AALBORG UNIVERSITY COPENHAGEN

A Proposal for the Implementation Process of New Lighting Technology in Office Spaces

Master Thesis of Lighting Design

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Abstract:
The implementation of new lighting technology in the Danish office sector is still rare, despite its promotion by both industry and government.

Current implementation procedures are fairly efficient for smaller projects, yet inefficient in large scale projects. Case studies show that efficient implementation of new lighting technology is possible also for large scale projects.

In addition, in all cases, little is known about end-user satisfaction due to the lack of post occupancy surveys in the process, and adjustments have to made well after completion of the project.

For large scale projects, the problem lies with the project leader, who underestimates the complexity and potential of new lighting technology, the necessity of a lighting professional to deal with this, and the budget.

To make the process more efficient, an implementation is proposed, which is based on facilitating factors of current implementation processes, with additional steps to counter its inhibiting factors, including post occupancy survey.

This model is argued to be more efficient, and as such reduce costs, increase end-user satisfaction, and contribute to research on the effects of new lighting technology.

Contents

Introduction

Lighting accounts for a considerable portion of both the cost and energy consumption in the commercial sector, including that of office buildings. Surveys within the European Union conclude that along with HVAC, lighting systems are the most significant contributors to energy expenditure (EC Commission Staff Working Document, 2016). Within this approximately 20% to 40% of the primary energy required by offices is for lighting (CELMA, 2011), and in the Danish case, electric lighting accounts for approximately 20% of total energy consumption (SBI PSO afslutningsrapport, 2016).

Despite this, new lighting technology, particularly solid state lighting or LEDs, are more efficient than their predecessors (US DOE, 2015, EU Green paper, 2011), and provide greater control over illuminance levels and correlated colour temperature (CCT). Besides their efficiency, and due to this greater control over light, LED lighting technology is also being promoted by the commercial sector as having health benefits. This is linked to research on light and the human condition by among others Goven, Laike, Knez, Kers and Figueiro, to name but a few, who have demonstrated how a change in spectral power distribution can affect psychological and physiological response.

Due to their projected long term benefits, national governments such as those of the EU have pushed for their implementation as the next generation of luminaires (EU Green paper, 2011), and as such they seem an unavoidable part of the cost of office buildings for the years to come.

It can be argued that this new focus on not just efficiency and visual acuity, but also on health and well-being, indicate a paradigm shift within the lighting industry. As such, there is a move towards the aspect of well-being and health which has been made easier with the developments within lighting technology, and the increased dynamic control they offer. New lighting technology is as such argued to be synonymous with dynamic lighting systems focused on both visual acuity and the human condition, which is equally implied when mentioned in this thesis.

The combination of the abovementioned aspects, i.e. energy expenditure, investment costs, research and development costs, research on light and the human condition, as well as the drive at the national level to implement dynamic LED lighting systems, result in a complicated picture which has an impact on the decision making processes involved when installing new lighting systems in offices.

This is further complicated by a number of factors which are inherent to any new and rapidly developing technology. Firstly, the continued research and development of better and more energy efficient luminaires have resulted in an industry that has increased in diversity and complexity (Afslutningsrapport PSO 346-034). Resultantly this development has expanded into new fields of technology such as those of lighting control systems and lighting control software. Secondly, the advances of research into the effects of light on the human condition has led to new specialist branches in the lighting industry in general, such as those focused on office lighting, museum lighting, hospital lighting, or lighting for Alzheimer´s disease care centres and old peoples care homes etc.

In all, the pace of these developments as well as the extent of their diversification have arguably been so great that at current consensus has yet to be established for new lighting standards in general (Architectural Lighting Technology, Feb. 2016), and its respective specialist fields. In addition, at a national level, authorities still lack an approach for the retro-fit and conversion of the lighting infrastructure (EU Interreg paper, 2016). This task is all the more challenging in light of the freedom that these new lighting technologies can offer in dynamically controlling the many individual parameters of light separately.

Although there have been some efforts at producing guidelines, the building industry has been slow in adopting them as part of their implementation strategies (Architectural Lighting Technology, Feb. 2016). This reluctance to adjust can leave many commercial lighting projects, including office lighting projects, open to a number of problems when implementing new lighting technologies. These can include long term cost overruns due to under-appreciation of the costs of up-to-date lighting technology, re-planning and re-budgeting to adjust for additional lighting costs or installation problems, cost-cutting at the expense of proper lighting systems, the procurement of wrong lighting products and lighting systems, the wrong application of lighting systems, dissatisfied end-users, and finally possible adverse effects with respects to health and well-being such as reduced work productivity and increased stress and fatigue.

Besides sporadic mention in non-academic journals, the topic of the implementation processes of new lighting technology in and of itself is seemingly absent from lighting research literature. With so much money invested in new lighting technology, and the slow pace with which this is implemented in offices, the following three problem statments are relevant addressing the issue:

- How efficient are current implementation processes for new lighting technology in offices?

- How can we increase the efficiency of current implenetation processes for new lighting technology in offices?

- How can the efficacy of new lighting technology in offices be assessed?

This thesis firstly aims at understanding how efficient current implementation processes for new lighting technologies in offices are. As such it will contribute to the management of new commercial lighting projects by charting current processes and analyzing these as to their efficiency. Secondly, it will propose an alternative implementation process model for new lighting technologies in offices to affect a more efficient implementation. This model will contribute to minimizing the aforementioned costly and complex challenges faced by the building and lighting industry today when implementing new lighting technology. Finally, as part of the proposed implementation process model, it will briefly suggest an end-user experience assessment example for new lighting technology in offices. As such it will contribute with basic guidelines on how to validate the efficacy of new lighting systems, the latter of which are dynamic and more complex than traditional static systems.

The study will assess the current processes firstly by an analysis of the state of the art in light and human physiological and psychological responses, secondly by wider analysis of general implementation procedures of lighting in Denmark today, and finally by a more focused study of three cases in the Danish office sector where new lighting technology has been introduced in the form of dynamic lighting systems aimed at increased health and wellbeing of office staff. These cases involve either lighting systems that have been implemented as part of newly designed buildings, or retro-fits which have been used to replace older systems. In all cases a programmable LED lighting system was used to adjust illuminance levels, and change CCT values depending on the time of day, the season, and the weather conditions.

In all, the literature review on light and the human condition, the general cases, and the three selected case studies will be used to provide a systematic overview of the complexity of new lighting technology, how these are currently implemented, and how the implementation process and the new lighting technology may be assessed and validated.

The analysis of the implementation process itself is based on theories and key concepts from the field of Implementation Science, and in particular Normalization Process Theory, the latter of which was developed to understand the implementation of new technologies in the health sector (Nilsen, 2015). As such the focus will be on the overall framework of the implementation process, and the determinants which influence the implementation outcomes. These determinants consist of various facilitating- and inhibiting factors of the process including the level of communication, the level of knowledge on new lighting technology for increased health and well-being, the responsibilities of the lighting professionals involved, the decision making process, and finally certain performance indicators such as end-user response and resulting light efficacy.

The analysis and results will serve as a basis for constructing a proposed theoretical implementation model for new lighting technologies. The proposed model will incorporate existing facilitating factors of current implementation practice, and will account for their inhibiting factors. This implementation model will be put forward as an alternative to current procedures, and is hoped to streamline the implementation process itself, and make it more efficient.

As a proposed model, it remains to be tested in a live project environment. This thesis therefore recommends further study and application of the proposed model in live settings.

Methodology

Introduction

The scope and nature of the research require the use of different methodologies to obtain, process and analyze the data. This implies that broadly speaking a Mixed Method approach has been applied overall, yet despite the presence of quantitative data, the weight of the study will be on the qualitative side of the study (fig 1). The following will outline the methods selected, the reasons for using them, as well as the biases that each method may have.

To understand the many aspects of the implementation process, semi-structured interviews were conducted with lighting professionals both for the general cases as well as the selected case studies. The efficiency of the implementation was rated by looking at a number of aspects, among others communication, decision-making, responsibilities, budget, knowledge, and end-user experience. These aspects, as well as the interview schedule, were based on preliminary open interviews with lighting professionals who had a rich and broad experience.

The analysis of the interviews was based on Normalization Process Theory, occasionally referred to as NPT in the text, which is one of the many theories of implementation science. NPT helped to understand the various factors of the process which influenced and drove the implementation process. In addition, this theory provided the analytical framework to understand how various elements in the process affected each other. A key tool in this was the use of thematic coding, which produced the relevant themes that were used in the NPT analytic framework. The implementation process was analyzed separately for the general cases and for the selected case studies, which equally allowed for their comparison.

To understand the aspect of knowledge in the implementation process, a literature review was conducted on research relating to light and the human condition, i.e. health/well-being. This was used as a basis for assessing what kind of knowledge was used in the implementation procedure, i.e. what knowledge the lighting designs were based on. For the general cases this was asked during the interviews, which as such were more general in nature. For the selected case studies this relied on both an analysis of the lighting concept of the project in question, in addition to the explanations given in the case study interviews.

Finally, the efficiency of implementing new lighting technology is not only dependent on a sound implementation model, yet is equally validated by, and dependent on a proper assessment method of end-user experience. Although this topic can only properly be discussed in a paper of its own, this study will briefly touch on and propose how such a survey may be drawn up for complex lighting technologies, using on one of the selected case studies as an example.

Mixed Methods Approach

The different techniques used to obtain data result in different types of data. The study uses both a qualitative and quantitative approach in the analysis. This is mainly done by necessity. To start with, understanding the implementation procedure implies understanding the human decision making processes involved. These decision making processes are accompanied for a great part by complexities of human interaction, the latter of which are best understood with qualitative data (Creswell & Clark, 2011). On the other hand however, the assessment of large numbers of people is most efficiently done quantitatively with closed ended forced choice questions, i.e. a questionnaire, which makes them well suited for statistical analysis. In addition, light as a physical entity is affected by its physical environment. This interaction and the physical environment is most efficiently understood through a quantitative approach, i.e. measurements, implying again the use of quantitative data.

The use of both types of data however provide for a more robust study. Qualitative data can be used to provide context to the quantitative data. This is especially important in identifying reasons, rather than results (Creswell & Clark, 2011) for certain phenomena. This is understood in a less direct way for this thesis, where for instance the analysis of the programming schedule and the topology of the lighting fixtures were put into context by the explanations from lighting professionals in the semi-structured interviews.

The two types of data, i.e. qualitative and quantitative data, are brought together and combined using a Mixed Method approach. This model allows for obtaining and processing each type of data separately (Fig 1), followed by a comparison between the different data sets in the final stages (fig 2). There are several variants of Mixed Methods approach which cater to different design objectives. In this study the Parallel Database variant is used which implies that the two types of data will be compared without converting one to the other. In other words, the quantitative data will not be qualified, and equally the qualitative data will not be quantified (Creswell & Clark, 2011). The methods used to obtain and analyze data within this framework were briefly touched upon in the introduction, and are discussed more in-depth in the following sections.

Figure 1.
Purple area indicates quantitative research and data, blue area indicates qualitative research and data. Both types of data are present in the same research, yet the weight is on qualitative research and data.

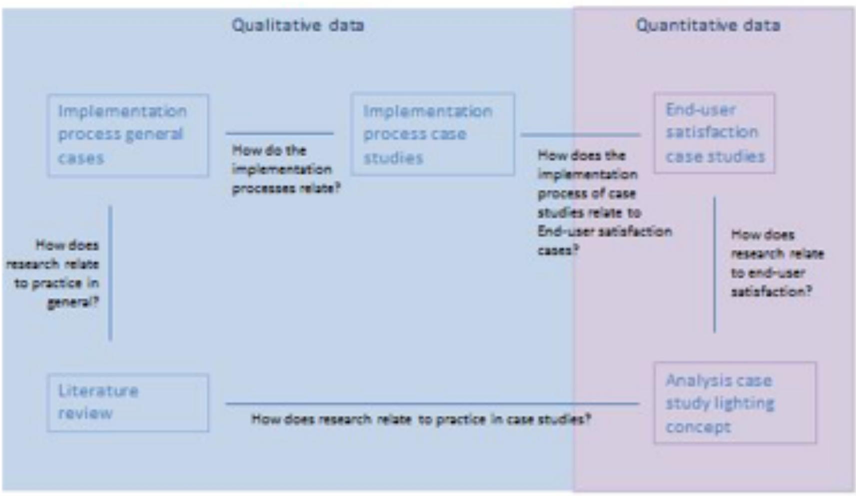


Figure 2.
Comparisons in Mixed Method approach can occur across the quantitative-qualitative divide.

Implementation Theory

Implementation theory is based primarily on studies aimed at assessing the effectiveness of medical trials of new treatments involving new medical technologies, and is linked to Evidence Based Practice (Nils, 2015). Currently however, much of the rationale and theoretical bases for the various theories that have been proposed so far remain weak or insufficient (Nils, 2015). In addition, the sheer amount of implementation theories that have been developed and proposed over the last decade have resulted in a confusing and disorganized situation with little overview (Nils, 2015). Nils has noted that there are a few tools and frameworks that are used to evaluate processes of implementation such as RE-AIM, PRECEED-PROCEED, COM-B, PARIHS, CFIR, EBP, BARRIERS, Normalization Process Theory etc. The popularity of these approaches notwithstanding, many are specialized for use in psychiatry, behavioural therapy, management structure, organizational goals, or may be simply only practical for use in multi-phase and multi-disciplinary projects.

Due to its applicability to this study, Normalization Process Theory was used to put the implementation process of the case studies in an analytic framework. As with most implementation theories however, and despite its wide application, there remains insufficient critical study on the theory itself. To this must be added that Normalization Process Theory was developed in particular for health care (May et al, 2007), and may seem at first glance an odd choice to understand office lighting. On the other hand however, one of the arguments for new lighting technology in offices is for health reasons and well-being, and from this perspective one may argue for the use of Normalization Process Theory. The applicability of Normalization Process Theory lies in its emphasis on the adoption and routinization of new technologies (May et al., 2007). In the case of new lighting technology this translates into understanding how this new technology is accepted and implemented by the various actors involved in the implementation process within the building industry itself.

A principle argument for using Normalization Process Theory is its focus on human agency, i.e. the attitude and behaviour of those involved in the implementation process (May et al., 2007). From the outset of this survey, and based on discussions, it was clear that this human aspect had an important impact on current implementation procedures, and as such its outcome.

Normalization Process Theory consists of four elements which may be described as key mechanisms that drive the process of implementation: coherence, cognitive participation, collective action and reflexive monitoring. Coherence relates to the understanding or acceptance of a new technology, cognitive participation refers to the engagement by those involved in the implementation process, collective action refers to the work that is done by those involved, and finally reflexive monitoring is the appraisal or assessment of the implementation (Murray et al., 2010). Each of these elements is dependent on human agency, i.e. participation and interaction, by those involved in the process. As such the overall outcome is determined by inhibiting (negative) or facilitating (positive) factors that occur as a result of the experience and actions of those involved in the process for each of the four elements (fig. 3).

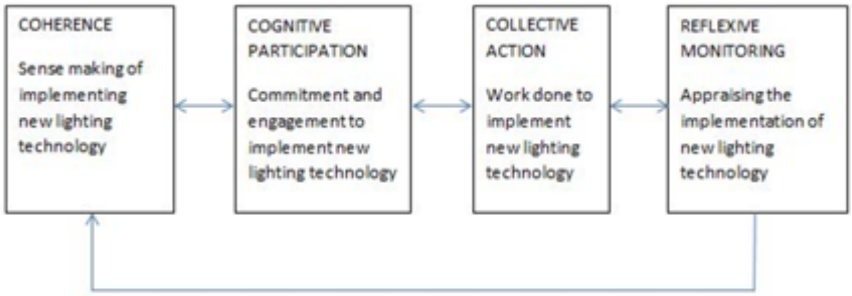


Figure 3. IPT components

The results of the analysis are presented in two ways which highlight the process and its determining factors respectively. These models are based on examples of other surveys conducted with Normalization Process Theory.

Literature Review light and the human condition

The case studies relate to lighting systems in offices that target the well-being of users, and as such aspects relating to the circadian rhythm such as rest and concentration, as well aspects relating to productivity such as concentration and interaction. This is in effect a typical example of how dynamic lighting systems are being developed and used today, and is based on the concept of changing the spectral power distribution during the day to support a certain desired behavioural response. As this field is relatively new, it is essential to understand what research has been conducted and to what end. As opposed to studies on energy efficiency, the results of dynamic lighting are more complex to interpret when applied to a real life setting, both with respects to physiological- and psychological impact. Besides light, human responses may depend on a variety of factors such as temperature, humidity, sleep-wake cycles, chronotype, eye-sight, age, view from the work station, social types, mental state etc.

The ability to compare the knowledge gained in research to that which is applied in praxis requires first and foremost a systematic review of research literature. By understanding its progress, and what current research on dynamic lighting and the human condition focus on, it is possible to understand what knowledge is being applied in the commercial sector, which research this is based on, and whether or not it is up-to-date, or based on validated research.

This thesis will conduct an evaluative literature review (Adams et al., 2007) which will act as a point of reference in understanding what knowledge is referred to in the implementation process of dynamic lighting systems. This method will equally allow to track whether knowledge on dynamic light and health is properly understood by investors and clients who seek to implement it, and what expectations the clients have for their end-users.

The literature review will focus primarily on biomedical / chronobiological trials involving the circadian rhythm and light, and trials on psychological / cognitive responses to light. It must be noted that although many terms are used freely in research literature, such as circadian lighting, human centric lighting and dynamic lighting, they denote a similar research focus on light and the human condition.

Bias in literature review

A concern within the literature review is the possible existence of publication bias, which in essence is the non-publication of studies based on the statistical insignificance of their results (Rothstein et al., 2005). There are however a number of other factors that have been identified which may contribute to publication bias including ´language bias (selective inclusion of studies published in English); availability bias (selective inclusion of studies that are easily accessible to the researcher); cost bias (selective inclusion of studies that are available free or at low cost); familiarity bias (selective inclusion of studies only from one's own discipline, and outcome bias (selective reporting by the author of a primary study of some outcomes but not others, depending on the direction and statistical significance of the results)´ (Rothstein et al., 2005).

