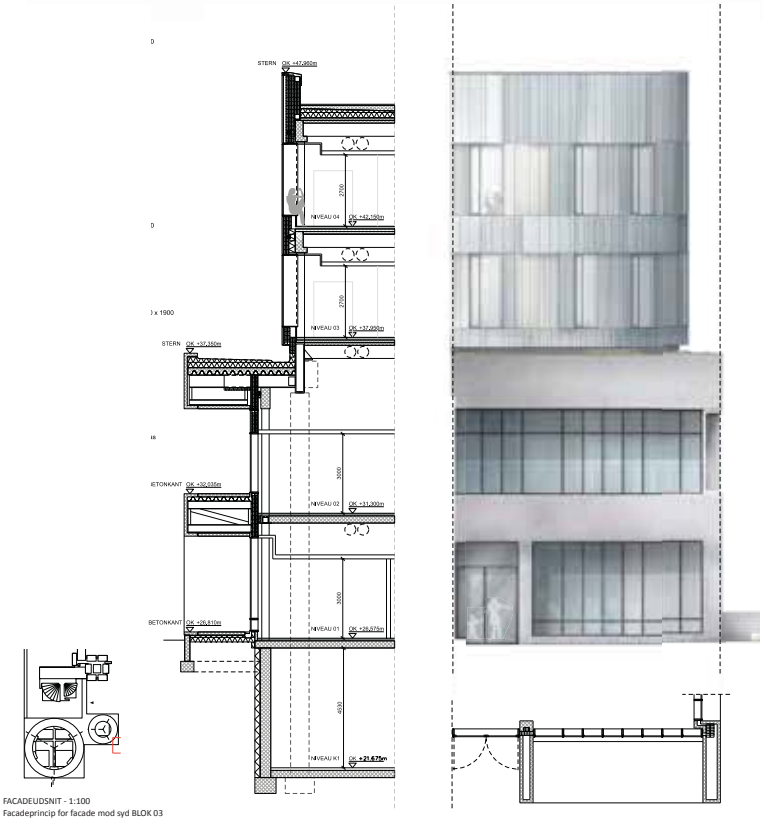
In this way, the method fundamentally breaks with the idea of quite similar wards at hospitals, instead – as something new – the method creates *different wards*, responding to the light.

The first step in applying the method at The New Herlev Hospital, is therefore to reduce and redistribute the glass area. The curtain-wall principle is abandoned in favor of a building with different facades. Inside the rooms, the location of the windows – as far as possible – take into account the sunlight during the day.

But how are the smaller window openings planned to better cater the health? Henning Larsen and Friis & Moltke Architects initially chose to work with *horizontal light openings*. That is, light openings which, similarly to *The Finsbury Health Centre* and *Skolen ved Sundet*, are based on the idea of creating a view, like the aforementioned window type *fenetre en longueur* favored by Le Corbusier. However, as we have seen in the literature studies, these low windows do not only reduce the skylight, they also reduce the healthy light entering the eye. As

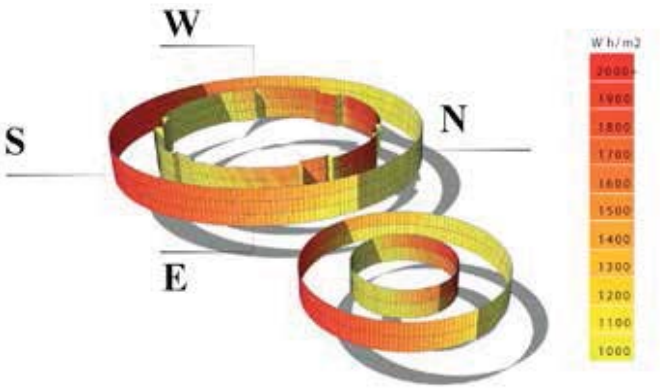
200 Daylight Autonomy (DA) is developed by the Association Suisse des Electriciens in 1989. DA, unlike the Daylight factor (DF), includes the geographical orientation and the weather data, however, it leaves out the time of day.





Top: The original, low, horizontal windows

Middle: The new, tall, vertical windows



Bottom: Both windows answer the energy of the sun which, according to calculations on The New Herlev Hospital, corresponds to approx. 1,130 Wh/m^2 to the N and approx. 2,460 Wh/m^2 to the south. Source: Henning Larsen Architects, Friis & Moltke Architects, 2012

described earlier, in the chapter *light and disease*[201], it makes a difference healthwise, whether the light comes from above or from the side.

These health considerations again affect and change the architecture at The New Herlev Hospital; the horizontal windows are abandoned in favor of *tall portrait windows* which have the same glass area, however distributed with a larger H:B ratio[202], letting more of the healthy skylight into the room and into the eye. These windows are also distinguished by the fact that they are capable of shielding the large variations in the morning sun and evening sun, which we have seen to the E and W.

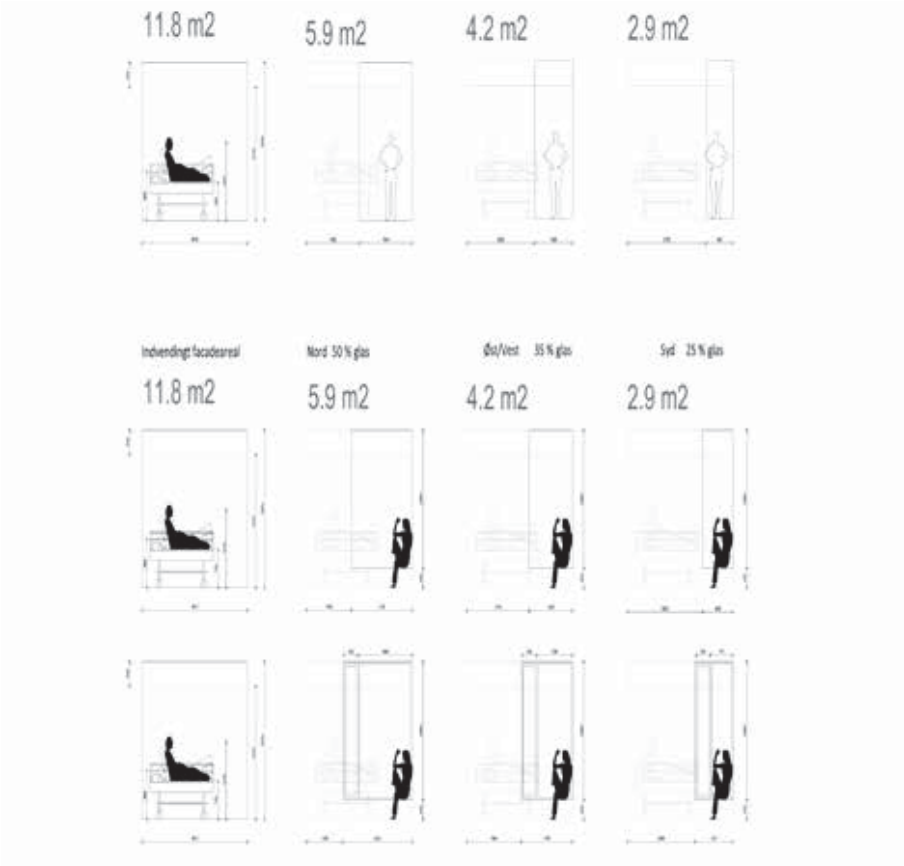
Henning Larsen and Friis & Moltke Architects apply the method, increasing the height of the windows. Based on the test rooms, a canopy is added on the inside, raising the ceiling-height with 0.5 m. In the practical light experiments, these tall windows are only applied to the facades facing E, W and N. S differs from the other orientations, having a lower window height, to protect against the high, more intense midday sun and the high UV amount at noon. However, Henning Larsen and Friis & Moltke Architects maintain the same tall window height throughout the facades regardless of the geographical orientation. A choice based on aesthetics, in order to create a more uniform appearance of the facades and the building.

However, the overall health considerations described in the method, together with the anatomy of the eye, change and shape the architecture of The New Herlev Hospital. The fenetre en longueur is replaced by Le Corbusier´s predecessors[203] classical tall, slim portrait windows.

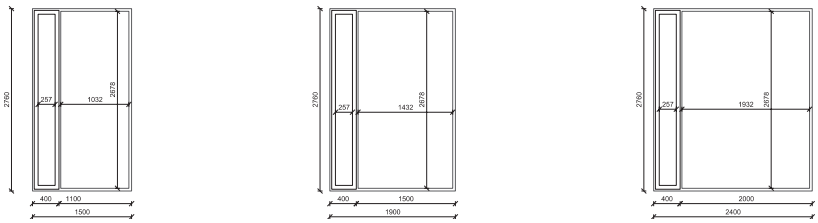
Another architectural change, applying this method, is the breakdown of the windows into separate parts; a view opening, a daylight opening and a fresh air opening. But here, especially the latter causes problems due to very strict demands on energy. While a fresh air opening increases the content of the UV-light and breaks down the UV-barrier, created by the glass – which, from a health perspective, contributes positively to the health[204] – it also raises a conflict between the measurable energy conditions and the health. At The New Herlev Hospital the fresh air openings were secured, with reference to this method, but not without a fight, and the consulting engineers laconically said; "if we are called out due to any problems with the air conditioning and see as much as a single window opened, we will immediately leave again".

The fundamental function of a window, as a link between the inside and outside, is challenged by these strict energy requirements, creating problems, not only when it comes to fresh air, light and cleanliness. In this context, it turns out that a fourth, albeit more invisible aspect of the fresh air opening becomes cru-

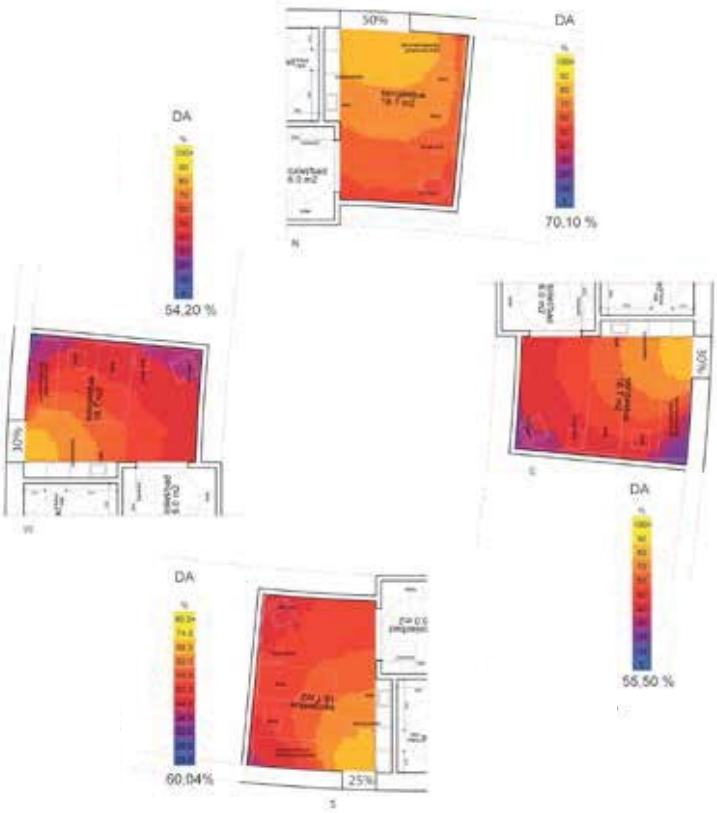
201 Op.cit. p. 51.
202 Windows with a total height of 3.2 m above the floor, by virtue of the internal canopies, see the description of the test rooms in chapter 6.
203 Colomina B. *The Split Wall, Domestic Voyeurism.* Princeton Architectural Press, 1992. Among other things, a disagreement between Le Corbusier and his teacher Auguste Perret regarding window types is described.
204 By acting antiseptically and by stimulating the production of vitamin D which many patients lack. Op.cit. p.42.



An analysis of the distribution of glass. At the bottom, the method is applied to increase the window width by reducing the lower portion of the window, which contributes least with daylight in the rooms, and replacing it with a windowsill, which functions as a sitting space. Note that bars and mullions help increase the size and width of the light opening



The original tripartite division; S, EW and N is changed to a tripartite division called SW, E and N. The windows to the S and W are smallest, to the E larger and to the N largest



An early calculation of the various wards. The differentiation of the light openings creates – as in the practical light experiments – a more even distribution of the light. The figure shows the calculated daylight autonomy for E, S, W and N. As can be seen, the new method creates more light to the N, where there is least light

cial, namely the fact that glass prevents the seasonal sounds from entering they are efficiently omitted by the modern, sealed, low-energy windows. Soundwise, the windows separate the inside from the outside, with the result that patients are often unable to sense whether it is spring or autumn, morning or evening, through the sounds. At *the hospital of the senses*, which The New Herlev Hospital is also called, this becomes an important argument for finally implementing the fresh air openings.

In my opinion, and in this method, the possibility of opening the windows may be just as important as the clear glass, though I am aware that a large, openable window challenges the climate system. To give the possibility of opening the windows the method therefore suggests that the fresh air opening be the smallest opening in a window, a suggestion which is followed at The New Herlev Hospital.

In practice, the light experiments show that E and W may not be similar. The New Herlev Hospital represents a slightly different asymmetry, which further reduces the light opening to the W; in this way, S and W now share the smallest glass area. While the original relationship between a small, a medium and a large light opening is S-EW-N, it is now changed, in the sense that S and W share the smallest opening, while E is larger and N largest. Put in other words, the relationship between small, medium and large changes to SW-E-N.

At The New Herlev Hospital, energy calculations confirm that W is the warmest facade during the day. This means that it is necessary to shield more from the sun to the W. However, this also applies from a health perspective, for, as we have seen, the evening sun varies throughout the day and the year, and too much – and too late – solar light and solar heat in the evening, during the warm summer period, is not appropriate for a good night's sleep. Our body temperature is higher during the evening hours, and a protection from the sunlight may indeed support the health better during the evening, than exposure to sunlight. In other words, this confirms the difference between E and W, which is embedded in the asymmetry I keep referring to.

By applying the method in practice at The New Herlev Hospital, the natural daylight and the clear, low-iron glass[205] is implemented, transforming the facades and the architecture so that the hospital better balances the morning, the noon and the evening sun. In the building process, the method helps provide a common language for the architects and engineers, making it possible to plan the architecture without compromising the light quality. Had it not been for this common strategy, a method, it would not have been possible to create differences between morning and evening light, and apply the clear, low-iron glass. A much easier solution would have been solar protective glass and a symmetrical building structure.