The effects of publication bias are that it can create a skewed understanding of the overall significance or weight of certain results in the absence of other completed studies (Rothstein et al., 2005). Although publication bias is an issue that can only be effectively addressed by the scientific community as a whole, it is a relevant bias that should be mentioned to mark the limitations of the study.

Structured / Semi-structured Interviews

Structured interviews: questionnaire

Although only briefly touched upon, the methodological basis for the end-user assessment example is shortly addressed. The assessment is based on forced choice closed ended questions, presented as a questionnaire. This approach is well suited to gather data from a large sample of respondents, in addition to which statistical analysis can be applied. The nature of the questions is directly related to the dynamic qualities of new lighting technology, and their impact on the human condition. This is further addressed in the chapter on end-user assessment.

Semi-structured interviews

The basis for understanding current implementation processes call for a deeper understanding of the management hierarchy and the decision making process of the professionals involved. An important aspect of the implementation process is the interaction that takes place between the professionals involved within the process itself. These relate to decisions and attitudes that often shape the implementation structure, and can be decidedly subjective in nature as well as context dependent. Interviews are well suited to put decisions into their contextual setting, and thus allow for a more thorough understanding of the implementation process.

Secondly, as a technique, the semi-structured interview allows the professionals more leeway in their answers, as well as more control over the direction of the interview topics. As such any new or unexpected angle can be easily introduced to the database, preventing bias in the choice of topic on the part of the researcher.

In general two types of professionals were interviewed: those involved in the case studies, and those not involved. The focus on both types served to counter any possible bias that may arise from respondents commenting on their own projects. The interviews will center on the position of the professional within the greater implementation structure, and their experience of the process.

Bias in qualitative research

Qualitative methodology of any kind, and in particular open interviews, are prone to bias due to the contextual and subjective nature of human emotional responses. This bias can come from both the researcher as well as the test subjects, and may include bias in the selection of the respondents, bias with respects to the topic of the interview as well as how this topic is dealt with, bias as a result of the order in which the questions are asked, bias as a result of the time and place of the interview, interactional bias e.g. the impact of gender and ethnicity on the researcher and the respondent during the interview, bias as a result of expectation when respondents try and please the interviewer with their response etc. (Norris, 1997)

Although these biases cannot ultimately be avoided for either qualitative or quantitative research (Rajendran, 2001), there are several methodological techniques that have been developed to counter this as much as possible within qualitative research.

The list of available techniques to account for these criteria are extensive, and are based on the expertise and experience of leading scholars on qualitative research such as Bryman, Shenton, Teague, Huberman etc. The following are the methodological techniques that have been selected to minimize the occurrence of bias in the qualitative part of the study, i.e. the interviews.

- Randomization in choosing the respondents.
- Background of the subjects must be certified as professionals capable of understanding the questions at hand.
- Focused line of questioning. This ensures that the issue is continuously

addressed, and that the interview does not stray off topic.

- Iterative questioning. By returning to a specific topic and question in a different way throughout the interview, the consistency and reliability of the response can be checked.
- Thick descriptions (Geertz, 1973) is a rich and detailed account of a culture under observation, which in this case is argued as the culture of professionals involved in the implementation of new lighting technology. This type of description makes it possible to compile a database with sufficient information to assess whether or not the results or conclusions of the research in question can be generalized (Bryman, 2012; Lincoln & Guba, 1985).
- Keeping a reflective diary. The interpretation of the answers from the respondents is based on the interpretation of the researcher. To assure that the line of questioning is not distorted throughout the process, or to assure that the reasons behind any change in focus of the interview are understood, the researcher must keep a separate account of the process.
- Audit trail, which is an account of the decisions and procedures of the research. This allows for a peer review of the process. (Shenton, 2002).

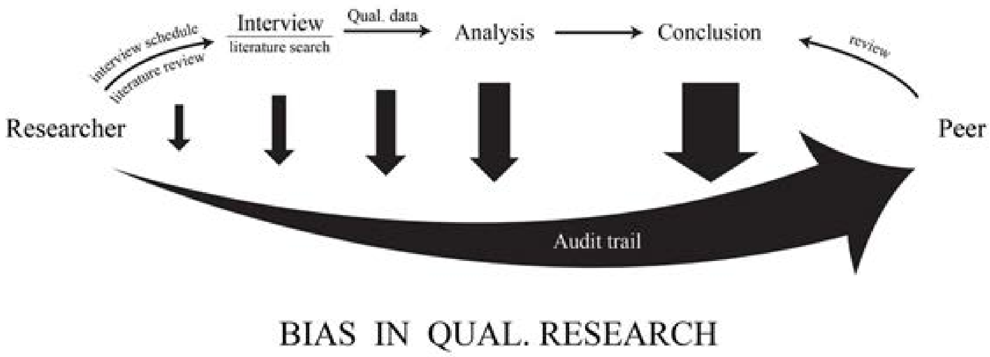


Figure 4.
Qualitative research counters bias with the use of the audit trail, which describes the proceedings and reasons behind questions, decisions and conclusions. The audit trail allows for peer review and critical analysis.

Thematic Coding

A key aspect of the Parallel Databases variant of the Mixed Method approach, as well as the application of Normalization Process Theory, is grouping the relevant qualitative data into themes. As such, the results from the qualitative responses were organized and analyzed by coding the data sets into recurrent descriptive themes, i.e. data reduction.

Bias in thematic coding

As with the case of all qualitative analysis, thematic coding is based on the interpretation of the researcher. This aspect makes it vulnerable to the bias that typically may stem from qualitative data in general. To counter this bias the process of coding must be explained in a reflexive journal, similar to the case of conducting interviews, to make it accessible for review.

Quantitative data

Lighting concept of case studies

The analysis of the lighting concept of the selected case studies was based on a number of factors which commonly impact the lighting situation of any space. Broadly speaking this involved geographical assessment with respects to the position of the sun, as well as other natural elements or structures in the surrounding area of the building, a sun-path analysis accounting for both the time of day as well as the seasons, the layout and design of the building itself, window type and size of the building, location of the work spaces, illuminance and CCT values of the luminaires, as well as the program sequence these follow, systems that control the intake of natural light, and finally human factors such as gender, age and eyesight which control human photoreception.

Literature review light and the human condition

Introduction

The promotion of new lighting technology for well-being and health is broadly based on research into light and the human condition. Although some aspects such as visual acuity, have been known for some time, other aspects, such as the effects of light on the circadian cycle, are relatively new. At the same time, the lighting industry has already started implementing lighting systems based on a few results. Research however still produces a variety of results which can be at odds with one another, especially in the field of light and the circadian rhythm. This raises the question of what research these new lighting technologies are based on, or how sound this research is. The following is a summary of the research conducted so far on light and the human condition. The list is not exhaustive, and is merely indicative of the general research foci so far, and their results. It has excluded research into the effects of ultra violet and infrared light on health, and the use of light as part of tissue regeneration and cancer treatment.

Research into the impact of light on our psychology and physiology have come from a variety of research disciplines including psychology, chronobiology, neurobiology, somnology, ophthalmology etc. Although there are some exceptions, the focus of research has been on topics which for the purpose of this thesis has been placed under the headings *Emotional response*, which cover such aspects as light being pleasant or unpleasant, *Gender*, *Age*, which addresses the medical aspect of sight, *Task performance*, which deals with performance speed, alertness, visual acuity etc., and *Circadian rhythm,* which studies for example sleep-wake cycles, seasonal affective disorder etc. In many studies the focus of research may be on a combination of these fields, where for instance a study on school performance for example may include the aspect of mood.

The results of many of these studies interact with topics studied in other fields such as somnology and psychology, and which feed into recommendations made by ministries and councils. Both of these aspects are touched on in the sub-chapter *Recommendations made by ministries and councils* and *Tangential research*.

Emotional response

Earlier trials involving subjective responses to light were conducted by among others Kruithof who attempted to show the relationship between illuminance, CCT and human cognitive response (Kruithof, 1941). Known as the Kruithof curve, this graph was an attempt to map the regions of illuminance levels and CCT that were comfortable and uncomfortable to human perception. Several trials have been conducted on this topic since Kruithof, with varying results. A review by Fotios of surveys conducted on the Kruithof curve concluded that it lacks scientific basis. Instead an alternative graph has been proposed in which illuminance, and not CCT, is the determinant factor. As such most research indicates that for CCT values between 2500 K and 6500 K, illuminance levels under 300 lx may be considered uncomfortable, whereas those above 500 lx are considered to be pleasant (Fotios, 2017).

Additionally, Schlangen et al. have demonstrated that for both 30 and 60 year olds, task lighting with an illuminance of 300 lx was found to be uncomfortably dim, whereas 2700 lx was experienced as too bright (Schlangen et al., 2014).

The relationship between light and cognitive response has also been studied by behavioural- and environmental psychologists. The results of these studies have shown a link between CCT and illuminance and a variety of cognitive responses such as alertness, calm and concentration. In addition, some of these studies have shown that these responses may be affected by among others age and gender.

Gender

In a study on indoor lighting and mood, Knez showed that at an illuminance of 300 lx, warm light was considered least negative for women with respects to mood, whereas for men this was found to be with cold light (Knez 1995). Similarly, Belcher and Kluczny found that compared to 215 lx, positive mood for women would decrease under 2175 lx, whereas men showed an opposite trend (McCloughlan et al., 199).

Other studies on the other hand have shown no significant differences based on gender (Baron, Rea and Daniela, 1992). These results were equally concluded from a cross cultural study by Küller et al., which found no significant difference between men and women with respects to mood and illuminance settings (Küller et al., 2006).

Age

Research on age, in particular those from ophthalmology, have demonstrated the effects of age on vision, which are in general detrimental. Due to increased yellow colouring of the lens, pupillary miosis (Turner and Mainster, 2008), macular degeneration and reduced efficiency of the transduction pathways (Jeffrey et al., 2012), the overall capacity to receive and process light reduces in a progressive fashion to approximately 80% by the age of 85 (Turner and Mainster, 2008).

In a trial on reading performance and age, Eldred found that over half of the participants suffering from age related degeneration, in this case maculopathy, preferred illuminance levels from 5920 lx to 7534 lx (Eldred, 1992). For elder people who do not suffer from such advanced age related impairments, illuminance levels are markedly lower. Yamagishi et al. showed that visual performance was optimal for elderly under lighting conditions with an illuminance of 470 lx and a CCT of more than 5000 K (Yamagishi et al., 2008). Figueiro in turn proposes a minimum of 300 lx as ambient illuminance, and at least 1000 lx for task lighting for elderly people (Figueiro, 2008).

Task performance

In a study on workers, Viola et al. showed that with an average illuminance of 380 to 400 lx, mood, sleep quality and performance were reported more optimal with a CCT of 17000 K than with a CCT of 4000 K (Viola et al., 2008). In a similar vein, Govén et al. found that alertness among workers increased as CCT levels moved upward from 3000K, and that 8000-17000 K light at 500 lx was optimal for well-being (Góven et al., 2007). Hawes et al. showed in a study on military personnel, that colour recognition, and verbal- and spatial cognition tasks were performed faster as CCT levels increased from 3000 to 6000 K (Hawes et al., 2012).

Research on school performance equally indicated these tendencies. Choi and Suk showed in a study on pupils that with illuminance levels between 500lx and 600 lx, task performance was optimal at 6500 K, whereas rest activities were optimal at 3500 K (Choi & Suk, 2016).

Studies by both Knez and Küller on the other hand, indicated that problem solving tasks and long term memory were optimum at either 300 lx of warm light, or 1500 lx of cold light (Knez, 1995), and that although mood was negatively affected by either too high or too low illuminance levels, these values were culture dependent, and could not be fixed (Küller et al., 2006). In other words, workers in one continent found illuminance levels well under 500 lx quite satisfactory, whereas their counterparts in another continent would not (Küller et al., 2006).

The circadian rhythm

Many of the aforementioned results have equally been explained in neurological research, particularly after the discovery of the third photoreceptor in the mammalian eye in 2002. In all, research has identified the biochemical link between sunlight and the human biologic clock i.e. the circadian rhythm. Its applications thus far have been therapeutic, whereby light therapy is used to target specific circadian related disorders such as disrupted sleep patterns, seasonal affective disorder, depressions, and cognitive- and behavioural disorders. These conditions may not only be the result of medical or psychological problems, but may equally be the result of work environment such as night shifts in hospitals, or the complete absence of natural light in submarine deployments, or mining work.

Research of this type typically center around the intrinsically photosensitive retinal ganglion cells (ipRGC); the spectral frequency of their peak sensitivity, the latter of which has been measured at 460 to 480 nm (blue); and the production of melatonin by the suprachiasmatic nucleus (SCN). By regulating the stimulation of the ipRGCs with the blue bandwidth of light, it is possible to affect the production of melatonin which, when present, induces among others calm and sleep, and when absent increases alertness (Hanford & Figueiro, 2013, Lucas et al. 2013). In general, trials involving this try to adjust and entrain the diurnal sleep/wake cycle with the intervention of blue rich white light, or blue light, and its opposite of red or ambient light. These interventions vary in length depending on the aim of the treatment and not in the least on the logical reasoning behind it.

Short term interventions

This research is typically focused on delayed sleep phase disorder (DSPD), advanced sleep phase disorder (ASPD), seasonal affective disorder (SAD), and Jet-lag (Morgenthaler et al., 2007), and involves short term interventions of blue rich light at set points in the day depending on the condition. In research on DSPD, Rosenthal et al. showed improved sleeping patterns by a combination of light exposure and light attenuation at two points in the day. The regimen involved a morning exposure of two hours to full spectrum light with an illuminance of 2500 lx, followed by a late afternoon attenuation of light by the use of dark goggles (Rosenthal et al., 1990). Similar results were shown by Lack et al. who exposed DSPD patients to a two hour morning cycle of 470 nm light (blue) with an illuminance of 470 lx (Lack et al., 2005).

With respects to seasonal affective disorder, a review by Terman et al. concluded that a therapy involving a daily dose of two hour exposure to light, with an illuminance of 2500 lx, was a successful treatment of SAD (Terman et al., 1989).

The efficacy of light involving trials to treat ASPD on the other hand remains inconclusive (Morgenthaler et al., 2007).

Continuous intervention

Other chronobiological research has focused on continued intervention throughout the day. Again, although this is not always the case, the focus is mainly on people with disruptions to their circadian cycle, the latter of which mostly relates to the older segments of the population, as well as those employed in night shift work.

Research by Figueiro et al. indicates that high circadian stimulation should have an illumination of at least 400 lx at the cornea and a CCT of 6500 K (blue rich light), and suggests this for daytime use. Evening hours are recommended to have an illuminance of under 100 lx at the cornea and a maximum colour temperature of 2700K (Figueiro, 2008). This intervention was equally proposed as a scheme for older healthy adults. Similarly, in a study on patients with Alzheimer´s disease and related dementia (ADRD), Sust et al. demonstrated that a scheme with a 1200 lx and 6500 K exposure during the daytime, and an 800 lx and 3000 K exposure after three o'clock in the afternoon managed to adjust and improve sleep disruptions and improve activity among the patients (Sust et al. 2012). Further, Ellis et al. proposed a lighting schedule (fig. 1) for older people and patients suffering from ADRD which would peak at noon with a CCT of around 6500 K and an illuminance of around 2500 lx (Ellis et al., 2013).

Shift worker disorder

A survey by Yoon et al. into night shift workers indicated that an exposure to 4000 lx to 6000 lx light between 1 and 4 AM, combined with light attenuation in the morning when the night shift workers traveled home, improved nocturnal alertness and daytime sleep (Yoon et al.,2002). Eastman et al. equally showed that continuous night time exposure to 5000 lx, followed by light attenuation resulted in better circadian adaptation (Eastman et al., 1994). As opposed to these continuous exposures, some research using intermittent exposure produced similar results. Crowley et al. showed that exposure to 5000 lx for 20 minutes per hour during night-shift in combination with light attenuation outside of work increased entrainment (Crowley et al., 2003). Boivin and James have equally shown that intermittent exposure throughout the shift to 3243 lx promoted circadian alignment (Boivin and James, 2002). Finally, Lowden showed that an exposure to 2500 lx for 20 minutes during a single break at night improved daytime sleep (Lowden, 2004).

Daytime work

Within a working environment for daytime workers, Van den Beld has proposed a curve (fig 5) which starts at 800 lx and 6000 K at 8.00 in the morning, which gradually decreases to 500 lx and 3000 K by 12.00. This is repeated starting with around 750 lx at 12.30 which again gradually decreases to 500 lx and 3000 K at 16.00. The aim is to synchronize the lighting with periods of alertness and relaxation, corresponding to melatonin and cortisol levels. (Van den Beld, 2002).

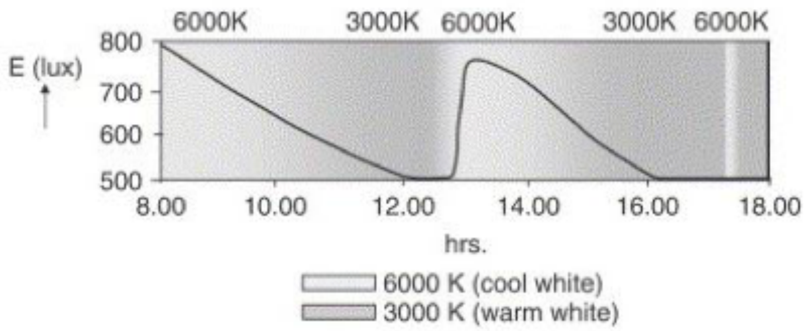


Figure 5.