205 That is a 2-layered diamond glass; 10 (diamond)-16 (argon)-ultra N-6 (diamond), with a total light transmittance of 80.9%.

As a lighting consultant and through the planning of the light at The New Herlev Hospital, I have come up with instructions on how and where the windows should be placed, helping to draw an outline of the method to all parties. In this context, it is interesting to see how the new energy requirements[206] in practice make it difficult to work with the clear and healthy glass. The existing energy requirements for new buildings, introduced in 2006, act as a challenge for architects and engineers, and not least for the energy advisors making sure that the requirements are met. Control and authorizations obviously contribute to the fact that these requirements are taken very seriously, since no architects, contractors or consultants are keen on designing buildings which may not be built, or even worse, may not be taken into use after construction, because they do not meet the requirements.

The fact that the energy requirements challenge the light and the architecture is nothing new. In 1977 a strict building regulation, BR77, resulted in *a porthole architecture*, which became a symbol of the failed energy discourses of the time. However, it created its own aesthetics which, despite concessions in 1978, lasted well up through the 80s.

In the same way, the energy requirements affect the architecture today. This means that e.g. air conditioning is standard in most buildings and The New Herlev Hospital is no exception. An air conditioning system is planned, blowing 17^0 C cool air into the building at approx. 3 l/s/m^2. This corresponds to approx. 200 m^3 of air per hour. In spite of this heavy air flow, it turns out to be difficult to maintain a room temperature below 27^0 C during the summer, simply because the building is so heavily insulated, causing the solar gain to be trapped inside the building. Quite paradoxically, this means that future low-energy houses in practice make the natural daylight – in the form of a clear, low-iron glass – impossible[207]. When we talk about light and health these airtight houses all seem to cause problems, or rather challenges, due to the fact that the energy consumption is only held down as long as the building does not overheat. Cooling often turns out to be more expensive, because it requires more energy than heating. This seems to be not only a challenge, but a fundamental problem, in designing the houses too airtight. Both when it comes to light and when it comes to health.

The application of the new method shows, however, that it is possible to balance the light in a healthier way, and at The New Herlev Hospital it is possible to base the architecture on the clear, healthy glass and at the same time comply with the new energy requirements – however it is difficult, and requires a deliberate strategy, a method, from the beginning of the construction.

206 BR06 puts a limit on the number of h/ year with temperatures above 26 degrees (100h) and 27 degrees (25h).
207 Today, diamond glass is not stocked in Denmark, due to a lack of demand. Source: Saint Gobain, Denmark.

Colors, geographical orientation and time

The Munsell color chart, here shown in a cool LED artificial lighting, 5.200K

The practical light experiments make it possible to study the color-rendering of the light during a day. This is done through *simultaneous-time-lapse-photography*, using the Munsell color charts, located at the interior facade wall of the control rooms. The Munsell color chart only receives internally reflected light, coming from the white plastered walls and ceilings and from the MDF floor[208]. All photographs are recorded through a day at equinox. The opposite page shows the result of these recordings. Based on the study several observations can be made.

N varies least during the day, also having least light intensity during the day, in general, the blue colors are rendered better than the other colors. However, the blue colors also seem to vary least during the day. The colors varying most are the bright, greenish and reddish hues. In general, the colors vary a lot to the S. Here, the dominating colors are the warm yellow and red hues, and even the blue color turns warmer. Initially, it seems as if the colors in an E-facing room are warmer at the beginning of the day, while the colors in the W-facing room subsequently turn warmer at the end of the day. Overall, both the light and the colors vary during the day. The differences are caused by the sun and thus the geographical orientation and the time of day directly influence the colors. As shown, the differences between E, S, W and N increase as the light grows stronger, and fade and become more alike as the light grows dimmer. First the red colors disappear, followed by the blue ones, and finally the bright hues of colors also disappear.

Other types of shielding

All the practical light experiments, as well as The New Herlev Hospital, have been based on *a reduction of the light opening*. However, there are basically two other ways to establish the necessary asymmetry at the facade level, namely by using *solar protective glass* or by using *physical shielding*.

All forms of shielding create the same necessary asymmetry relative to the asymmetrical light of the sun. Either in the form of differences in the solar protective glass, depending on the solar radiation, or e.g. in the form of horizontal slats in S-facing windows and vertical slats in E- and W-facing windows. Physical shielding does not impair the quality and the health aspects of the light, as the solar protective glass does, and it offers both an aesthetical and an architectural potential however, in this field further research needs to be done. In this context, an additional light experiment[209] is carried out, applying the new method on a physical shielding, based on *generative architecture*. The focus area of the study is the W-facing ward, and the light opening is planned and compared, partly through *reduction of the light opening* and partly through *physical shielding*[210]. The trial explores new options to shield the architecture against the evening sun, based on the equinox[211]. On the op-

208 See chapter 6.
209 In coorporation with Niels Martin Larsen, Phd, Aarhus School of Architecture, 2013.
210 Light opening in both studies, match 34% of the inner facade.
211 The experiment was carried out on 5 April 2013.


e
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Solar protective glass

Reduced light opening

Physical shielding

posite page, both studies are shown, using *simultaneous-time-lapse-photography*. The generative physical shielding (top) and the W-facing test room with a reduced light opening (bottom). The generative pattern is formed by an algorithmic generation of form, based on a system developed to distribute small, 14-sided cells by means of a so-called DLA algorithm. This system provides a relatively airy and branched structure, comparable to the way the crystals grow in nature. This growth algorithm is coupled with a simulation of the path of the sun at equinox. While the pattern grows, the system analyzes the extent to which a particular cell helps to shield the bed area in the room from direct sunlight. This is essential for the cell to become part of the final pattern. In this study, it is the bed itself which is protected from direct sunlight. At the same time, the ability to protect the area around the bed is weighed by a random factor, in order to preserve the nature of the pattern. The system does not seek to achieve a 100% protection against the sunlight. The built-in sample indicates approx. 80-90% protection against of the direct sunlight. At the same time, a zone is kept free in the form of a view to the right side of the room; here the pattern of growth is gradually reduced towards the center of the opening.

As can be seen, both rooms shield against the evening sun in the bed area, here at equinox. As previously described, the light at equinox supports the circadian rhythm of the body; the light of the sun neither enters too early in the morning nor too late in the evening. However, in the summer the sun will set later in the NW at PM. 21.57 and both light and solar gain may challenge the health – at this time of year, the physical shielding will not constitute an equally effective protection against the evening sun. The sun in *summer west* is therefore an important benchmark for the design of the physical shielding of the W-facing facade. Through further processing and modeling, the shielding may be improved, better taking into account the summer sun in the evening – like the facades facing E, in the same way, may be improved to better balance the early morning sun in *summer east*. Another factor which can be improved is the visual contrasts caused by the physical shielding. Surfaces only receiving internally reflected light appear dark in contrast to the surroundings outside. As seen here, it creates an experience of gloomy and dark shielding during the day, also impairing the view out. The reflected light in the full depth of the shielding, equal to 0.5 m, may provide some reflected light, reducing these contrasts. However this was only partially successful. Future experiments may further uncover these possibilities and perspectives.


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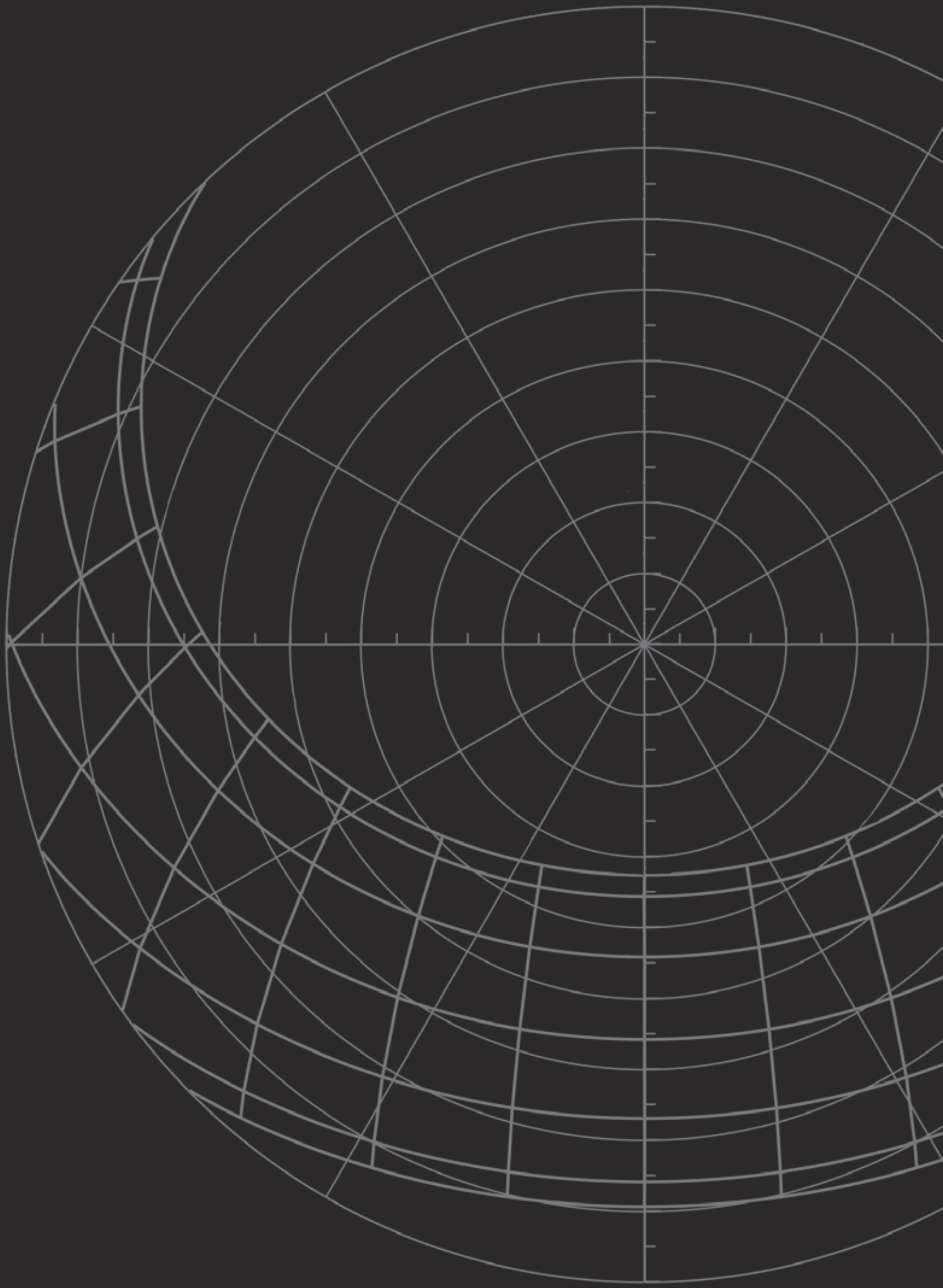
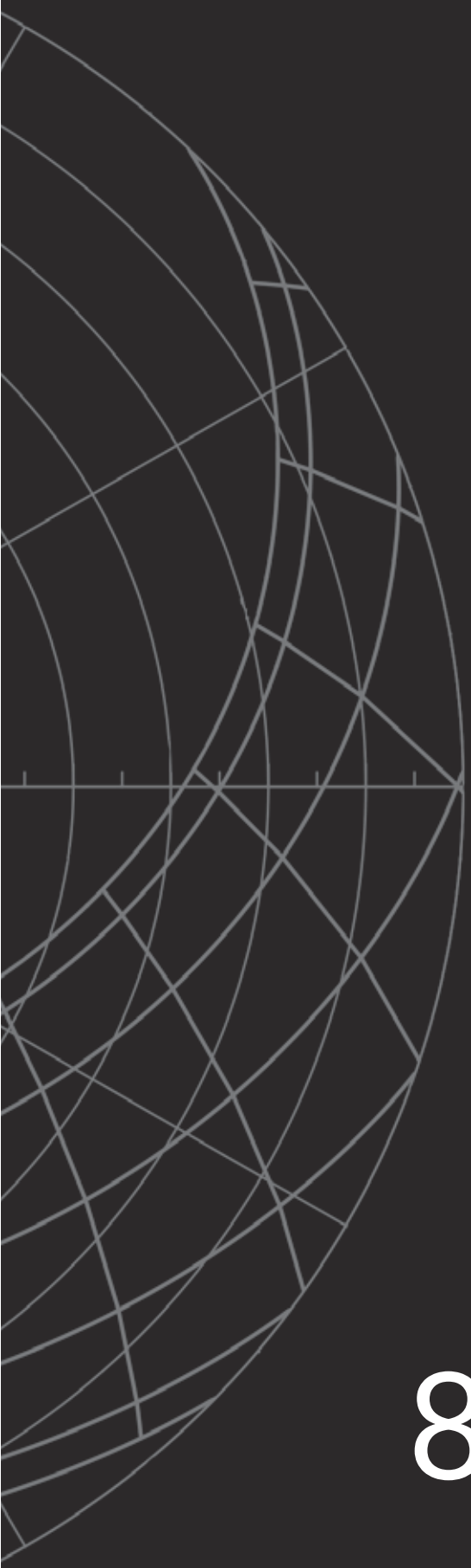




8 CONCLUSION

8. CONCLUSION

The literature studies indicate that light is an important factor when it comes to health. Overall, they show that multiple ailments and diseases are treatable and preventable by the effects of light. The literature studies also indicate that darkness and variations between light and darkness during the day may have an impact on health. Through the practical light studies some of these differences in light are demonstrated, differences which are primarily caused by two factors, the geographical orientation and the time of day and year. Architecturally, this means that the geographical orientation is of importance to the light, and thus to health.

The thesis develops a new method which, based on these facts, shows how the light may be planned in a healthier way in architecture, a method which is subsequently tested in practice at The New Herlev Hospital, which is planned and built using the method. At The New Herlev Hospital the method is addressed at the facade level; in this way, the method is used to create and transform an otherwise symmetrical building into an asymmetrical building which relates better to the light and to the body's various needs for light during the day. In the following, the overall research questions of the thesis are answered, followed by concluding remarks and perspectives.

RQ1: How does light support the general health?