Attempts have been undertaken by the commercial lighting sector to incorporate the findings into dynamic lighting schedules for both day time work, such as a model by Ellis et al. (Ellis et al., 2013) (fig. 6), night shift work, and total packages including both (fig.7).

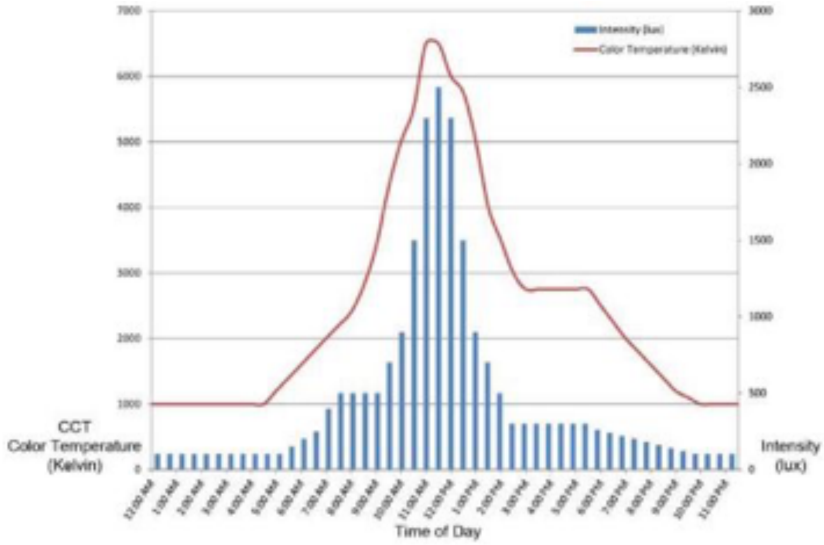


Figure 6.

In a study by Zumtobel´s Research Centre for User-centred Technologies and the Fachhochschule Vorarlberg, Dornbirn, the following 24 hour lighting schedule was proposed for the control centre of a police station (fig.7). In this there is a night time setting of a constant CCT of 3000K and a constant illuminance of just under 160 lx from 23:00 to 06:00, followed by a sharp increase to 6000 K and just over 600 lx between 08:00 and 09:00, a gradual decrease until 18:00 to 4000 K and 350 lx, followed again by a sharp increase until 21:00 to 5000 K and just over 400 lx, and finally a decrease until 23:00 to night-time levels again. The report makes direct references to German industrial norms study on the biological effects of lighting. (https://www.zumtobel.com/PDB/teaser/DE/Project_report_Polizeileitzentrale.pdf).

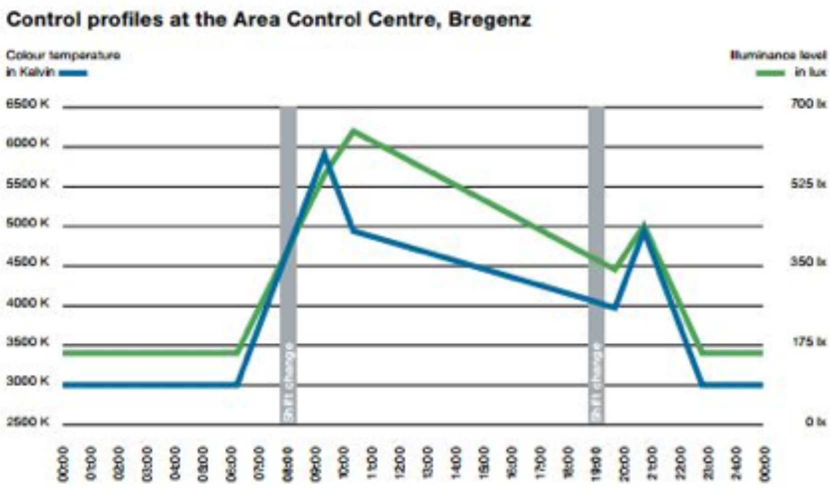


Figure 7.

Recommendations by ministries and councils

There are a host of recommendations that have been published especially for older people, yet these are extensions of existing building codes and as such focus predominately on visual acuity and task performance. To start with, the European building codes have incorporated CCT levels, besides the already existing illuminance levels, for a variety of spaces which require high precision manufacture or operations, or colour recognition tasks. Examples of these include a minimum CCT of 5000 K, and a minimum illuminance of 1500 lx for colour inspection of multi-colour prints, a minimum of 5000 K and 750 lx for painting classes in art schools etc.(DS/EN 12464 2011). Despite this, requirements for CCT are still not present for office spaces in the European and Danish building codes. This indicates a continued focus of the building codes on visual acuity in office environments. The requirements stipulate as such an illuminance of 750 lx for work involving technical drawings, and 500 lx for typing and writing (DS/EN 12464 2011).

The German institute for norms (DIN/Deutsche Institut für Normung, 2013) however have produced a technical report on the photo-biological effects on humans, and have put forward some very basic recommendations for the building industry on lighting and health. These recommendations are careful, and do not go beyond mentioning the importance and effects of the blue spectrum of white light on alertness, and waking up in the morning etc. (DIN SPEC 67600:2013 – 04)

Although none of the abovementioned research on light and well-being are present in requirements for office lighting, some guidelines relating to geriatric care centers, which typically find themselves at the cross roads of requirements and recommendations for medical centers, private lighting, and the treatment of ADRD, have put forward recommended illuminance levels and CCT values. An example of this is a report by the Danish ministry of social affairs for geriatric care centers with in-house care facilities. In addition to recommended illuminance levels of between 500 lx and 750 lx for tasks such as reading and writing, they equally suggest the minimum requirement for CCT of 5000 K for examination situations, which can nonetheless occur in the private spaces of the elderly under care. In addition, the report devotes sections to the importance of CCT and behaviour, CCT and the circadian rhythm, and which combinations of illuminance and CCT are considered comfortable for older people (Socialministeriet, 2004).

Tangential research

In a recent departure from the focus on the ipRGC´s peak sensitivity towards blue light, Walmsley et al., showed in a study on mice that entrainment may occur due to the changing spectral power distribution (SPD) with a focus on the ratio between the blue and yellow bandwidth (Walmsley et al., 2015).

An important aspect of research on the circadian rhythm is the study of the sleep-wake cycle. As an effect of the combination of the circadian rhythm and sleep homeostasis, sleep cycles for humans have been argued to be biphasic, although current society is interrupting this with technology (Ekirch, 2001).

Finally, besides natural light, the parameter of view has a sizable effect on human responses. The positive impact of windows and natural views on well-being and health have been indicated by among others Ulrich (1984), Kaplan & Kaplan (1989), Ulrich et al. (1991), Kaplan (1992), Rohde (1994), Tennessen & Cimprich (1995), Lewis (1996), Shibata & Suzuki (2004), Bringslimark et al. (2007), Kweon et al. (2008), Valtchanov & Ellard (2015) etc. These results are reflected in the results by the earlier mentioned studies by Küller et al. which showed that a positive mood was determined more by proximity to a window than by illuminance.

Conclusion

The literature review makes some points clear about the research so far. In all there is a general consensus that the spectral range of 460 to 480 nm has an effect on the circadian cycle, and that this, in combination with certain illuminance levels, make it possible to influence sleep cycles, alertness and relaxation depending on the saturation levels of blue light. It can be stated in general that light with illuminance levels under or around 300 lx, and CCT levels under or around 3000 K (warm light) promote relaxation, calm and rest, whereas light with illuminance levels above or around 400 lx and CCT levels above or around 4000 K (cold light) promote alertness and concentration.

In addition, the notion of pleasant and unpleasant light predominately relate to light above 500 lx and below 300 lx respectively, and is irrespective of CCT levels provided they fall between 2500K and 6500 K.

Preferred Illuminance levels on the other hand may be culture- and gender specific, or related to the presence and proximity to windows and views. Research on gender indicates that men and women may have opposite preferences with respects to illuminance levels and CCT values. Equally, the psychological impact of windows and view may affect mood in a positive way, and must be taken into account in the evaluation of light conditions and emotional response.

Further, increases in age imply an overall decrease in the ability to receive and process light by an average rate of 10% for each decade. Older people need an illuminance of around 500 lx – 1000 lx to perform tasks optimally, and may require up to 7500 lx depending on the age-related eye condition.

Finally, there exist several proposals for dynamic lighting which depend on whether it is used for daytime work, night shift work or for therapeutic purposes. Proposals for office environments alone may range from a fairly flat CCT/illuminance curve with one peak at noon, to a curve involving two peaks. These proposals again may be different for night shift work, which may include low illuminance and CCT levels to a sequence involving high illuminance and CCT levels. For age and age-related conditions such as Alzheimer´s disease, the daytime sequence usually implies much higher CCT values and illuminance levels, although the change to overall lower levels may maybe abrupt and not along a curve .

Discussion

Four points can be made with respects to the research in general. Firstly, the field of biomedical and chronobiological research remain fairly separated as a discipline from that of research into psychological and cognitive responses. Because most research on office lighting has been conducted as part of psychological and cognitive research, they thus remain fairly unattached from neurological research trials.

This separation is equally clear from the second point, and involves the research focus of these fields. With one or two exceptions, biomedical and chronobiological research is typically aimed at developing therapies for conditions related to circadian rhythmic disruptions such as Alzheimer´s disease, severe sleeping disorders, Delayed Sleep Phase Disorder and Advanced Sleep Phase Disorder etc. Psychological and cognitive research on the other hand has mainly focused on parameters involved in task-performance such as concentration, alertness and fatigue, and how these can be used in daytime and night time working conditions.

Thirdly, although some trials result in very specific illuminance and CCT levels, the consistency of results can still vary by several hundred units. In other words, illuminance levels for older office workers may be stated to be between 500 to 1000 lx for reading. Proposed CCT levels, in turn, for night shift work can vary between 2500 lx to 5000 lx.

Fourthly, there is a lack of clear consensus on the sequence of illuminance and CCT when implementing more complex lighting designs for work and health. Both night shift and day shift work have a variety of proposed lighting schedules with different time dependent CCT and illuminance values. Although it is clear that light for health and well-being implies a dynamic system, it remains a matter of debate how the spectral power distribution of its light should change throughout the day, or throughout the seasons.

Finally, the human response to light, whether for visual acuity, or for well-being and a healthy circadian rhythm, depend on a number of factors such as age, gender, mood, chronotype, job, and what one is generally used to. These make it fairly challenging to provide a neat set of proposals. In addition, the design of a lighting schedule is dependent on the ultimate goal of the light in question, such as work productivity, human well-being, therapy etc. These goals may clash at the fundamental level. For example, a dynamic system focused on work-productivity may choose ambient light settings not for the goal of rest, but for the goal of reducing the tension in atmosphere during meetings and interviews, the latter of which has little to do with our sleep-wake cycle, and thus well-being. This complexity is reflected in research which at points can lead to contradictions, and which with respects to dynamic office lighting ultimately remain inconclusive as to precise levels of CCT and illuminance, and timing.

The variation of not only the test foci, but equally the results, and the absence of consensus on some issues, arguably make it challenging for the lighting industry to orientate themselves. This is equally reflected in the analysis of the interviews with lighting professionals, and current implementation processes, where research was hardly said to be consulted.

Interviews with lighting professionals

Introduction

Thirteen interviews were conducted with lighting professionals and others involved in the implementation process, to get an understanding of how current implementation processes look like, with a focus on their efficiency. A distinction was made between those directly related to the selected case studies, and those who were not (tab.1, tab. 2). The interviews were conducted in an informal atmosphere and recorded, although some references to names or companies have been deleted from the interview transcriptions, and thus remain anonymous. The average duration of the interview was an hour, and the location and time ranged from office hours at companies, to evening hours at cafés.

Respondents and selection

There were a number of biases that needed to be accounted for with respects to the choice of the respondents. The following does not relate to the epistemological bias involved in the method of interviewing in and of itself, which has already been addressed in the methodology section.

Firstly, a healthy practice in avoiding bias in interviews is random selection of the respondents. In this case the lighting professionals were selected from a random selection of companies, with the exception of the two case studies.

Secondly, the term lighting professionals may imply anybody who has become professionally employed to implement lighting systems. Because the education of lighting design as a discipline is fairly new in Denmark, most professionals involved in lighting still come from a variety of backgrounds. These may range from industrial designer, electrical engineer to architect. This invariably results in a possible bias where the back ground of the lighting professional may determine the direction or choice of the themes that are brought up during the interview. The selection procedure tried to keep a diverse range of backgrounds in choosing the respondents.

A final bias relates to the experience of the respondents. The field of lighting design may relate to a wide variety of applications, e.g. landscaping, interior offices, psychiatric wards etc. To avoid bias stemming from the area of experience of the lighting professionals that were interviewed, the respondents were chosen to represent overall a wide variety of lighting applications.

Respondent	Background	Experience
1	Architect	Exterior lighting
2	Lighting designer	Exterior lighting
3	Industrial designer	Exterior lighting
4	Electrical engineer	Interior lighting
5	Architect	Interior lighting
6	Architect	Interior and exterior lighting
7	Industrial designer	Interior lighting

Table 1. randomization of respondents not related to case studies

Respondent	Background	Experience
8	Architect	Interior lighting
9	Sound eng/stage lighting	Interior and exterior lighting
10	Programmer	Interior and exterior lighting
11	Teknisk chef	Interior lighting
12	Manager chef	Interior lighting
13	Teknisk chef	Interior lighting

Table 2. respondents for case studies

Questions, interview schedule

The choice of questions was determined by two elements. Firstly it was based on preliminary discussions with experienced lighting professionals. These open discussions gave an insight into the various aspects that come to play when implementing new lighting technology. Secondly, the focus of the topics was guided by implementation science, or more precisely Normalization Process Theory. The framework of this theory allows for implementation processes to be analyzed by identifying its inhibiting and facilitating factors. Normalization Process Theory is based on four aspects: coherence, cognitive participation, collective action and reflexive monitoring. These aspects are interrelated and affect one another, which in turn affect the entire implementation process (fig 8).

Coherence refers to the general understanding by all participants of the new technology that is being implemented, in this case new lighting technology. This must be understood as whether or not participants see the sense in implementing the new technology. Cognitive participation refers to the commitment of the participants in the implementation process. This relates to the initial decision making process of the participants, and can be said to be the first practical step in the implementation process itself. Collective action refers to the work performed by the professionals involved. This is not meant in the sense of what is expected to be performed, but what is actually effectively done in the implementation process. Finally, reflexive monitoring refers to the appraisal of the new technology in question. This relates to how the new technology is experienced, or in effect, whether or not it has the intended effect.

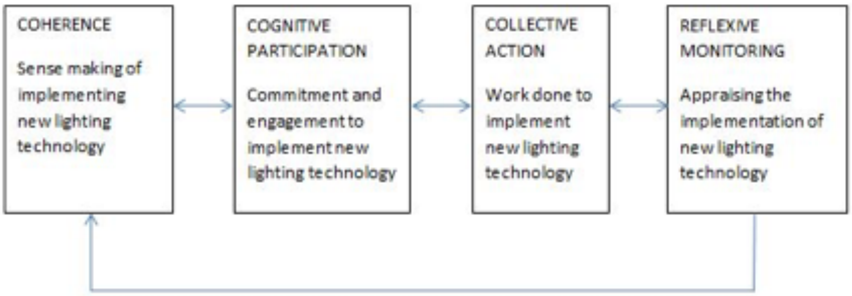


Figure 8.
NPT model used as basic categorization of themes from the semi-structured interviews.

By identifying the topics both relevant to Normalization Process Theory and to the lighting professionals from the preliminary orientating discussions, the following seven topics were addressed in the interview:

- Hierarchy and relevant team members in the implementation process,
- responsibilities, and how this is determined,
- communication, forms of communication and their effects on the process,
- decision making process, what these are based on and how things are decided,
- transforming a design to a lighting program,
- implementation efficiency: open question as to what works well, and what works less well in current implementation processes,
- knowledge on new lighting technology, and what this is based on.

Although the topics were set in the interview schedule, the respondents were allowed leeway to address specific aspects they deemed important. In addition, it was decided that any new aspects that derived from the interviews would be added to the interview schedule, and asked about in the following interview. This implied that a very short follow up interview would be conducted with respondents who had already been interviewed to ask to comment on the new aspect in question.

The responses from the preliminary orientating discussions however were so thorough and extensive that none of the subsequent interviews revealed any new aspects for any of the topics. Instead, it was more common during an interview that only certain aspects sprung to mind during the interview, whereas others did not. In these cases, and in line with the set-up of the interviews, respondents were asked to comment on other aspects which they had not mentioned during the interview. Most respondents on the other hand viewed all themes equally important in retrospect, even when they had not brought it up themselves.

The respondents from the case studies were asked to comment both on the topics with respects to their general experience, as well as with a focus on the specific project that had been selected as a case study.

Thematic analysis

The approach of adding aspects to the interviews as the sessions progressed affects the analysis of the responses in two ways. Firstly, the overall themes and aspects from the responses cannot be weighted with respects to one another as each respondent will have answered all of the questions and touched on all of the topics and aspects. It is thus fairly impossible to say which aspects and topics were seen as most important. Secondly, patterns of consistency in the responses can only relate to how similar respondents viewed certain aspects or themes, and not how often these were mentioned.

The raw data, i.e. responses from the interviews, was analyzed by structuring them along recurrent themes. To this end the interview responses were summarized and condensed into short descriptions. The overall responses were for the most part uniform despite the random nature of the choice of respondents, their backgrounds and their field of experience.

Salient themes

The following themes and aspects emerged from the interviews, and have been summarized and placed under their topic heading:

Hierarchy and relevant team members in the implementation process,

> There are two types of projects: large scale commercial projects, where lighting is merely one part of the project, and smaller specialized projects, where lighting is the main part. In large scale commercial projects the project leader is usually an architect. In these projects the lighting professionals are usually headed by an engineer under which the lighting designer works. For smaller projects, where lighting is the main part of the project, the project leader usually is the lighting professional.

In these smaller cases there is no real hierarchy under the project leader in the strictest sense. Team members usually include an electrical engineer, a lighting programmer, and sometimes a visualizer, who work on an equal footing.

Responsibilities, and how this is determined,

Responsibility of tasks in large commercial development and refurbishment projects is decided at meetings and put on paper. In smaller projects this is assumed, and based on routine and experience. In these cases the exchange of e-mails functions as the de-facto agreement, and as a point of reference during disputes.

Communication, forms of communication and their effects on the process,

- There is no post occupancy survey due to budget constraints. This is sometimes solved by the lighting designer, if deemed necessary, by squeezing this in the budget for services and maintenance, or by redefining it not as post occupancy but as maintenance.

- Communication in large projects can sometimes be a problem in large commercial projects. Sometimes the lighting design team is not invited to attend meetings as they are not considered relevant for the meeting in question. In these cases changes are made unilaterally, which may still affect the lighting design. Information in these cases is obtained by reading the minutes of the meeting, but this is rarely sufficient information. Proper information must mostly be sought after by the lighting designer.

- Close proximity to the clients usually results in the best results for the project. By being able to explain directly all the aspects of the lighting technology and their cost, problems can be avoided during the commissioning phase. In large projects this is rarely possible or realistic.

- The client is preferred to be involved at every step to avoid misunderstandings and disappointments.

Decision making process, what these are based on and how things are decided,

- In large scale commercial projects meetings are held only with parties thought to be relevant for the meeting in question. If the lighting design team is not present, decisions are taken without considerations from the lighting design team. These unilateral decisions may then unwittingly affect the lighting design, which can cause problems during the implementation process.

- In some cases the client changes the design without informing the lighting designer, which can cause problems during the implementation process.

Transforming a design to a lighting program,

- Lighting design firms usually have their own in-house lighting programmer. Larger engineering or architectural firms usually hire a lighting programming firm, or ask the manufacturer of the products to recommend or provide the lighting programmer.
- The programming is seen by some as not a problematic issue, especially by those who have an in-house programmer, or are familiar with the programming company. Others find it sometimes challenging.
- If the manufacturer is not asked to provide the programmer, the actual programming is done by either providing a lighting script, which mentions the illuminance and colour temperature along with the time frame, or by having the lighting designer and the programmer work together on the spot to determine the lighting scenario.

Knowledge on new lighting technology, and what this is based on.

- Knowledge is gained from the network, and interaction with other professionals in different fields, and sometimes through seminars. Academic research is very rarely consulted.
- Budget constraints, which affect the time table, are the determinant factor which prevent professionals from seeking in-depth and critical knowledge.

Implementation efficiency: open question as to what works well, and what works less well in current implementation processes:

- Complexity and potential of new lighting technology is under-estimated, except in specialized projects such as museums and care centers. There needs to be more awareness of this complexity by project leaders, so that they can inform the clients.
- Budget and time is under-estimated for new lighting technology, and needs to increase. This is much less the case for smaller specialized projects.
- The role of the lighting professional is under-valued and they need to be recognized as an expert in their own right.
- Architects tend to assign themselves tasks of the lighting professional, adding to design problems and budget problems. Their needs to be much more awareness of the potential and value of the lighting professional.

- Manufacturers are assumed, and often mistakenly assumed, to be the same as lighting professionals, or automatically assumed to be able to perform the same job as the lighting professional, only at a cheaper rate. There needs to be more understanding between the difference between a manufacturer, who sells a product, and a lighting professional, who provides consultancy and design.
- The contribution of the lighting professional is under-valued. There needs to be given more credit to lighting professional if the lighting design was specifically prominent in the project. Most respondents viewed this as a serious problem.
- The specifications for lighting in the architectural brief are usually not precise enough, and needs to be done better. This is because of budget constraints which affect working hours for the project. In smaller projects and the specialized areas of museums, healthcare wards and hospitals this is much less the case.
- In large commercial projects there needs to be more reciprocal appreciation and respect between project leader (architect) and lighting professional.
- Proximity to the client and between professionals produces the best results.
- In large scale projects responsibilities and tasks are best decided at meetings and put on paper. In smaller projects these are best decided informally by phone or e-mail, and based on routine.
- There needs to be a budget for post occupancy surveys, so that the industry can develop best practices and understand what works and what does not.
- Post occupancy is usually seen as an additional cost. By decreasing the budget slightly for other areas this can be made available.

Analysis of implementation

The results from the thematic coding have been summarized in fig 9. The respondents indicated the existence of two types of lighting projects, i.e. two types of implementation processes: large scale commercial projects, and smaller specialized lighting projects.

The results from the interviews, i.e. the thematic coding, have been applied to the framework of Normalization Process Theory. In other words, the responses from the interviews have been placed in their responding NPT component (coherence, cognitive participation, collective action and reflexive monitoring). As the relationship between these four aspects is known, the scheme can indicate which themes and aspects from the interviews may be considered important, and what effect they have. This may be seen as a form of weighting, and thus the importance of a certain theme or aspect can be established.

Two types of scheme have been used to understand the implementation process. The first scheme is a general overview of the NPT components, their relationship with one another, and the corresponding topics and responses from the interviews (fig.10, fig.12). The second scheme (fig.11, fig.13) highlights the determinants of the implementation process, i.e. the inhibiting and facilitating factors in the implementation processes, and how they relate to one another. This is a slightly modified version of the standard Normalization Process Theory scheme. The following is the analysis of the implementation procedure for each of these types of lighting projects.

SALIENT THEMES OF INTERVIEW

Salient themes in implementation process of new lighting technology	Large commercial building projects	Smaller specialized lighting projects
Is potential of new lighting technology clear?	Not by project leader	Yes, generally
Is complexity of new lighting technology clear?	Not by project leader	Yes, generally
Is new lighting technology valued?	Not by project leader	Yes
Is the potential of lighting professionals clear?	Not by project leader	Yes
Are lighting professionals valued?	Generally under-valued by project leader/client	Yes
Is there willingness to invest time and money for new lighting technology?	No	Yes
Is there adequate budget for the new lighting technology?	No, under-estimated by project leader/client	Yes, generally
Is the lighting professional involved early in the project?	No	Yes
Is the separation of tasks/ responsibilities between lighting professional and architect clear?	Not usually	Lighting designer is the project leader
Are responsibilities clear in the implementation process between professionals under the project leader?	Yes	Yes
Is research for new lighting technology sought after?	No	Rarely
Is information for new lighting technology sought after?	Yes, by lighting designer	Yes
Is the architectural brief adequately detailed?	Not usually	Yes, generally
Is communication adequate in the implementation process?	Sometimes problematic	Yes
Is communication between the lighting professional and the lighting programmer adequate?	In varying degrees	Yes, mostly
Is end-user feedback sought in the implementation process?	No	Sometimes
Is post occupancy survey conducted after completion?	No	No
Are results satisfying for professionals?	Yes, generally	Yes, generally
Are results satisfying for end-users?	Assumed yes	Yes
Is there acknowledgement of the lighting professional after project completion?	No normally	Yes, usually

Figure 9. Salient themes are different depending on two project types: large scale commercial projects and smaller specialized lighting projects.

LARGE SCALE PROJECTS, THEMATIC ANALYSIS OF RESPONSES

NPT COMPONENT	RELEVANT INTERVIEW QUESTION	EVALUATION RESPONSES
COHERENCE Sense making of implementing new lighting technology	Is the potential of new lighting technology understood?	By the Client / Project leader: no By the Lighting professional: yes
	Is the complexity of new lighting technology appreciated?	By the Client / Project leader: no By the Lighting professional: yes
	Is new lighting technology valued?	By the Client: no By the Project leader: sometimes By the Lighting professional: yes
	Is the lighting professional valued?	By the Client: no By the Project leader: generally no
COGNITIVE PARTICIPATION Commitment to implement new lighting technology	Is there willingness to invest time and money in new lighting technology?	By the Client / Project leader: no By the Lighting professional: yes
	Is the budget adequate for the new lighting technology?	According to Client/Project leader: yes According to Lighting professional: no
	Is the lighting professional involved early in the project?	According to the Project leader: yes According to Lighting prof.: not always
	Is there a separation of tasks and responsibilities between lighting professional and architect?	For the Project leader: yes For the Lighting professional: not always
COLLECTIVE ACTION Work done to implement new lighting technology	Are responsibilities clear in the implementation process?	By the Client / Project leader: no By the Lighting professional: no
	Is research sought after?	By the Client: no By the Project leader: no By the Lighting professional: no
	Is information sought after?	By the Project leader: yes By the Lighting professional: no
	Is the architectural brief adequately detailed?	According to the Project leader: yes According to Lighting prof: not always
	Is communication adequate in the implementation process?	According to lighting professional: sometime yes, sometimes not
	Is communication adequate between lighting prof.and lighting programmer?	No
REFLEXIVE MONITORING Appraising the implementation of new lighting technology	Is end-user feedback sought after?	No
	Is post occupancy survey conducted?	No
	Are results satisfying?	For professionals involved: generally yes
	Is the lighting professional acknowledged after completion?	No

Figure 10. Thematic analysis of responses for large scale commercial projects. The themes are categorized next to the relevant NPT component.

LARGE SCALE PROJECTS, INHIBITING AND FACILITATING FACTORS

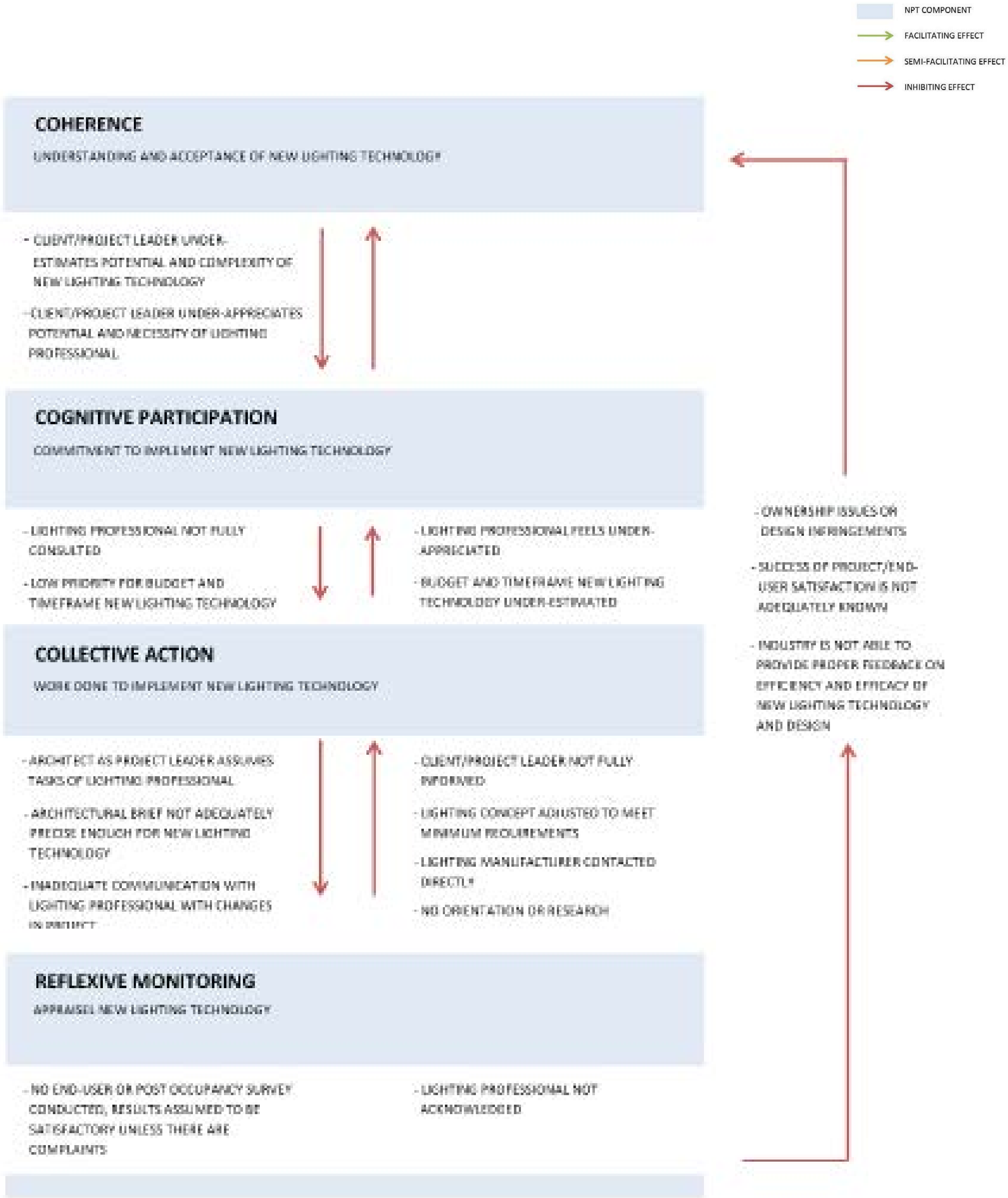


Figure 11. Relationship and effect of attitude of the various actors in the implementation process for large scale commercial projects.

SMALLER LIGHTING PROJECTS, THEMATIC ANALYSIS OF RESPONSES

NPT COMPONENT	RELEVANT INTERVIEW QUESTION	EVALUATION RESPONSES
COHERENCE Sense making of implementing new lighting technology	Is the potential of new lighting technology understood?	By the Client: yes By the Project leader: yes
	Is the complexity of new lighting technology appreciated?	By the Client: yes By the Project leader: yes
	Is new lighting technology valued?	By the Client: yes By the Project leader: yes
	Is the lighting professional valued?	By the Client: yes By the Project leader: yes
COGNITIVE PARTICIPATION Commitment to implement new lighting technology	Is there willingness to invest time and money in new lighting technology?	By the Client: yes By the Project leader: yes
	Is the budget adequate for the new lighting technology?	According to Client: yes According to Project leader: not always
	Is the lighting professional involved early in the project?	Yes
	Is there a separation of tasks and responsibilities between lighting professional and architect?	Yes
COLLECTIVE ACTION Work done to implement new lighting technology	Are responsibilities clear in the implementation process?	Yes
	Is research sought after?	By the Client: no By the Project leader: no
	Is information sought after?	By the Client: yes By the Project leader: yes
	Is the architectural brief adequately detailed?	Yes
	Is communication adequate in the implementation process?	Yes
	Is communications between lighting professional and lighting programmer smooth?	According to lighting professional: yes
REFLEXIVE MONITORING Appraising the implementation of new lighting technology	Is end-user feedback sought?	By the Client: rarely By the Project leader: no
	Is post occupancy survey conducted?	By the Client: rarely By the Project leader: no
	Are results satisfying?	For professionals involved: generally yes
	Is the lighting professional acknowledged after completion?	Yes, usually

Figure 12. Thematic analysis of responses for smaller specialized lighting projects.The themes are categorized next to their relevant NPT component.

SMALLER LIGHTING PROJECTS, INHIBITING AND FACILITATING FACTORS

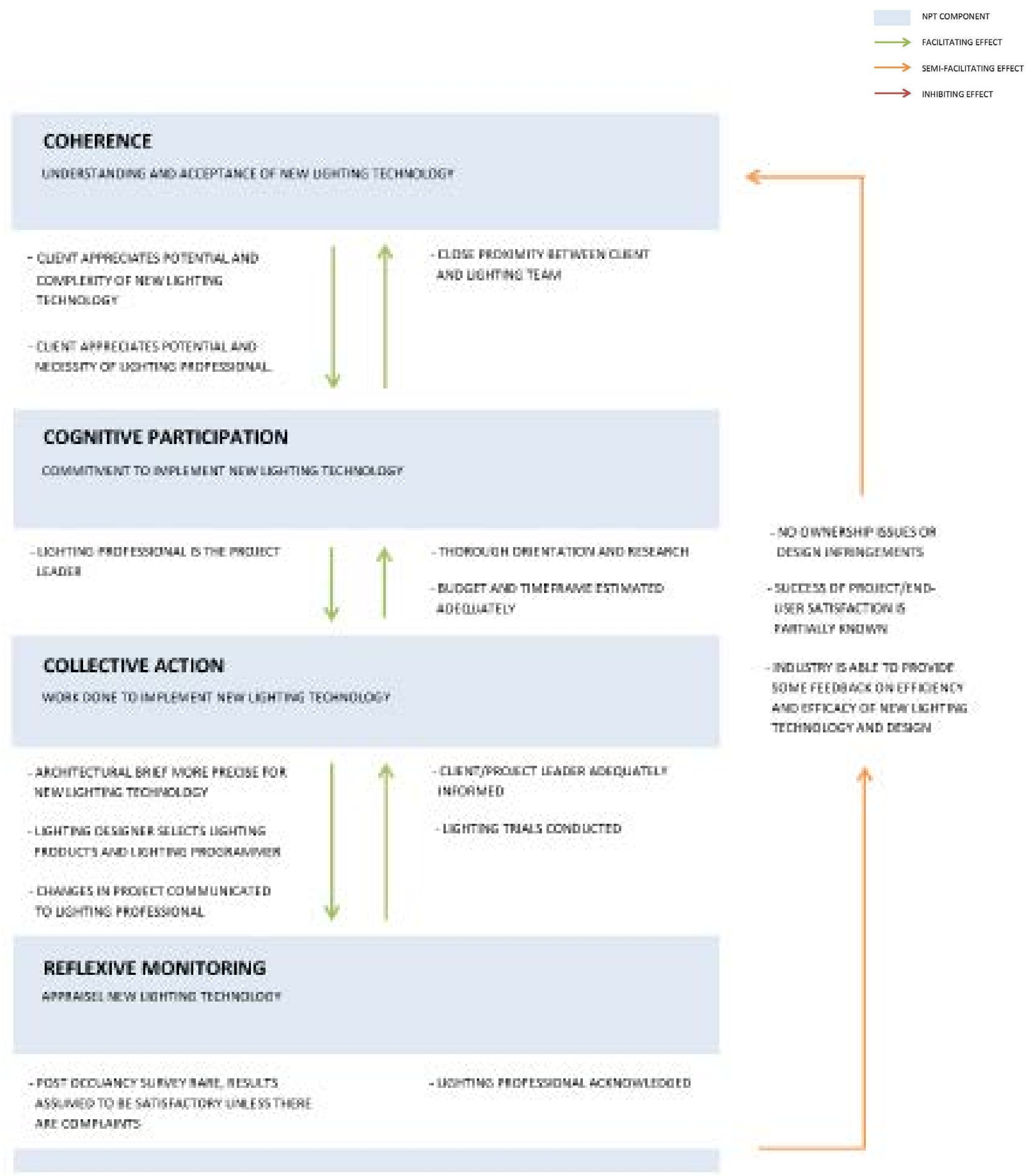


Figure 13. Relationship and effects of attitude of the various actors in the implementation process for smaller specialized lighting projects.