Especially elderly and hospitalized patients suffer from vitamin D deficiency. Vitamin D is primarily formed through the UVb light of the sun, and the lack of vitamin D is caused by the fact that they often spend more time in the indoor environment. The literature study indicates that the latitude and the weather – along with the quality of the glass – can be a contributing factor to this vitamin D deficiency.

The discovery of *the missing piece in the lighting puzzle* in 2002 means that light is again closely related to health, a.o. because of its essential role in the maintenance of the circadian rhythm. However, the literature study renders a quite complex and nuanced picture of the concept of *light and health*, an image which greatly concerns the interplay between light and darkness in relation to the time of day – subsequently making it necessary to differentiate between morning light and evening light.

Today, light is a recognized form of non-medical treatment of people suffering from winter depression (SAD). At the same time, light actually enhances the effects of other medical treatments for depression. The literature study, here too, shows that the circadian rhythm plays a very important role. Light in the morning hours proves to be more effective as a therapeutic treatment than exposure to light during the evening hours.

The literature study also renders a complex picture of the relationship between sunlight and the development of skin cancer. Several studies show that outdoor workers actually have less risk of developing skin cancer than indoor workers.

Finally, it turns out that light also acts antiseptically to bacteria. Which – in a hospital context – can help reduce hospital acquired infections (HAI) which annually cost several million DDK in prolonged hospitalization and loss of healthy life.

Within all these health areas, the literature studies and the practical light experiments show that the quality of glass is important. They both indicate that glass transmits the healthy light very differently. Therefore, the thesis establishes the following concepts; *the UVb-factor* and *the unhealthiness factor* for glass. Overall, in all the experiments, the clear, low-iron glass provides the healthiest light.

RQ2: How can a healthier light be planned architecturally?
The fundamental starting point for a healthier architecture seems to be the clear, low-iron glass. However, the field studies suggest that a unilateral worship of sunlight often fails, since it challenges both the light and the health. The field studies show that too large glass facades create problems, both lightwise and healthwise, since they impede the clear glass and the healthy daylight. Instead the field studies emphasize a need to *balance* the sunlight, instead of *optimizing* it.

The practical light experiments confirm that the major differences between summer and winter rather emphasize the need to balance the sunlight, instead of optimizing it, indicating that this balance can basically be achieved in two ways:

1) The orientation of the building
2) The form of the building and the facade

1) The orientation of the building involves several factors. Firstly, the fact that the building in its starting point relates to the asymmetrical light and heat from the sun. Secondly, central health aspects indicate that the distribution of morning light and evening light is essential. While the morning light has positive effects and stimulates the circadian rhythm and the general health, the evening light, and heat, counteract the circadian rhythm and the health.

However, the light experiments show that both the morning and the evening light vary greatly at our northern latitudes. Both must be balanced architecturally throughout the year. Seen from a health perspective, a deliberate planning of the principal orientation of a building may help to balance the morning light and the evening light in a healthier way throughout the year. However, this balance can be difficult to find. An orientation of the faca-

des directly to the N, S, E and W appears to work best around the equinox, at times when the sun rises due E and sets due W and when the days and nights are of equal length. But when we move away from equinox, this orientation is challenged from a health perspective, e.g. in the winter season not much morning sunlight will enter to the E, while in the summer season there will be too much – and too early – sunlight in the morning, and too much – and too late – sunlight in the evening.
The light experiments instead suggest that an orientation towards what is called *winter east*, may balance the light in a healthier way throughout the year at northern latitudes. In this way the early morning sun in the summer is reduced, while the later, sparse morning sun in the winter is better utilized. In this way, the morning sun is better balanced throughout the year – also during the cold winter months – simply because the facade of the building is oriented towards it. Such an orientation will, accordingly, mean that the building does not have a dark north side without sunlight through the dark winter months – from equinox to equinox – something which, according to studies, can affect the health adversely.

2) The form of the building may, as a starting point, relate to the asymmetrical light distribution of the sun over time and place. This can be achieved by different types of asymmetrical shapes or shieldings. In symmetrical building forms, such shieldings may either be achieved through asymmetric use of *solar protective glass*, through asymmetric, *differentiated light openings*, or through asymmetric *physical shielding,* relative to E, S, W and N.

But of course also the architectural form itself can help to reflect this asymmetry through an asymmetrical building shape. The response of the architecture to the asymmetrical daylight is thus asymmetry, an answer, which not only can be addressed at the building level, it can also be addressed at the window and facade level.

Embedded in this asymmetry is a localization of the architecture to both time and space – a fundamental relationship. A healthier planning of light, and a healthier architecture, supports diverse needs of light and darkness during the day. If we relate light, architecture and health, the aforementioned asymmetry points at a redistribution of the light, so that facades facing E, S, W and N are not uniform. This asymmetry separates E from W, either through orientation, building form or through the planning of the facade and the location, size and design of the light openings. Such an asymmetrical light planning not only separates morning and evening light, at the same time it also allows the use of the clear, low-iron glass – which in itself has several health benefits.

RQ3: Can the artificial lighting – and the interplay between natural and artificial lighting – be enhanced and better integrated in the architecture?
The light experiments stress the importance of good artificial lighting, especially during the winter season, where we, seen from a health perspective, may not get enough light. The light experiments indicate that asymmetrical artificial lighting creates both better detail- and better space-rendering compared to symmetrical artificial lighting. Like asymmetrical – or asymmetrically placed – artificial lighting provides more room for the long transitions between light and darkness, which are characteristic at our northern latitudes.

The light experiments also indicate that the experience of light not only depends on the level of illuminance, it also depends on the light distribution and the shadow-rendering. Finally, the geographical orientation and the season affect how the artificial lighting is perceived.

The thesis sets the stage for further research in this field to improve the interplay between daylight and artificial lighting, integrating the daylight and the artificial lighting in architecture. Again, it seems that the interaction between daylight and artificial lighting can be improved by studying the geographical orientation and the differences in daylight this creates.

A showdown with Modernism and the international style
A light planning based on *a cloudy sky* and daylight factors per definition omits the geographical orientation. In this way, light is reduced to a functional factor in the architecture, a factor which only creates good visual environments – without taking into account the health aspects of light.

In this context, a unilateral focus on high daylight factors and *open planning* does not seem to be a rational solution, it creates, as we have seen, a need for poorer and more solar protective glass, a protection which may energywise seem reasonable, but light- and healthwise it turns out to be less rational.

Seen from a light perspective, the geographical orientation is interesting for two reasons, partly because it is a determining factor in the balance of the large differences in light during the day, and during year and partly because it is a prerequisite in the planning of architecture based on clear, low-iron glass and natural daylight.

Exclusively to optimize the quantity of light during the day does not seem rational for the health. The unhealthiness factor of glass puts a question mark to high daylight factors and demands of high utilization of the daylight. Instead, the light quality should be an important factor when we talk about light and health.

In the planning of the new hospitals in Denmark these years, the Medical Association drew up a wish list, where it is notable that:

A good environment with natural light and noise reduction reduces the risk of errors and benefits the health of the patients. This basic fact should inspire the design of hospitals when it comes to the architecture[199].

However, as this thesis has sought to clarify, the natural daylight is not just something which comes by itself. As we have seen, the natural light is often challenged in buildings with too large glass facades not taking into account the geographical orientation and the direct sunlight. Instead, it requires a new method to organize and plan a healthier light and a healthier architecture. A healthy architecture can not only be solved technologically, it may rather, as Alvar Aalto describes, be solved *architechnologically*[200]. This thesis is an attempt to develop such a method to help organize and plan a healthier architecture.