By positioning the results of the responses in the analytic framework the following conclusions may be drawn about current implementation processes in general. There is a marked difference between large scale commercial projects and smaller specialized lighting projects. Whereas the smaller projects are fairly efficient when implementing new lighting technology, this seems to be the opposite case for large scale projects, where lighting is just one aspect of the project. result in a difference in how smooth the implementation process goes.

For larger commercial projects a prominent inhibiting factor is the general lack of appreciation of the complexity of new lighting technology, and the necessity of lighting professionals as a specialist to deal with this. This has a knock on effect in budget estimation, and time-labour estimation, which in all cases is under-estimated and performed without consultation of the lighting professional. In addition, architects, who are usually project leaders in large scale projects, are unaware that they do not have to shoulder the task of lighting design, and proceed to attempt to deal with the new lighting technology, often without thorough knowledge. Through lack of time and budget, and due to the architect taking over the responsibilities and work of the lighting professional, proper description of requirements in the architectural brief becomes impossible, which leads to cost problems and technical problems during the commissioning phase. At this point costs for lighting are eventually only enough to cover basic lighting requirements in accordance with the building codes, which may lead to dissatisfied clients and end-users. An additional problem in this is the lack of post occupancy surveys , and the lackof research that is consulted, which prevents the industry and research as a whole from gaining new knowledge on the effects of new lighting technology, or what may be deemed cost effective and what not. Although the budget for post occupancy is mostly viewed as an additional cost by the industry at large, a few respondents noted that it is not a question of increasing the budget, but redistributing the budget differently from the outset, as only minor sacrifices would have to be made on the part of other costs. The question of ownership of a lighting project or a lighting design stems from the under-appreciation of the complexity of new lighting technology, which results in an under-appreciation of the lighting professional, their necessity, and ultimately their contribution.

The implementation process for smaller and more specialized projects such as museums, health care facilities and hospitals, is much smoother as the lighting professional is directly involved from the outset either as project leader, or is involved directly in budget estimation and quality requirements of the lighting and lighting system. The types of clients generally involved in these projects are focused on lighting technology from the start and put aside a greater budget. Communication between lighting designer and clients in these projects is closer and more direct, resulting in feedback and scrutiny of the final product. Similar to the large scale projects, research is not really consulted and post occupancy surveys are extremely rare. Problems due to ownership issues are much less in these cases, and usually a lighting company or lighting designer as senior responsible is given due credit for the results of the project. Nevertheless, one respondent mentioned that on occasions when no proper recognition was given, the client or company in question would be blacklisted whether or not they offered a new project.

CASE STUDIES

The complexity of new lighting technology, and the challanges of implementing these is demonstrated by the case studies which were selected. Dansk Metal, COWI and DTU (Danmarks Teknisk Universitet) are a union, an engineering firm and a university that have each installed dynamic lighting systems in their office complexes. For the first two, Dansk Metal and COWI, the new lighting installations were part of a wider construction and refurbishment project in their offices.

For all three cases there was a particular emphasis to apply a state of the art in lighting design and lighting technology for their overall design. As such an LED based dynamic lighting system was chosen, which involved adapting the illuminance and colour temperature of the light between warm and cold, based on a predetermined time frame. An important aspect of the planning, as is the case with any lighting project, involved an analysis of the space and not in the least developing a sound concept.

The abovementioned case studies are still a fairly rare undertaking for Denmark with respects to LED dynamic lighting systems on such a large scale. Although there are some examples of earlier dynamic lighting technologies which have been applied to offices, such as the case of Top Danmark, these older retrofits involved fluorescent lighting and not solid state lighting technology.

The following is a very brief description of the case studies´ lighting project, which, depending on the project, was still in various stages of development. The emphasis of this section will be on the concepts and designs, and the various factors that determine these. Primary focus will be on the Dansk Metal project as this is in its final stages of development. The case studies of COWI, which finalized its project a number of years ago, and DTU, which has come half way the installation process, will be used as additional cases to highlight certain aspects. This introduction does not discuss any critical or theoretical issues unless these are relevant to the topic of this thesis: the implementation process.

The case studies indicate how complex new lighting technology is when applied to office environments. The increased freedom of control over various aspects of light equally increase the complexity of the concepts and their application. The outcome and implications of this complexity affect the implementation process, the results of which are subsequently discussed at the end of the chapter, and in the following chapters.

DANSK METAL

Introduction

This main office of the metal workers labour union is a four story office building located in Copenhagen´s Sydhavn area. In this retrofit 1200 LED luminaires were placed which were centrally controlled by a lighting program (DALI). The planning of light distribution took into account the depth of the building, the relative position of the interior spaces with respects to the orientation of the sun, the working conditions for the office staff, and finally the energy consumption for lighting. The basis for the design for the working conditions came from two directions. Firstly it was based on studies of the circadian rhythm, and how this can be affected by blue rich and red rich light, and secondly it was based on the architectural concept of zoning.

Sun path analysis

Part of the management of the indoor lighting conditions, as well as ventilation and heating, is the control of the natural light coming through the windows. The building is equipped with both automatic- and manual sun screens. One façade of the building faces roughly the south, and is as such exposed to most of the direct sunlight. This position equally determines the location of the balconies, and where most of its double pane windows are placed. Sun-path analysis for summer solstice (21 June), and winter solstice (21 December) shows that in the winter the north facing facade is not exposed to direct sunlight (fig.15, Revit). In addition, due to the low angle of the sun in this period, the offices located on the south side of the building are directly exposed to both the sunlight as well as the sun. In the summer, the north facing façade is exposed to direct sunlight for a brief moment in the morning. This exposure lasts until about 10.30 AM, after which the sun rises higher and moves away from this side of the building. As in the case of the winter period, the rest of the day this façade remains in the shadows, whereas most of the direct sunlight falls onto the south side of the building.

In addition, the immediate surrounding area of the building is void of large trees and other buildings, and as such there is no blockage of natural light from the physical environment (fig.14).

Figure 14 . Area around the Dansk Metal building has no other buildings or large tress.

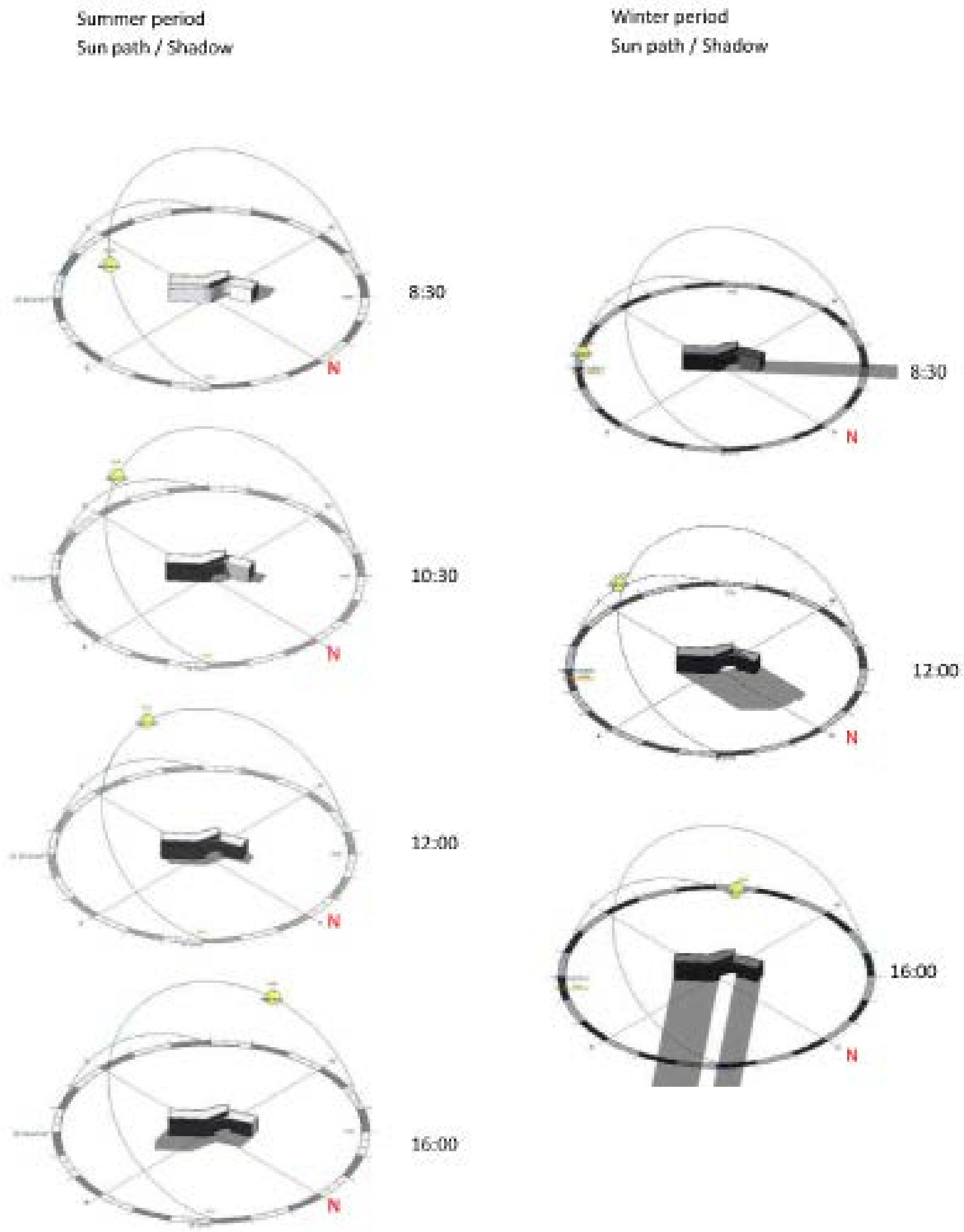


Figure 15 . Movement of the sun shows that the northern facade is covered by shadow for the most part.

This situation is relatively simple when compared to the COWI and DTU buildings. Although the COWI office complex is aligned in roughly the same way as the Dansk Metal office, and although both offices have no buildings or tall vegetation surrounding their cadastral plot, the COWI building itself is a more complex structure. The office complex consists of six separate blocks which are connected by smaller hallways and catwalks. When these blocks are taken into account separately the sun path analysis is equally more complex. COWI´s tallest tower effectively puts almost four of these blocks in its shadows (fig.16, fig.17). In addition these smaller blocks have most of their office space and office windows located towards the façade facing COWI´s tallest tower. As such sun light can only directly reach certain windows of the smaller blocks during a certain time frame and season. This is primarily the case during the summer period, when sunlight can reach the smaller buildings due to the high angle of the sun. In the winter period on the other hand the smaller buildings remain for the most part in the shadows (fig.18)



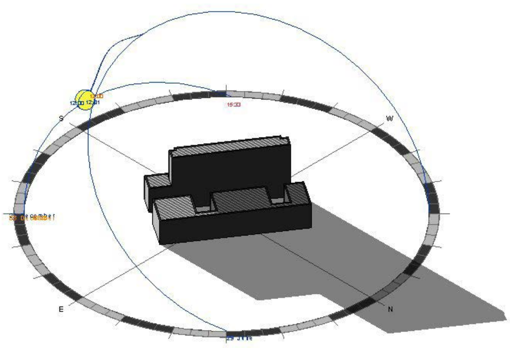


Figure 16. Figure 17. Figure 18.

The position of the large tower at COWI puts its smaller offices in its shadow (Revit sun path analysis winter solstice, 21 December). The design of the smaller blocks create naturally darker areas (centre photo).



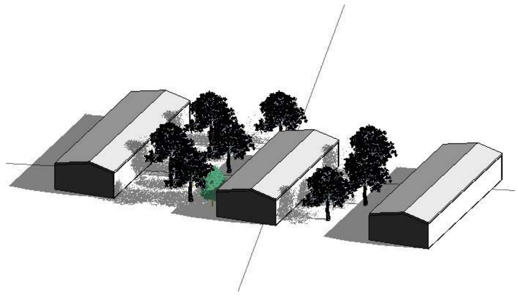


Figure 19. Figure 20. Figure 21.

Trees block sunlight on parts of the facade (Revit sun path analysis sinter solstice, 21 December).

As opposed to both the case of Dansk Metal and COWI, the DTU office can be argued to be more evenly exposed to the sun, as the alignment of the building is almost along a north-south axis. This building however is surrounded by tall trees and other buildings, which cast shadows on both of its facades depending on the time of day (fig.19, fig.20). In the morning the eastern façade is exposed to the sun. During this time three large trees block the sun and create a shadow over three areas of this façade (fig.20, fig.21). During midday both facades are equally lit with no shadows on the facades, after which the western façade is exposed. On this side, and similar to the situation on the eastern façade, a number of big trees block the sun and create large shades on a number of areas on this façade. The facades are least affected by shadows during the summer, and mostly affected during the winter when the low angle of the sun creates longer shadows. It is also during the winter, especially in the morning, that the shadow of the building facing its eastern façade can cover part of the office.

Due to the aspect of shadows on the facades, the COWI and DTU cases are slightly more challenging when it comes to a comprehensive lighting system which takes into account daylight factor and daylight harvesting.

Daylight Factor and windows Dansk Metal

The daylight factor at the Dansk Metal building (fig.23) is impacted by the cross section, i.e. width of the office spaces, and the size and type of the windows. The building as a whole is long, and about 18 meters from window facade to window façade inside. There are two main types of windows which measure 300 cm x 154 cm (l x b) and 300 cm x 74 cm (l x b) (fig.22) respectively. The distances between the single pane windows is about 154 cm, and between the double pain windows 74 cm. The south facing façade has 116 double pane windows and only 5 single pane windows. The northern facade has a mixture of both windows. The top floor has 23 double pane windows and 6 single pane windows primarily located in the middle. The third floor has on its left 16 double pane windows, and on its right 23 single pane windows, the second floor has on its left 7 double pane windows, and on its right 34 single pane windows, and the first floor has on its left, and 27 single pane windows and on its right 14 double pane windows.

Figure 22.
single pane window / double pane window The automatic blinds on the double pain window are down (right photo).

Both window types are double glazed, run from floor to ceiling, and are recessed about 18 cm into the wall. The daylight factor calculations were made using Velux Daylight Visualizer, based on CIE overcast sky outdoor illuminance levels (10000 lx).

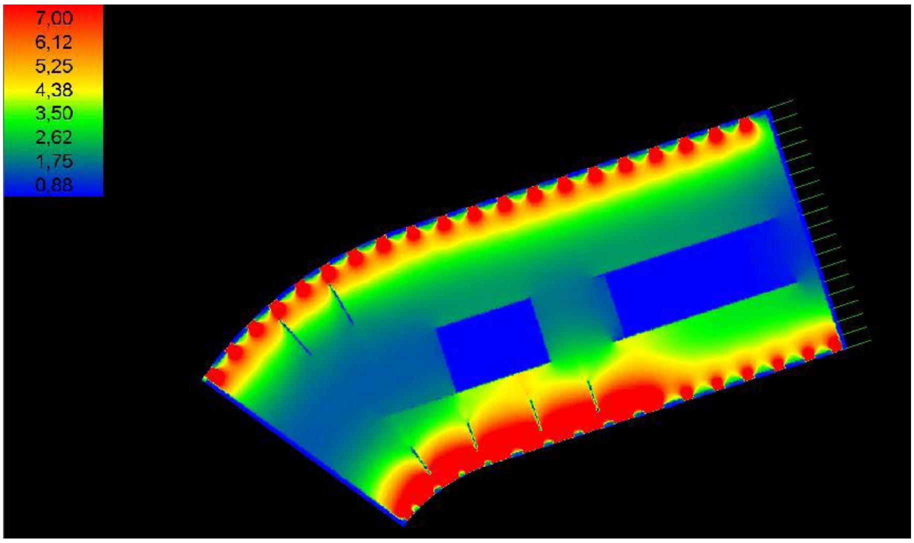


Figure 23.
Daylight factor Dansk Metal, typical section (Velux Daylight Visualizer)

With the double pane windows an illuminance of about 700 lx reaches up to 2 meters into the building, after which this decreases to 400 lx at 4 meters. At about 5 meters these levels drop to around 200 lx, and decrease further with increased distance from the façade until the center of the building. With the single pane windows these values decrease more rapidly towards the middle of the area. After about a meter the illuminance levels drop from about 700 lx to 400 lx. At 4 meters these levels stand at around 200 lx, and drop further as the distance from the windows decreases.

Due to the narrow shape of the building, as well as its longer windows, the Dansk Metal building is able to make fairly good use of the daylight, although the use of widely inter-spaced single pane windows on the dark side of the building can be questioned.

Similar to the Dansk Metal case, both the DTU building, which has a cross section of around 15 meters, as well as the main tower at COWI, which has a cross section of about 12 meters, are relatively slender buildings. DTU on the other hand has only one type of window, which are triple pane double glass, and measure around 280 by 130 cm (fig.26). As such they are wider than those of Dansk Metal, and cover the entire width of the individual office rooms. Unlike the Dansk Metal case however, the window shelf of the DTU windows is relatively high, and stand at around 120 cm. Similar to the Dansk Metal case, the tall tower at COWI equally has long windows measuring around 90 by 240 cm., yet are single pane Their shelf height is around 60 cm, and the windows are spaced at about 30 cm, and recessed about 18 cm into the wall both from the inside and outside (fig.24). This deep recess , particularly on the outside, restricts the light more than in the cases of COWI´s smaller office blocks, Dansk Metal and DTU, of which the windows are relatively flush with the external facade.

One of the challenges at COWI are its five smaller yet still sizable office complexes located on the shadow side of the plot. Although the tower block is designed along the same concept as both the Dansk Metal and COWI buildings, i.e. long and slender, and are therefore more efficient in using daylight, the smaller office complexes are more rectangular in shape. There are several types of windows which differ mainly in height. Some of the windows are double pane and measure around 180 by 190 cm (fig.25), with a shelf height of 44 cm. Other windows are single pane and measure around either 115 by 50 cm, or 115 by 110 cm, with a shelf height of 92 cm (fig.25).

Figure 24.
Windows in the COWI tower recessed on both sides of the wall, blocking natural light.

Figure 25.
COWI has several types of windows in its smaller offices which are placed in the same office space.

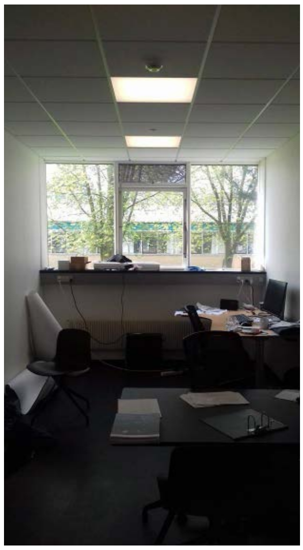


Figure 26.
Window at DTU starts relatively high, yet covers the width of the office.

The cases for the smaller COWI office blocks and DTU are arguably more challenging due to the surrounding structures and trees which block the sunlight, and in case of the smaller COWI offices, their rectangular shape and smaller window area. These factors prevent natural light from penetrating deep into the building, and daylight harvesting may be less efficient in these cases.

Concept Dansk Metal

The design concept addresses several aspects related to human responses to light in a work environment. Firstly, it provides light to support concentration and visual acuity, which is necessary at the workstations. This is predominately related to the use of light with a high colour temperature range, i.e. cold light, as well as higher illuminance levels. Secondly, the design equally provides light that supports recreational activities, or winding down, which is typical for short breaks during work, or informal meetings. This light is primarily used in common areas such as the canteen and smaller kitchen and seating areas. This light has a lower colour temperature range, i.e. warm light.

Thirdly, the concept incorporates the aspect of the circadian cycle in the design. Although this is related to certain aspects of the work environment, there are some differences. Whereas work related lighting may involve light to promote concentration, the circadian cycle involves a gradual change throughout the day in luminance and colour temperature to support other functions such as sleep, appetite, the immune system etc. This cyclical change is not only dependent on the time of day, but equally on the seasons and natural sleep patterns.

Finally, the design has incorporated the idea of providing variation in the peripheral view of the employees, which relates more to studies on the impact of views than that of light or the circadian cycle. This is achieved by using a combination of different size fixtures that are run at differing intensity. In other words, the uneven distribution of light is used to break up an otherwise monotonous backdrop from the point of view of the workstations. This checkered pattern is intended to increase visual comfort, i.e. slight variation of spatial layout in the peripheral view of the office staff.

The three abovementioned aspects, i.e. work conditions, circadian cycle and peripheral view, result in a space that is broken up into different zones each of which have their own lighting concept.

Static and dynamic lighting concept

The lighting system uses daylight harvesting (fig.27), and employs lux sensors to regulate and maintain a basic minimum constant illuminance of 200 lx in all areas. This includes the use of automatic blinds that are regulated separately for each of the facades (fig.28). The area towards the facades, i.e. the window areas, is where the workstations, kitchens, formal meeting rooms and toilets are located. Here dynamic lighting is used which adjusts its light according to a combination of the circadian cycle and the need to stimulate concentration and alertness for work. By using daylight harvesting the luminaires are dimmed when there is enough natural light coming in through the windows, the latter of which is greatly determined by the sun-path and the daylight factor.

Figure 27.
Daylight harvesting at Dansk Metal allows luminaires closer to the windows to be dimmed.

Figure 28.
Natural light is controlled with automatic and manual blinds.

Figure 29.
Zoning at Dansk Metal uses different CCT of light depending on the function of the space.

Because the depth of the building creates permanently darker areas towards the center, daylight harvesting has little impact in these zones. In addition, these darker areas have been designated as recreational zones for the office space, as well as form the backdrop of the peripheral view of the office staff. As such the light used here is static and kept at low colour temperatures. (fig.29, fig.30, fig.31)

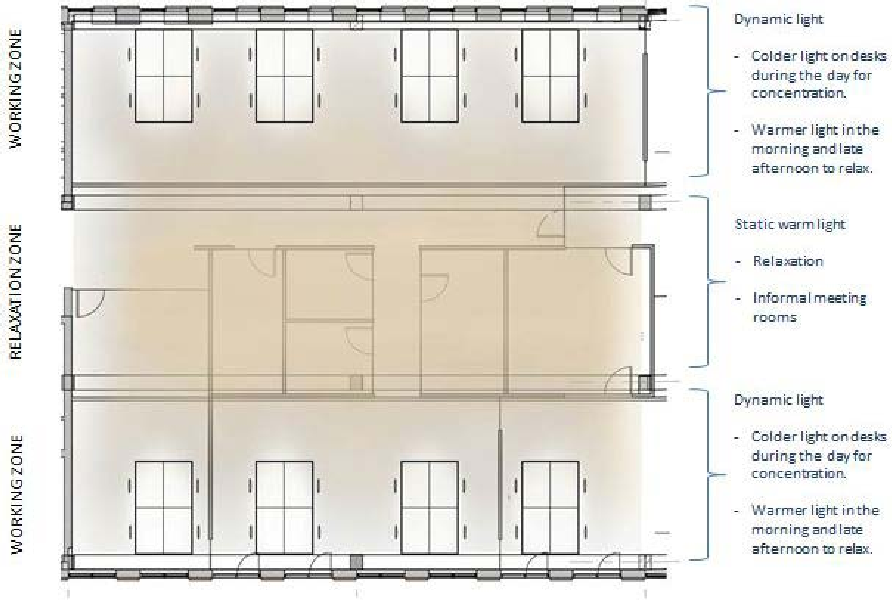


Figure 30.
Two general lighting zones exist at Dansk Metal: dynamic light is used at the work stations located by the facades, static low CCT light is used in the central common areas and meeting rooms.

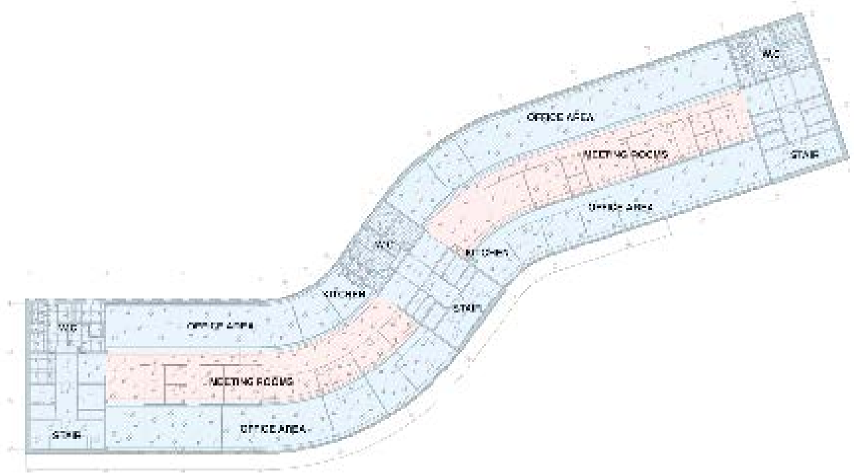


Figure 31.
Typical lighting topography. Red indicates static low CCT light, blue indicates dynamic light.

To create the variation in light pattern, two different sizes of LED luminaires have been used which each provide a different illuminance. The larger ones are Ø450 mm and run at 30% capacity, whereas the smaller ones, which measure Ø 265 mm. run at 75 % capacity (fig.32).

Figure 32.
Dansk Metal has two types of luminaires that dot the ceiling.

The lighting for DTU are standard office sized rectangular LED luminaires of 60 by 60 cm (fig.33), which were used for the entire building. COWI however had a number of different LED luminaires due to the existence of several office blocks. The luminaires were custom designed of various sizes (fig.34).

Figure 33.
DTU uses one type of luminaire.

Figure 34.
Two examples of the diffenet types of luminaires at COWI. Both are custom designed. The luminaire on the left is 60 cm, on the right 100 cm.

Besides the general functional areas such as the stairs, toilets and kitchen areas, the office area itself (fig.35) provides the highest CCT and illuminance on the workstations and in the formal meeting rooms, which changes throughout the day. The lowest CCT is in the area of the informal meeting rooms (fig.36), where due to the distance from the windows illuminance levels are relatively lower throughout the day.

Figure 35.
Typical office space at Dansk Metal. Two types of luminaire are used to create variation in light. Daylight harvesting allows for luminaires closer to the window to be dimmed. Light has a high CCT during peak working hours.

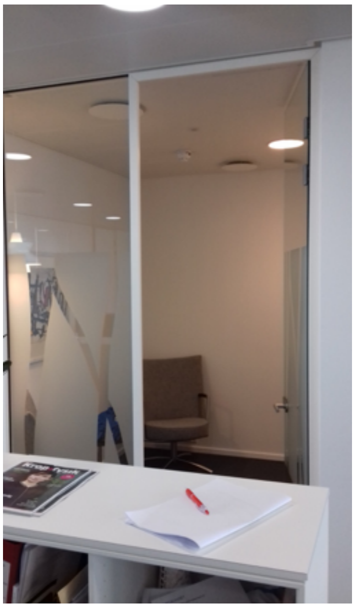


Figure 36.
Meeting room at Dansk Metal uses static low CCT lighting.

The use of daylight harvesting is similarly employed at COWI, which is used to control the illuminance of the luminaires. The luminaires closer to the windows are dimmed or on stand-by mode when enough light comes through the windows (fig.37). In COWI´s tower this creates a similar situation as with Dansk Metal, as the depth of both buildings are similar. Unlike the case of Dansk Metal on the other hand, which only has a few desks placed in the middle of the building in the naturally darker areas, a common layout in the COWI complex includes work stations in the center of the office spaces both in the tower as well as the smaller complexes (fig.39, fig.40). During the fieldwork it was noted that the smaller COWI office complexes had semi-desk luminaires which were installed to serve two desks at a time, and which could be dimmed manually (fig.38).

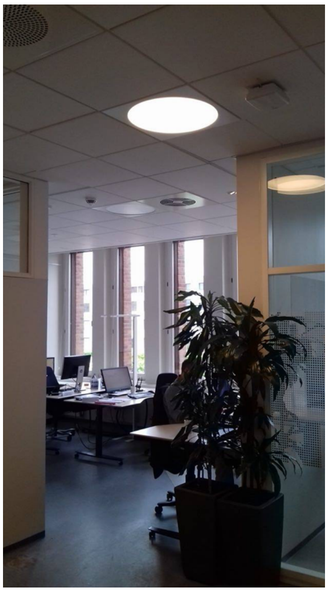


Figure 37.
Daylight harvesting at COWI allows for luminaires by the windows to be dimmed or switched off.

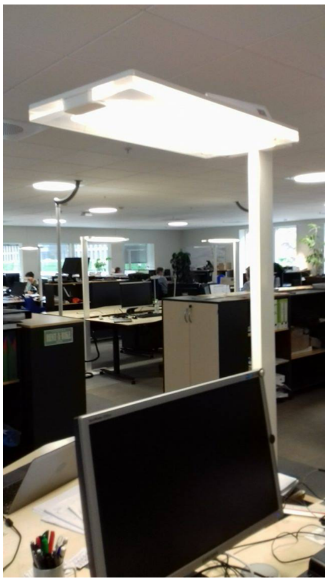


Figure 38.
Offices in the shadow of the COWI tower use special dimmable desk lights which cover two desks.

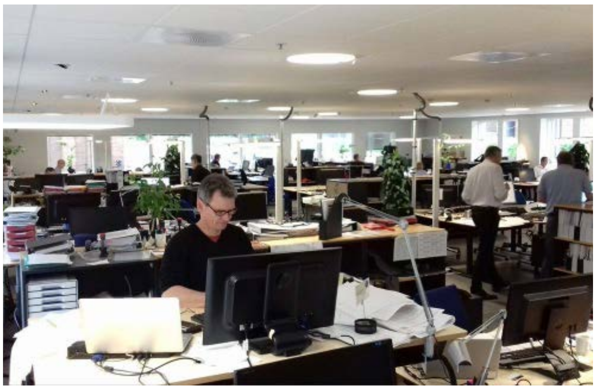


Figure 39.
Desks in the smaller buildings located in the central office areas. Special desk lighting is used in the central areas.

Figure 40.
Desks in the tower are also placed in the centre of the space. The narrower width of the office space allows natural light to reach the central areas, and desk lighting is used less.

Lighting schedule Dansk Metal

The dynamic lighting schedule used at Dansk Metal is based on two proposals, and is a combination of the standard lighting program as put forward by the provider of the system, and the input from the lighting designer. Whereas the luminance is set to an average of 200 lx throughout the day, which is controlled by automatic blinds, the colour temperature ranges from 2700 K to 6500 K, which is time and space dependent. In addition, two separate lighting schemes are used to account for daylight savings and seasonal changes in daylight hours. The lighting schemes thus cover equinox and solstice (tab.3, tab.4).

Winter		
Time	Illum. (lx)	CCT (K)
04.00	0	2700
05.00	0	2700
06.00	0	2700
07.00	0	2700
08.00	200	3000
09.00	200	3500
10.00	200	4000
11.00	200	5000
12.00	200	5500
13.00	200	6000
14.00	200	6000
15.00	200	5500
16.00	200	4000
17.00	0	2700
18.00	0	2700
19.00	0	2700
20.00	0	2700
21.00	0	2700
22.00	0	2700

Table 3.

Summer		
Time	Illum. (lx)	CCT (K)
04.00	0	2700
05.00	0	2700
06.00	200	2700
07.00	200	2700
08.00	200	3000
09.00	200	3500
10.00	200	4500
11.00	200	5500
12.00	200	6500
13.00	200	6500
14.00	200	5500
15.00	200	4500
16.00	200	4000
17.00	200	3200
18.00	200	3000
19.00	0	2700
20.00	0	2700
21.00	0	2700
22.00	0	2700

Table 4.

Winter and summer CCT schedule for Dansk Metal. Highest CCT at peak working hours.

Season	Date	Dynamic program	Static program
Spring	15/2 - 15/5	06:00 – 18:00	18:00 – 06:00
Summer	15/5 – 15/8	06:00 – 18:00	18:00 – 06:00
Fall	15/8 – 15/11	06:00 – 18:00	18:00 – 06:00
Winter	15/11 – 15/02	08:00 – 16:00	16:00 – 08:00

Table 5.
After hour schedule for lighting at Dansk Metal. Lights are set to stand-by and are off.

During after-hours and at night the light is on standby and off unless the system senses someone is in the space (tab.5).

The lighting schedule at Dansk Metal is similar to that of COWI in that CCT slowly rises to one peak and decreases after. At COWI however, the highest level of CCT were different depending on the office block in question (tab.6). The tower block including one of the smaller office buildings, which fell partially outside the shadow of the tower block, were measured to reach a maximum CCT of 3000 K between 10.00 – 16.00 o´clock. The remaining smaller offices, which were mostly located in the shadow of the taller tower, rapidly rose to 4000 K by 10 o´clock in the morning, and reached 5000 K between 12.00 – 13.00 ´clock, after which it decreased to 4000 K by 15.30.

Time	CCT (K) tower/offices outside tower shadow	CCT (K) offices in tower shadow
11.00	3000	4000
12.00	3000	5000
13.00	3000	5000
14.00	3000	4500
15.00	3000	4000

Table 6.
Measured CCT at COWI's two main building types. Difference in CCT may relate to position of the building in question.

Indoor materials and design Dansk Metal

The floor in the main office areas of the Dansk Metal building is a dark gray carpet, which prevents the room from seeming overwhelmingly bright and loud, and which enables it to hide stains and damages much better. Architecturally speaking this dark colour equally creates a calmer atmosphere. A sizable portion of the partitions inside the building are glass, which together with the white ceiling create a brighter and more open space. This also allows the natural light in the working areas to penetrate deeper into the building. The partition walls between the working areas and the smaller meeting rooms in the center of the building are solid. Some of the walls facing the working areas have been decorated with warm colour materials, in this case large lattice works made of wood. This colour reflects warmer light, adding to the variation in the peripheral view of the office workers, and creating the anticipation of the relaxation zones located in and behind this area (fig.41).

Other sections of the building, in particular the smaller meeting rooms, have white walls which reflect the warm light and avoid the space feeling overly cramped and gloomy.

Figure 41.
Common areas have darker materials such as wood to create an informal atmosphere and lower CCT for light. Light still needs to be adjusted to lower CCT.

The interior design, i.e. darker floor, white ceiling and white walls is a universal concept and as such has been equally applied to the COWI and DTU projects (fig.44, fig.45), although in the case of COWI the differences between the various office spaces and buildings can be great. There is however a design feature which sets the Dansk Metal building apart from the other two cases. The Dansk Metal building has windows that run from the floor to the ceiling, and as such have no window ledges. Both the COWI and the DTU buildings are older, with more traditional windows that start at some distance from the floor. Although especially the COWI complex has many types of windows and ledges, they are all capable of reflecting light upwards to the ceiling, and possibly also cause glary conditions at certain angles with respects to the work stations. In the case of DTU the ledges are more uniform, and start at 123 cm height from the floor. The colour of the window ledges on the ground floor is black, and those on the first floor are white (fig.42, fig.43). As such the window ledges on the first floor reflect more natural light into the room than those on the ground floor.