Concluding remarks

The thesis focuses deliberately on the positive effects of light on the health. This is done, knowing that the light of the sun also causes many ailments and diseases. However, the thesis is not called *light, disease and architecture*, therefore, it is up to others to depict the more pathogenic effects of light and architecture. But the thesis has taken a step away from Modernism's unilateral worship of light and thus approached the opposite stance by stressing a middle stance, a balance between *exposure* to and *protection* from the light of the sun, a balance that may seem difficult to find.

The light experiments are all based on the hospital ward and only study rooms with one window. This has its limitations and is not intended as a prescription for a good and healthy architecture. On the contrary, the experiments show several limitations of rooms with only one window. The large differences in sunlight, depicted in the light experiments, would have been avoided – or at least reduced – if the rooms had had light openings towards two corners of the world. Also the shadows and the contrast in the rooms would be quite different, as two light openings reduce and eliminate the shadows and the contrasts from each other. Finally, a room with light openings to two corners of the world better utilizes the sunlight over a longer period of time during the day and the year.

In the description of light, the light experiments have focused on the circadian rhythm and the health. More specifically the light of the sun is linked

199 Ugeskrift for Læger 2012;174(26). 2012.
200 Op.cit.p. 80.

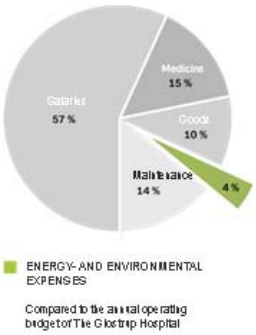
to the circadian rhythm. This approach has been taken because the sunlight represents a large part of the total light intensity, and because the sun affects the serotonin levels and thus the circadian rhythm.

Light and atmosphere is not described, as the aesthetics and the spatial considerations are only described through an overall health discourse.

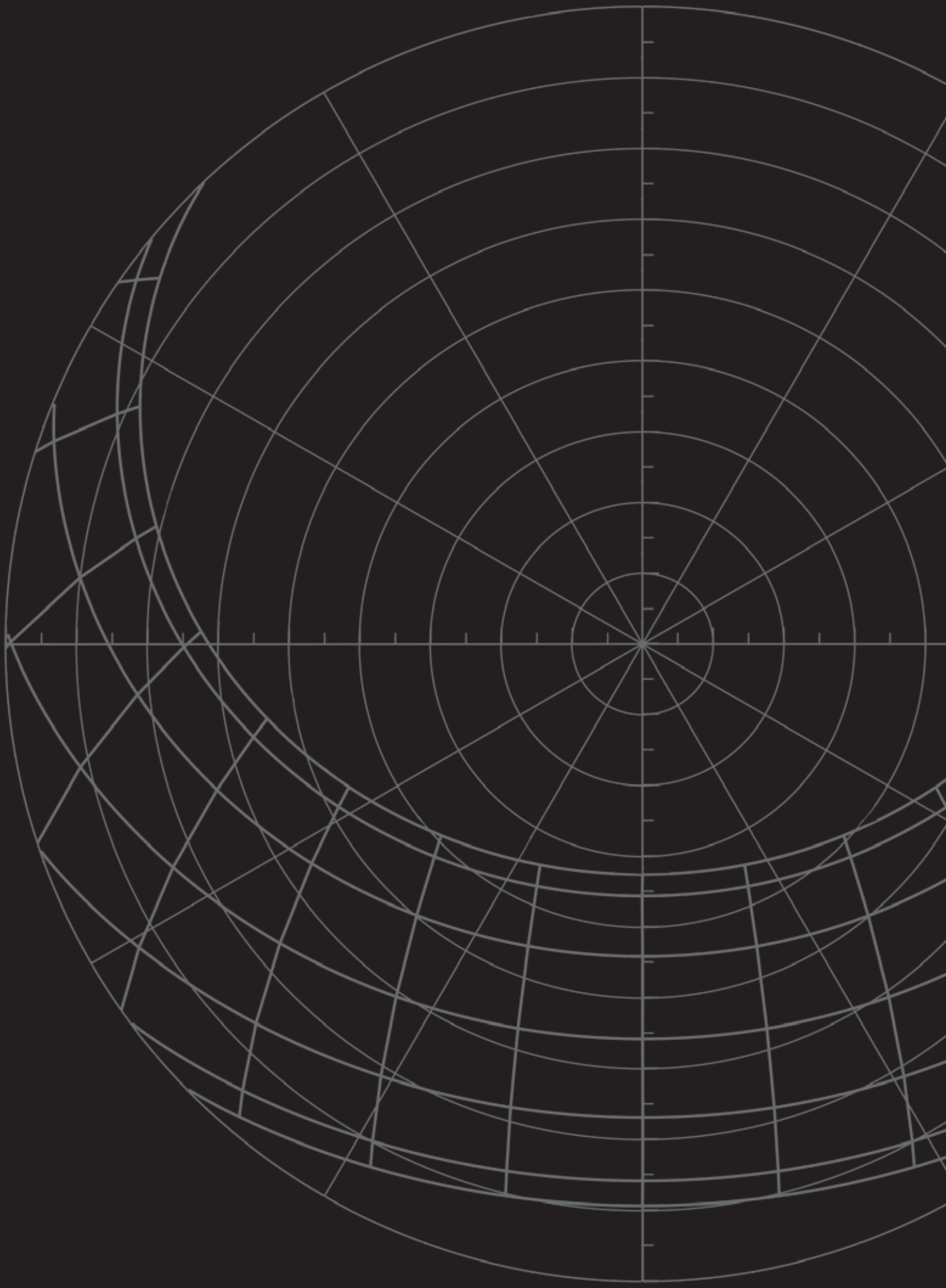
No medical experiments have been performed in this thesis. The effect of all the light experiments on the human health is solely based on literature studies and practical light studies. Testing whether it works in practice remains to be seen, and may wait until The New Herlev Hospital is completed in 2017.

Perspectives

In the 2010s energy optimization has become even more acute because of the global warming and the need to reduce the CO2 footprint. In this context, the compass becomes an important anchor point for an energy-efficient and sustainable architecture. However, an energy-efficient and sustainable architecture is not necessarily synonymous with a healthy architecture. At a hospital, approx. 90% of the total operating costs is spent on salaries, medicine, etc, only about 4% is spent on energy and environmental costs[201]. Currently there is no easy way to quantify the significance of a healthier architecture, however, if the proposed actions in this thesis only have the slightest effect on the sick days among staff and the well-being in general at a hospital, the expenses may quickly be recouped, in the form of reduced costs for replacement staff and a better health. In this context, the architecture plays an important role, helping to increase the health among the patients as well as the productivity of the staff, yet studies demonstrating this are yet to come. Perhaps the new method and the application of the new method at The New Herlev Hospital may help to clarify this role and quantify how much a healthy architecture costs – and last but not least, can earn back. Architecture in the future is not just about energy, building and operating *costs,* it is also about health and the *income* of a good health.



201 The annual operating budget from Glostrup Hospital. Published in the design program for The New Hospital Glostrup Neurorehabilitation Centre, 2012.



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Chapter 8

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EQUINOX 21. SEPTEMBER

Sunrise AM. 06.00 (suntime)
Sunset PM. 18.15

Daylight
5.24-18.52

Civil twilight
04.41-05.24 and 18.52-19.35

Nautical twilight
03.55-04.41 and 19.35-20.20

Astronomical twilight
20.20-03.55

SUMMER SOLSTICE 21. JUNE

Sunrise AM. 03.37 (suntime)
Sunset PM. 20.57

Daylight
03.00-21.20

Civil twilight
02.39-03.00 and 21.20-21.55

Nautical twilight
all night

Astronomical twilight
all night

WINTER SOLSTICE 21. DECEMBER

Sunrise AM. 08.37 (suntime)
Sunset PM. 15.49

Daylight
07.52-16.35

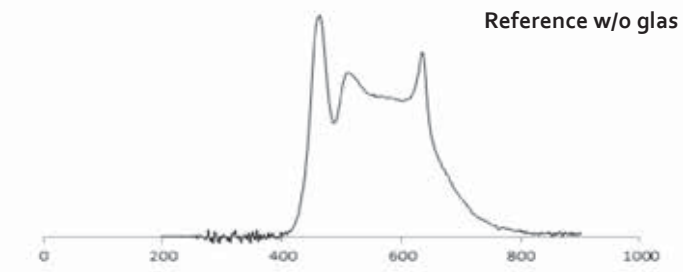
Civil twilight
07.05-07.52 and 16.35-17.22

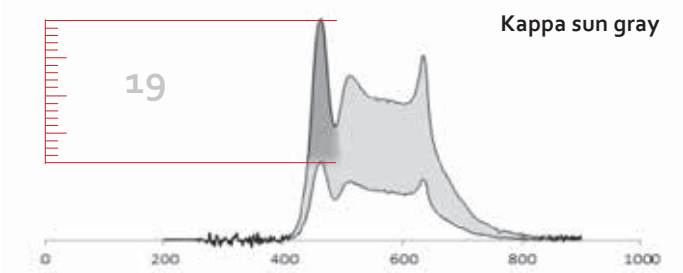
Nautical twilight
06.20-07.05 and. 17.22-18.06

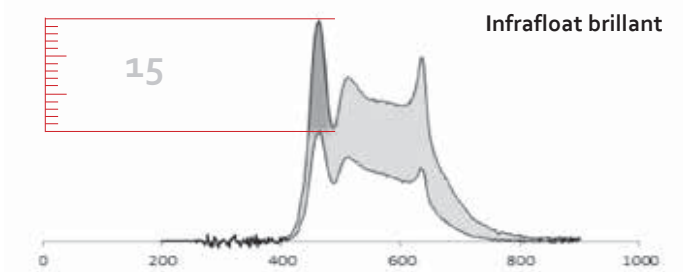
Astronomical twilight
06.20-18.06

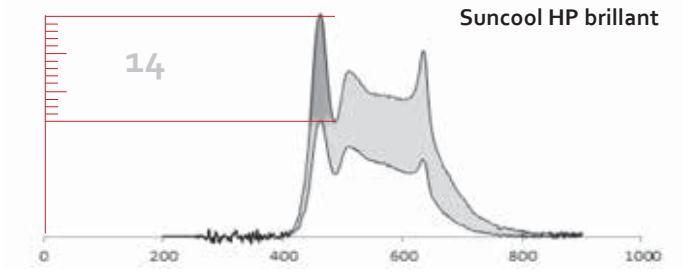
ANNEX – THE UNHEALTHINESS FACTOR

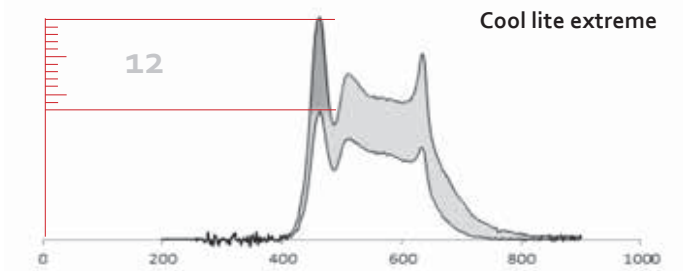
Reference Glass











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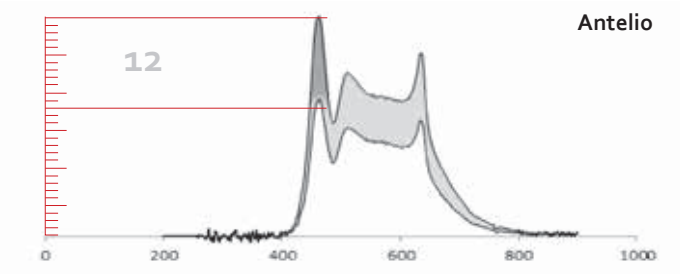
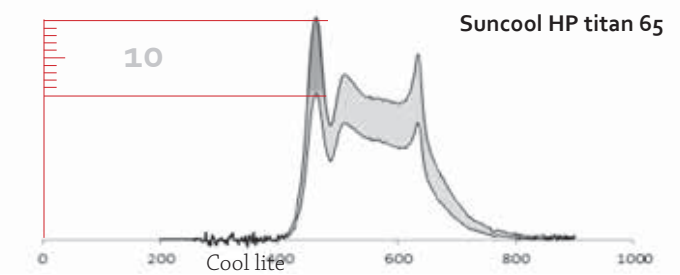
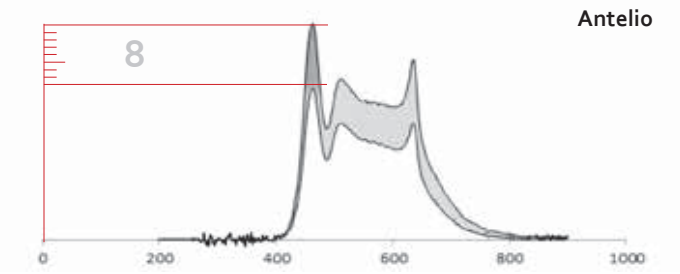
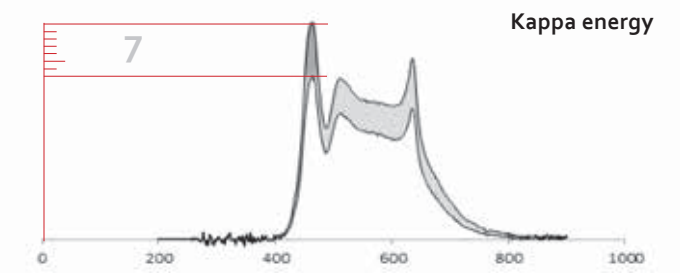
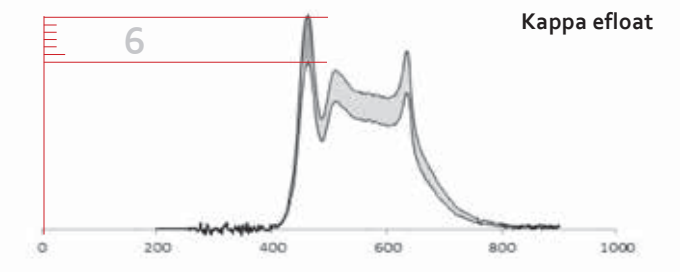