Figure 42.
Darker sil reflects less light.

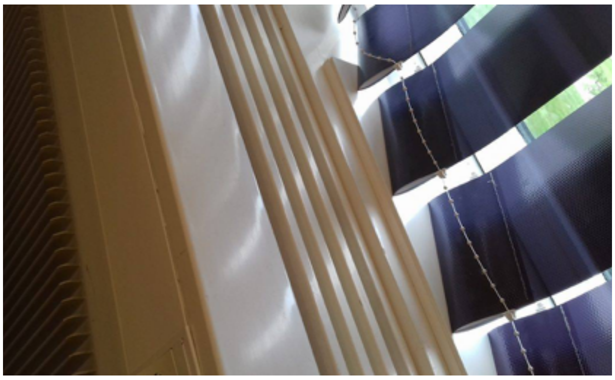


Figure 43.
White sil reflects light into the space, blinds are used to control this.

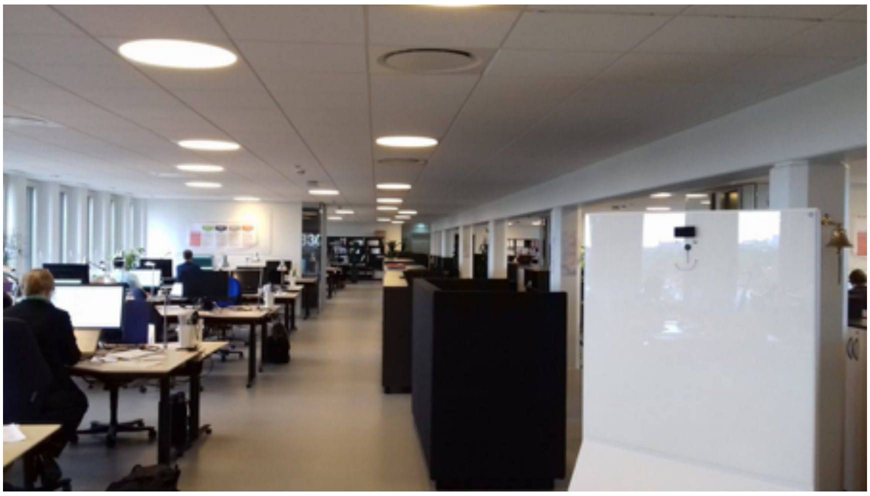


Figure 44.
Some areas in COWI has lighter colour floors, which create less contrast.

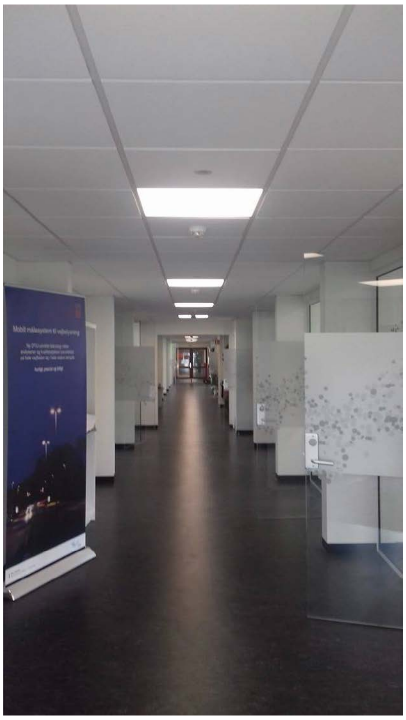


Figure 45.
DTU floor is dark, which absorbs light and creates greater contrasts.

Photographic analysis Dansk Metal

FIRST FLOOR

Figure 46.
Double pain tall windows on both facades allow more natural light to come in, making their use of daylight harvesting more efficient.

Figure 47.
Common areas are more informal, with materials that have warm colours. The white walls are broken up with paintings, which reduce the brightness of the space. The CCT of the luminaires in these areas should be lower, yet still needed to be adjusted.

Figure 48.
Common areas are approached in a similar way for all floors, and on all wings of the building.

Figure 49.
Smaller windows and high furniture block a lot of natural light, and create dark areas.

SECOND FLOOR

Figure 50.
Although these two areas are located opposite each other, the area on the south facing facade (right photo) has double pain windows and lower furniture. Enough natural light comes in to allow the daylight harvesting system to dim or switch off the luminaires by the window. Single pain windows and partitions have the opposite effect for the opposite area (right photo).

Figure 51.
Dark wall absorbs natural light, and use of wood in the common areas creates an informal atmosphere with warmer colours. Lights need to be adjusted to lower static CCT levels.

Figure 52.
Area located at opposite ends show the difference between the two facades of the building, and how this impacts the amount of natural light that enters the areas, and affects the efficiency of daylight harvesting. Lights on the southern facade are dimmed by the window (right photo), light son the northern facade are not (left photo).

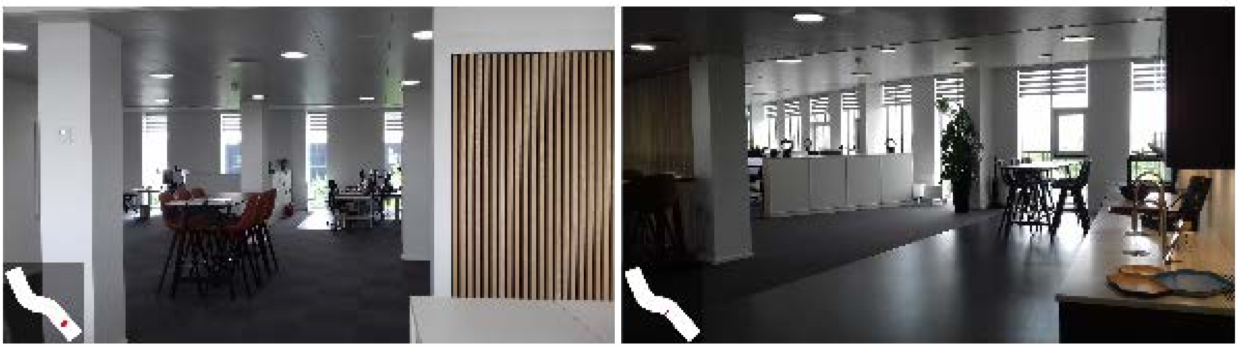


Figure 53.
Common areas use warmer colours to create informal spaces.

Figure 54.
An exception to informal spaces are the waiting areas outside of the executive offices. Althoug warm colours are used, the floor and location to the window creates a bright area.

Figure 55.
Area located at opposite ends show the difference between the two facades of the building, and how this impacts the amount of natural light that enters the areas, and affects the efficiency of daylight harvesting. Furniture has similar dimensions, yet double pain windows allow in more natural light on southern facade (right photo).

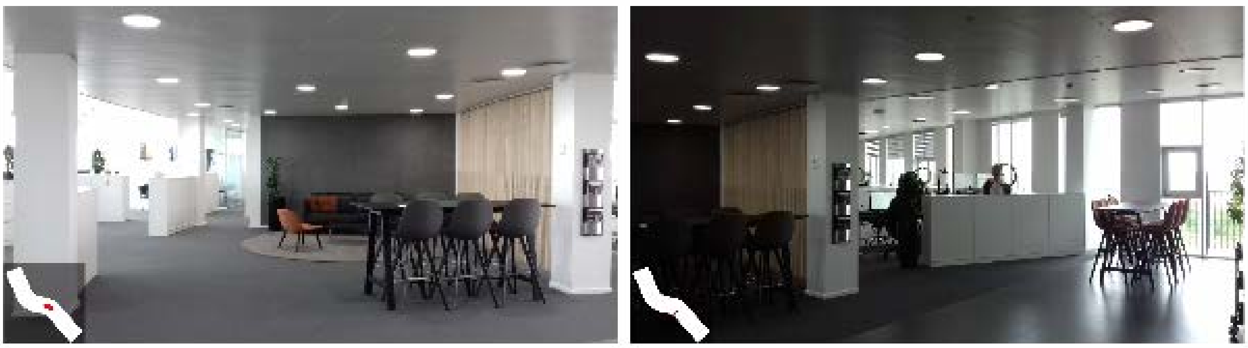


Figure 56.
Common areas are approached in a similar way for all floors, with the use of light absorning materials and colours to create a darker informal area.

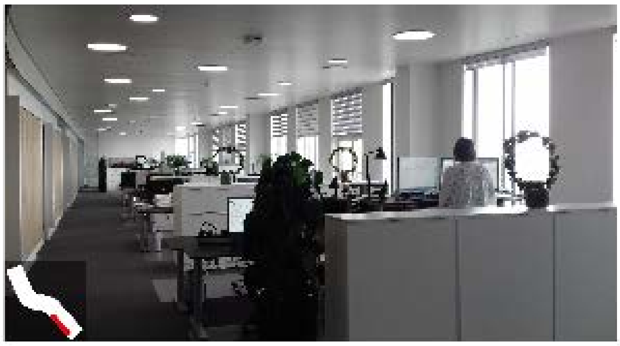


Figure 57.
Northern face (left photo) with double pain windows creates similar lighting conditions as the opposite area on the southern facade, which equally has double pain windows.

THIRD FLOOR

Figure 58. Informal areas created with darker light absorbing materials and colours.

Figure 59.
Some office spaces are located in the middle of the building, although this is rare. As such they are at equal distance from the sunny side of the building, with its double pain windows, as the shadow side, with its single pain windows.

Figure 60.
Small informal area, with darker colours and materials. Light still needs to be adjsuted for lower static CCT levels.

Figure 61.
Similar to the lower floors, an exception to the usual approach for informal areas are the waiting areas outside the executive offices, which are generally brighter.

Figure 62.
The top floor where the executive office is located, as well as two work stations, is sorrounded by windows on three sides. The use of glass partition walls allows natural light to flood the entire space.

Figure 63.
Similar to the lower floors, common areas have darker colors which break up and absorb light to create informal areas. Eventhough natural light can reach the space through the glass partition walls (left photo), or eventhough the area is located next to a window, the darker colours, paintings and plants create a darker informal area.

Figure 64.
The top floor has double pain windows on both facades, which allow in a lot of natural light and increase the efficiency of daylight harvesting.

FOURTH FLOOR

Figure 65.
Informal areas. Sometimes enclosing benches are used to craete an informal seating area, with lower illuminance levels and warmer CCT. As with other areas, the luminaires still had to be adjsuted to lower static CCT levels.

Figure 66.
Waiting area outside the executive offices on this floor use dark colours to absorb light and create an informal atmosphere.

Theory vs Practice

An important part of the implementation procedure of new lighting technology is the aspect of feedback with respects to the efficacy of the lighting system in question. Although COWI officially concluded its lighting installation some years ago, and Dansk Metal and DTU are still in the process, a few notable comments can be made about the similarity of the cases which indicate that adjusting and fine-tuning of the system are inherent aspects of any project involving new lighting technology, and that this may take some time even after formal completion.

Firstly, due to complaints, both COWI and Dansk Metal had to adjust the original CCT levels of the lighting schedule to lower values. At the time of the fieldwork, informal talks revealed that these levels were still too high for some of the staff.

Secondly, COWI and Dansk Metal both had some issues with the use of time delay in their lighting control systems. In the case of COWI, the original lighting system included an irradiance meter located on the roof of the building, which adjusted the CCT of the luminaires with a time delay, depending on weather conditions. Because of noticeable erratic CCT fluctuations with the odd cloud however, this idea was abandoned. At Dansk Metal, this time delay was part of the automatic blinds, which according to informal talks, were said to come down at illogical times, making the spaces darker.

Thirdly, the lighting for the common areas at Dansk Metal was dynamic and reached high CCT during the day, even though the concept for these areas was to be static warm light. Although not directly related, the dynamic schedule at COWI showed markedly different peak CCT levels depending on the office block in question.

Finally, it was noted for Dansk Metal that some areas used tall furniture or separation walls between the work stations. These were installed to control noise levels between work stations, yet prevented an even distribution of light coming from the windows and the luminaires, and created dark areas in the process.

These various issues indicate the complexity of new lighting technology and its planning, and that it is still a field that is in development. As such many concepts that look sensible and logical on paper, such as peak CCT levels, time delayed control systems, or the use of external CCT sensors to regulate CCT levels of the luminaires, may in effect produce opposite results in practice. In addition, the case studies also show that the planning of new lighting technology on paper can overlook unforeseen things which only become clear in practice, such as the impact the control of noise can have on the lighting in work spaces. Finally, in theory, the programming of lighting is possible with not too many problems, In practice however complex systems are prone to human error, and things can be easily overlooked, such as the wrong CCT levels for the common areas at Dansk Metal. The cases show that with new lighting technology, what is planned on paper does not necessarily correspond to what happens in practice.

Figure 68.
Partitions in certain sections at Dansk Metal block the light.

Figure 67.
Luminaires in common areas at Dansk Metal not yet programmed for low static CCT

It is likely that Dansk Metal, as in the case of COWI, will have to continue to adjust and fine tune the lighting to get the optimal results, which is argued in this thesis as a very normal part of the implementation process. This is also a good indication of how the process will most likely be for the DTU case. Although the lighting system for DTU has been installed and connected, the system remains to be programmed for dynamic use, and fine-tuned to adjust for the various end-users and its sun-path and shadow situation. Because in the case of Dansk Metal the system was installed just over a year ago, it is arguable that a similar time frame of adjustments will be necessary for DTU if they follow the same implementation procedure.

IMPLENTATION PROCESS CASE STUDIES

The complexity of the lighting, and the application of state of the art technology, makes the case studies relevant to understanding how implementation processes looks like in live projects, i.e. how efficient they are. The assessment has only been done for the Dansk Metal and COWI case studies, as the DTU case was not far enough into the implementation process for a full overview.

Thematic analysis interviews

The responses from the case study interviews showed important differences to what was otherwise viewed as typical implementation procedures as discussed by the lighting professionals in general. The main differences relate to the size of the project in question, which for the selected case studies were large scale commercial projects, and the difference in their implementation approach, the latter of which resembled more the aspects typically found in smaller specialized projects.

The thematic analysis for the two case studies was guided by the same themes that were selected for all semi-structured interviews and as such there was no difference between the interview schedule for the lighting professionals in general and those of the selected case studies. The following is a summary of how a certain aspect was addressed in the implementation process for each of the case studies:

Hierarchy and relevant team members in the implementation process,

Dansk Metal: large commercial project, lighting and ventilation retrofitting. Client assumed senior responsibility, and contacted architect firm for the overall retrofit, who in turn contacted a lighting designer. Programmer was also contacted by the client.

COWI: large refurbishment project. Lighting was one aspect. In-house lighting designer, technicians and services, external programmer contacted by lighting designer.

Responsibilities, and how this is determined,

Dansk Metal and COWI: decided at formal meetings, further decided informally at lower level.

Communication, forms of communication and their effects on the implementation process,

Dansk Metal: no formal post-occupancy survey, yet smaller feedback questionnaire. Close proximity between client and lighting designer, and rest of the team.

COWI: no formal post-occupancy survey, yet smaller feedback questionnaire. Close proximity between client, lighting designer and end-user.

Decision making process, what these are based on, and how things are decided,

Dansk Metal: on-site meetings where decisions were made in a hands-on manner.

COWI: formal meetings

Transforming a design to a lighting program,

Dansk Metal: Vanpee

COWI: Services + Logtech, Philips design put forward by DTU. Kelvin meter on roof abandoned as impractical.

Knowledge on new lighting technology, and what this is based on.

Dansk Metal: Lighting designer is a researcher.

COWI: knowledge based on network and experience.

Implementation efficiency in case studies: open question as to what worked well, and what worked less well:

- Complexity and potential of new lighting technology appreciated by clients.
- Client could not anticipate certain needs with respects to the lighting system, but was not adequately informed about these, and not presented with a choice of products to address these.
- Budget and time estimated more adequately for new lighting technology.
- The role of the lighting designer valued and recognized as an expert.
- Architect aware of the potential and value of the lighting designer.
- Manufacturer only contacted for light fixtures, which in the case of COWI were redesigned by the lighting designer. Difference manufacturer and lighting designer understood.
- The contribution of the lighting designer valued. Ownership not an issue in case studies.
- The specifications for lighting in the architectural brief were very precise.
- Proximity to the client and between professionals produced the best results.
- Responsibilities and tasks decided at meetings and put on paper. Smaller tasks decided informally by phone or e-mail, and based on routine.
- No budget set aside for post occupancy surveys, though small feedback questionnaire handed out. For COWI there was no need for adjusting the light, Dansk Metal adjusted the light.

Analysis of implementation

Similar to the analysis of the general large scale commercial projects, and smaller specialized lighting projects, the responses for each case study is placed in two types of frameworks based on Normalization Process Theory. The first framework gives an understanding of how the various aspects highlighted in the interviews relate to one another in the overall implementation framework (fig.69, fig.71). The second scheme shows the facilitating and inhibiting factors of the implementation process, and how they affect the implementation process (fig.70, fig.72).

COWI and Dansk Metal were large scale projects of which lighting formed only a part of the total project. Usually such large scale projects tend to put lighting at a lower priority both with respects to time and budget, which often makes more complex lighting designs such as dynamic lighting impossible. In the case of COWI and Dansk Metal however the aspect of lighting was given equal priority and ample space within the budget.

The case studies show that from the outset there was an increased appreciation of the complexity of new lighting technology, and its potential. As such the lighting professional was seen as essential in understanding this technology and was consulted on the budget and time frame for the project. In turn the lighting professional was in more direct contact with the client and the project leader, and was kept informed on changes. The programming of the lighting sequence was done in cooperation with specialist lighting programming firms and not by manufacturers of lighting products, and their expertise in dynamic lighting was equally consulted in the process.