Cool lite







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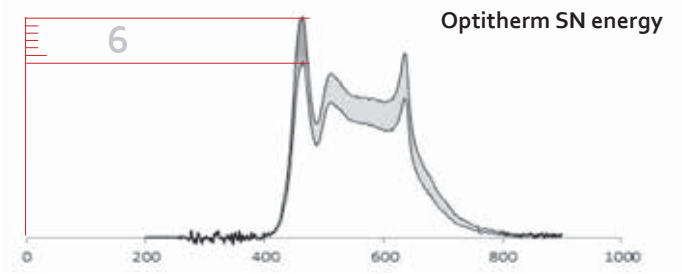

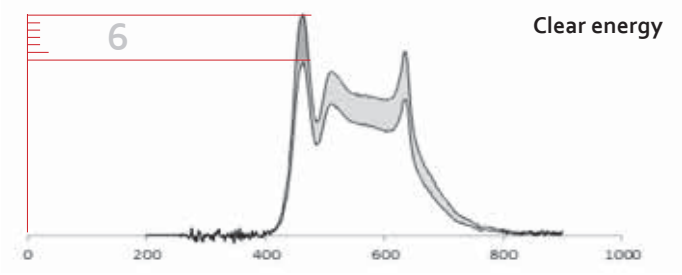

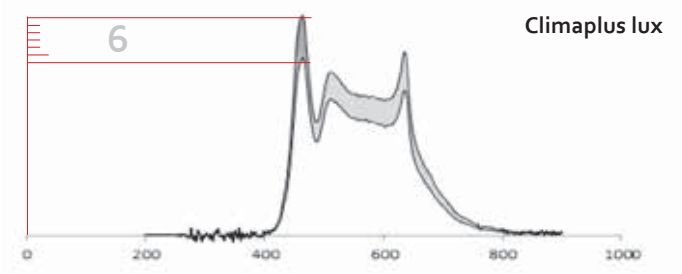

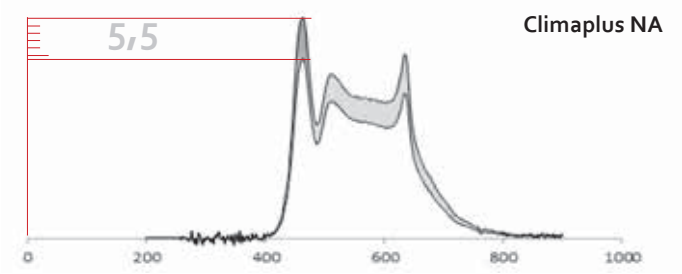

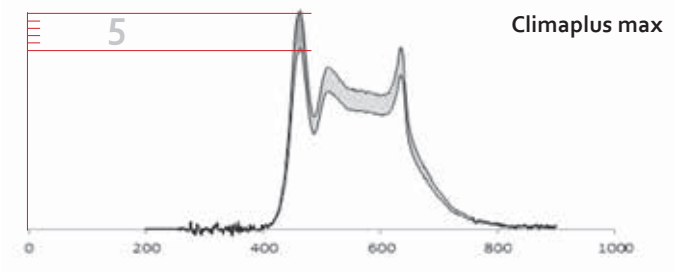

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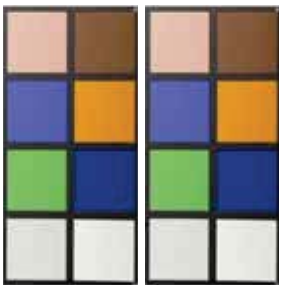

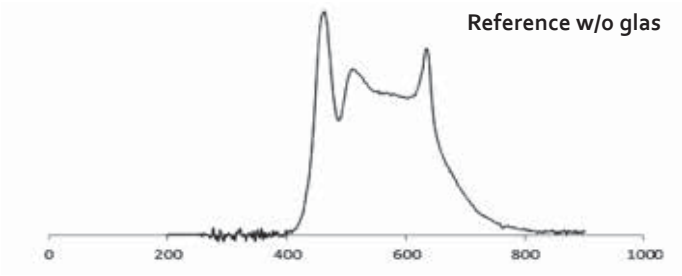

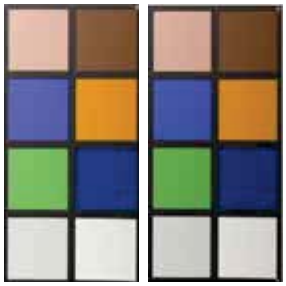

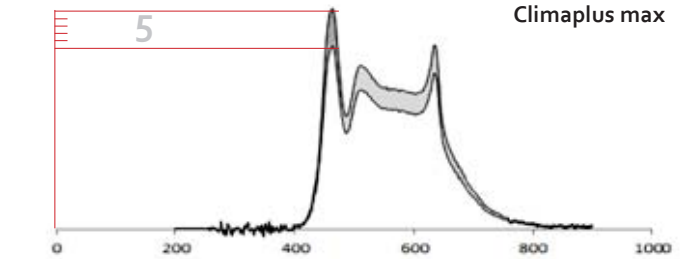

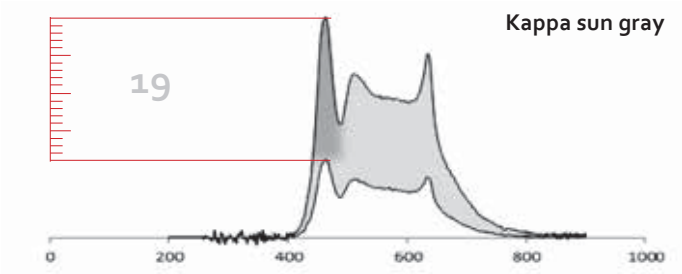

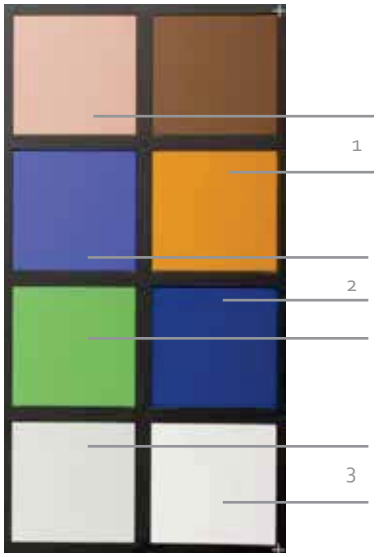

Left: The 8 colors in the light experiment are based on a Munsell color chart. The Munsell color chart is selected because it is a recognized international standard for colors. The colors chosen represent 8 of a total of 32 colors. They are used as a reference, showing three characteristics:

1) The warm colors show the ability of the glass to reproduce skin tones

2) The blue and green show the blue and green tint of the glass, changing the light, a shift often caused by the content of iron in the glass

3) The neutral grays show the intensity of the light and the light loss through the glass

Above: The unhealthiness factor is proportional with the relative reduction of the light (450 nm - 480 nm) which stimulates the circadian rhythm

The glass samples are listed by their unhealthiness factor, starting with the most unhealthy glass (Kappa sun gray, with the UH-factor 19) and then gradually up to the least unhealthy glass (ClimaPlus max, with the UH-factor 5)

All measurements are done in collaboration with DTU Photonics and SBI, at the SBI light laboratory in Hørsholm, 2012. All measurements are measured in the visible spectrum, i.e. without the UV spectrum