Both projects can be said to have been implemented fairly efficient, yet as the subchapter *Theory vs practice* showed, many adjustments were still being made a year after the new lighting system had been installed. The analysis of the implementation process indicates one inhibiting factor which can be argued to lie at the root of the adjustments that were still necessary after completion. Similar to the general cases, the process of implementation in the selected cases of Dansk Metal and COWI had no end-user satisfaction or post occupancy survey. As such, understanding the effects of the new lighting system in practice is a slower process, and relies for the most part on informal feedback. In other words, current implementation processes are less efficient with respects to feedback and adjustments of the lighting system.

DANSK METAL, THEMATIC ANALYSIS OF RESPONSES

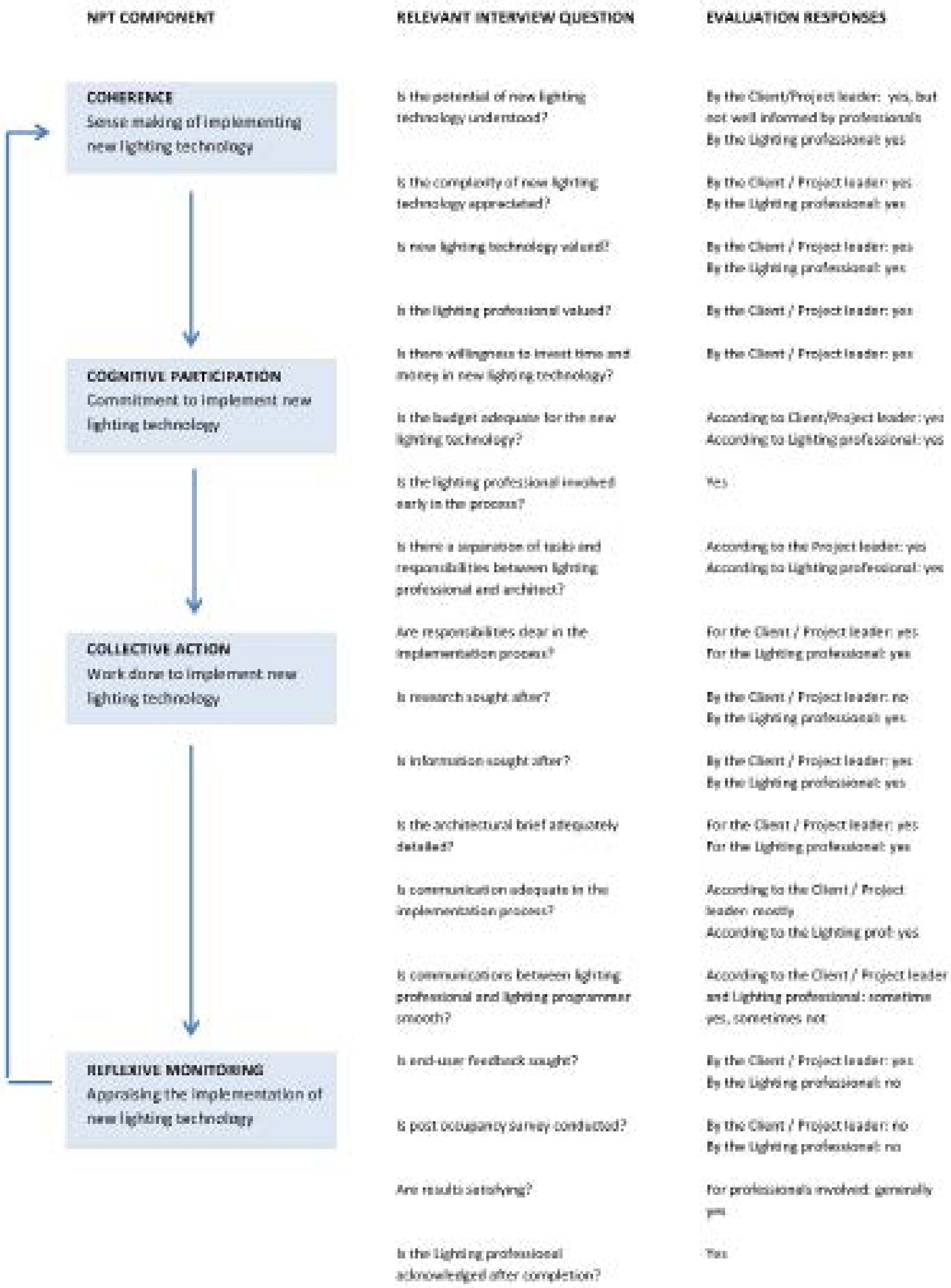


Figure 69.
Thematic analysis of responses for Dansk Metal.The themes are categorized next to their relevant NPT component.

DANSK METAL, INHIBITING AND FACILITATING FACTORS

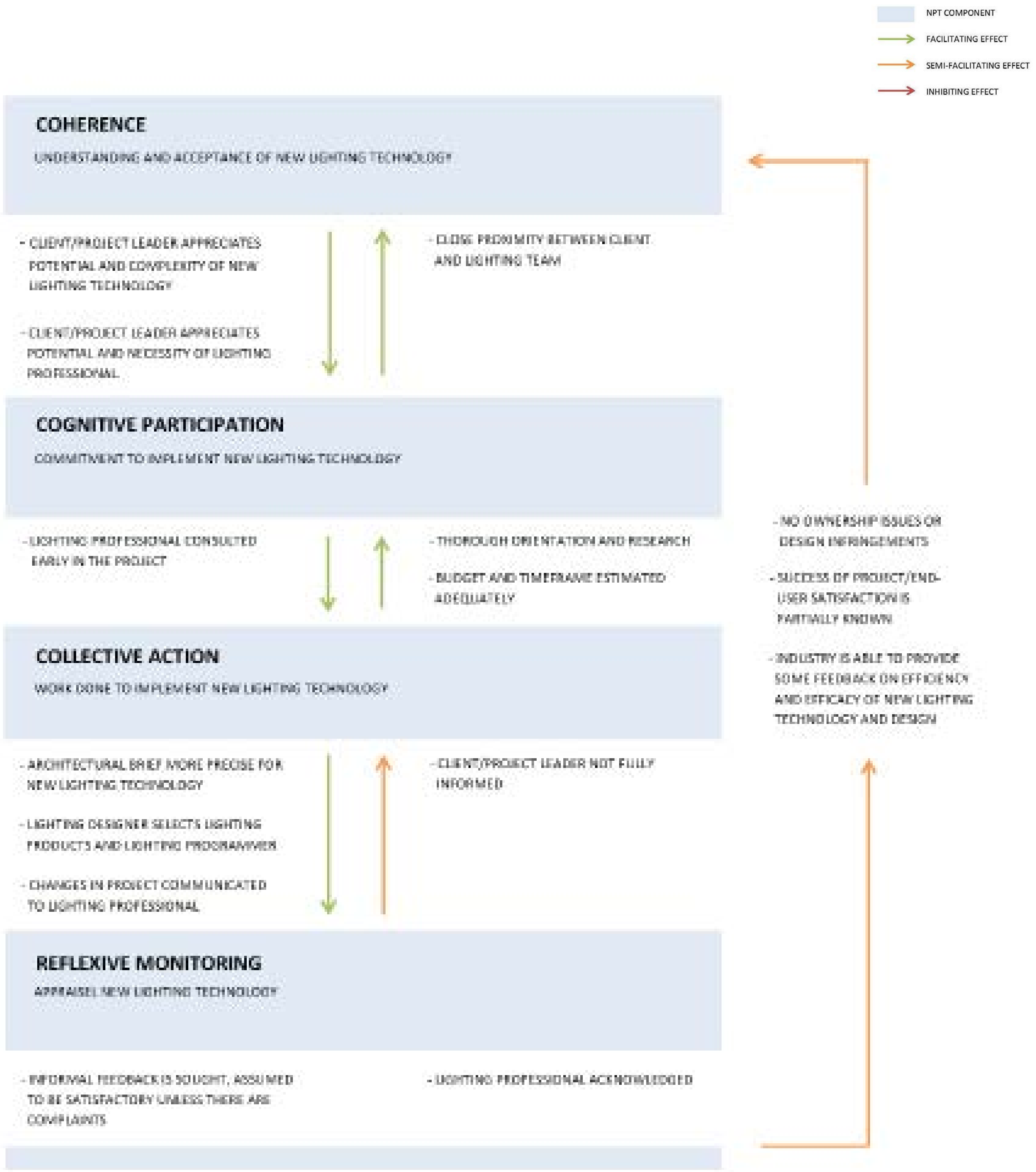


Figure 70.
Relationship and effects of attitude of the various actors in the implementation process for Dansk Metal.

COWI, THEMATIC ANALYSIS OF RESPONSES

NPT COMPONENT	RELEVANT INTERVIEW QUESTION	EVALUATION RESPONSES
COHERENCE Sense making of implementing new lighting technology	Is the potential of new lighting technology understood?	By the Client: yes By the Project leader: yes
	Is the complexity of new lighting technology appreciated?	By the Client: yes By the Project leader: yes
	Is new lighting technology valued?	By the Client: yes By the Project leader: yes
	Is the lighting professional valued?	By the Client: yes By the Project leader: yes
COGNITIVE PARTICIPATION Commitment to implement new lighting technology	Is there willingness to invest time and money in new lighting technology?	By the Client: yes By the Project leader: yes
	Is the budget adequate for the new lighting technology?	Yes
	Is the lighting professional involved early in the project?	Yes
	Is there a separation of tasks and responsibilities between lighting professional and architect?	Yes
	Are responsibilities clear in the implementation process?	Yes
COLLECTIVE ACTION Work done to implement new lighting technology	Is research sought after?	By the project leader/lighting professional: yes
	Is information sought after?	For the Project leader/Lighting professional: yes
	Is the architectural brief adequately detailed?	According to the Project leader/ Lighting professional: yes
	Is communication adequate in the implementation process?	According to the Project leader/ Lighting professional: yes
	Is communications between lighting professional and lighting programmer smooth?	Yes
REFLEXIVE MONITORING Appraising the implementation of new lighting technology	Is end-user feedback sought?	By the Client: no By the Project leader/Lighting professional: not extensively
	Is post occupancy survey conducted?	Not extensively
	Are results satisfying?	Generally yes
	Is the Lighting professional acknowledged after completion?	Yes, internally (internal project)

Figure 71.
Thematic analysis of responses for COWI.The themes are categorized next to their relevant NPT component.

COWI, INHIBITING AND FACILITATING FACTORS

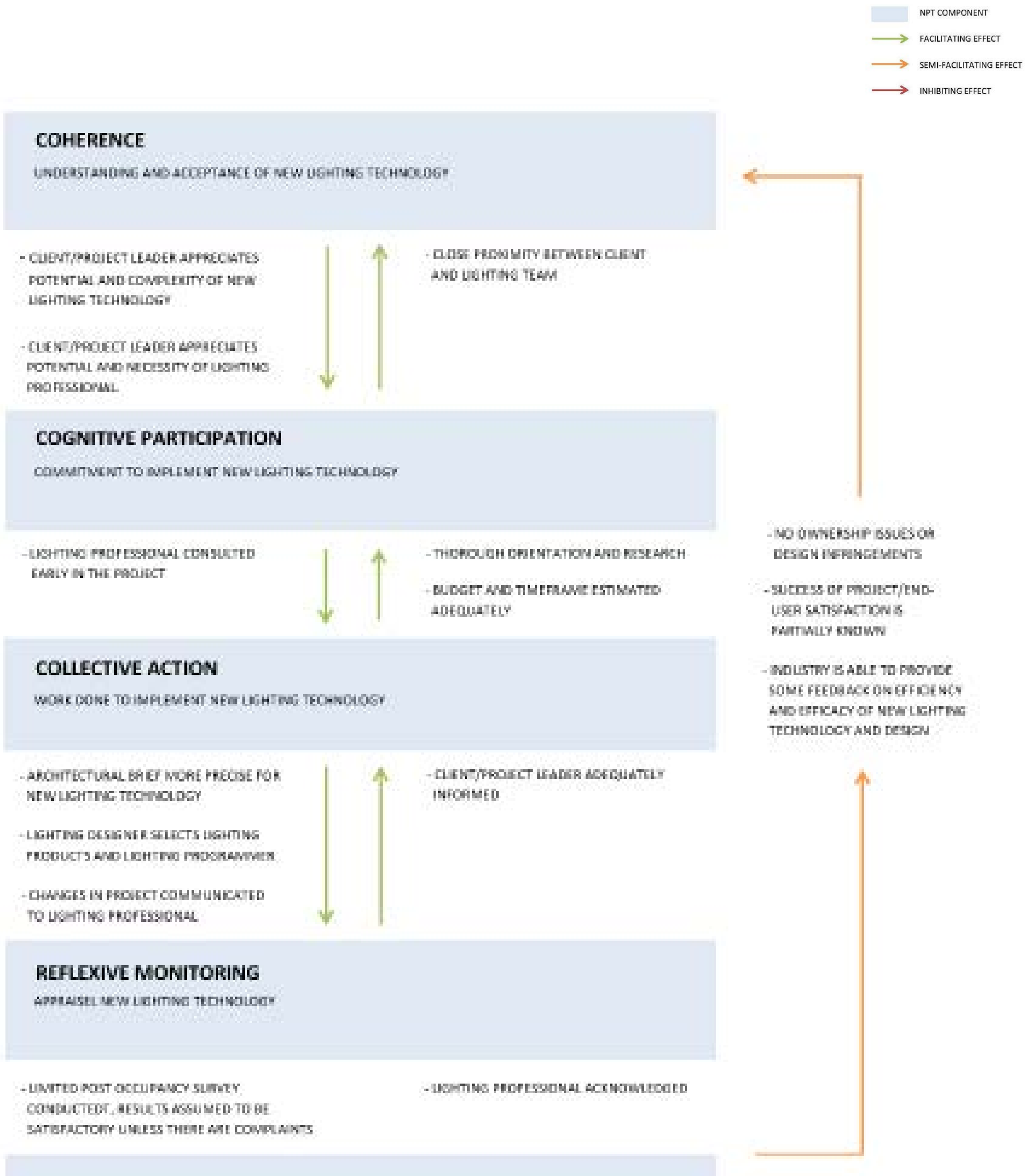


Figure 72.
Relationship and effects of attitude of the various actors in the implementation process for COWI .

Proposed implementation process model for new lighting technology

When the case studies are compared to the two basic implementation models from the general interviews, i.e. the general experience of lighting professionals, the case studies show a remarkable resemblance to how smaller and more specialized lighting projects are usually conducted. As such the case studies share many factors which are seen as facilitating in the implementation process by lighting professionals, and which make them fairly efficient. In both instances there is an increased appreciation of the complexity of new lighting technology, and equally an understanding of the necessity of the lighting professional. Although the lighting professional was not a project leader in the case studies, they were involved early on in the project and were in close proximity to the project leader and client. As such the lighting professional was consulted on the budget and time frame for the lighting part of the project, and changes in the project were done in consultation with the lighting professional. Finally, in both instances the lighting professional was recognized after completion of the project.

Unlike the previous general cases, the lighting professional in the Dansk Metal and COWI cases also consulted research.

Two points however remain which may be argued as being inhibitive in the implementation process.

Firstly, after installation the client in one case study encountered limitations of the system which he thought should have been pointed out to him, as he assumed what he needed should have been anticipated by the lighting professionals who he consulted.

Secondly, although both cases sought feedback of sorts, a full post-occupancy survey was not conducted. In the case of COWI, a short questionnaire was sent around to the office staff, which produced no real complaints according to the lighting professional in charge. In effect it may be argued that this validates to some degree the success of the project, and as such the efficiency of their implementation procedure. However, new lighting technology is still relative unchartered waters, which can be seen in the adjustments that were necessary in the case studies after the end-users started working under the new lighting conditions. As such end-user satisfaction surveys are deemed essential to the implementation process with respects to new lighting technology.

When the data is analyzed for both the general interviews with the lighting professionals, and the interviews with the lighting professionals and professionals involved in the selected case studies, it is possible to identify the facilitating factors and inhibiting factors of current implementation procedures where new lighting technology is installed. These relate to the following main determinants (tab.7):

Determinants in implementation of new lighting technology
1 Anticipating clients needs and informing clients of options
2 Appreciation of potential and complexity new lighting technology
3 Understanding of potential and necessity of lighting professional
4 Appreciation of budget and time frame for new lighting technology
5 Appreciation of the stage at which to involve the lighting professional
6 Understanding responsibilities and tasks of lighting professional
7 Appreciation information and research on new lighting technology
8 Appreciation of details for architectural brief
9 Appreciation on the necessity of communication with lighting professional with changes
10 Communication between lighting professional and lighting system programmer
11 Appreciation of post occupancy, or end-user satisfaction survey
12 Acknowledgement lighting professional after completion of project

Table 7

These determinants can be facilitating or inhibiting depending on how they are implemented. In other words, each determinant is facilitating if it is implemented, and inhibitive if it is not implemented. The proposed implementation model is thus based on these points, and is organized within the framework of the NPT scheme (fig.73). As such it is broadly divided into four fields which relate to the understanding of new lighting technology (coherence), commitment to participate in new lighting technology (cognitive participation), the work that is done to implement new lighting technology (collective action), and appraisal of new lighting technology (reflexive monitoring). The determinants are placed under their respective fields, where the relationship between the fields highlights how one affects the other. As was indicated in the case studies, adjustments continued to be made after the office staff started working under the new lighting conditions. It implies that the implementation process is by necessity not a linear model, but involves a cycle in which feedback constantly provides the project with new data for adjustment. This cycle arguably stops when the end-users are generally satisfied.

This thesis argues that if the proposed implementation process model is applied, a positive feedback loop will be created between research and knowledge, the commercial application of new lighting technology, and end-user satisfaction. This in turn will result in a more overall efficient implementation of new lighting technology for the building industry and the lighting industry in particular.

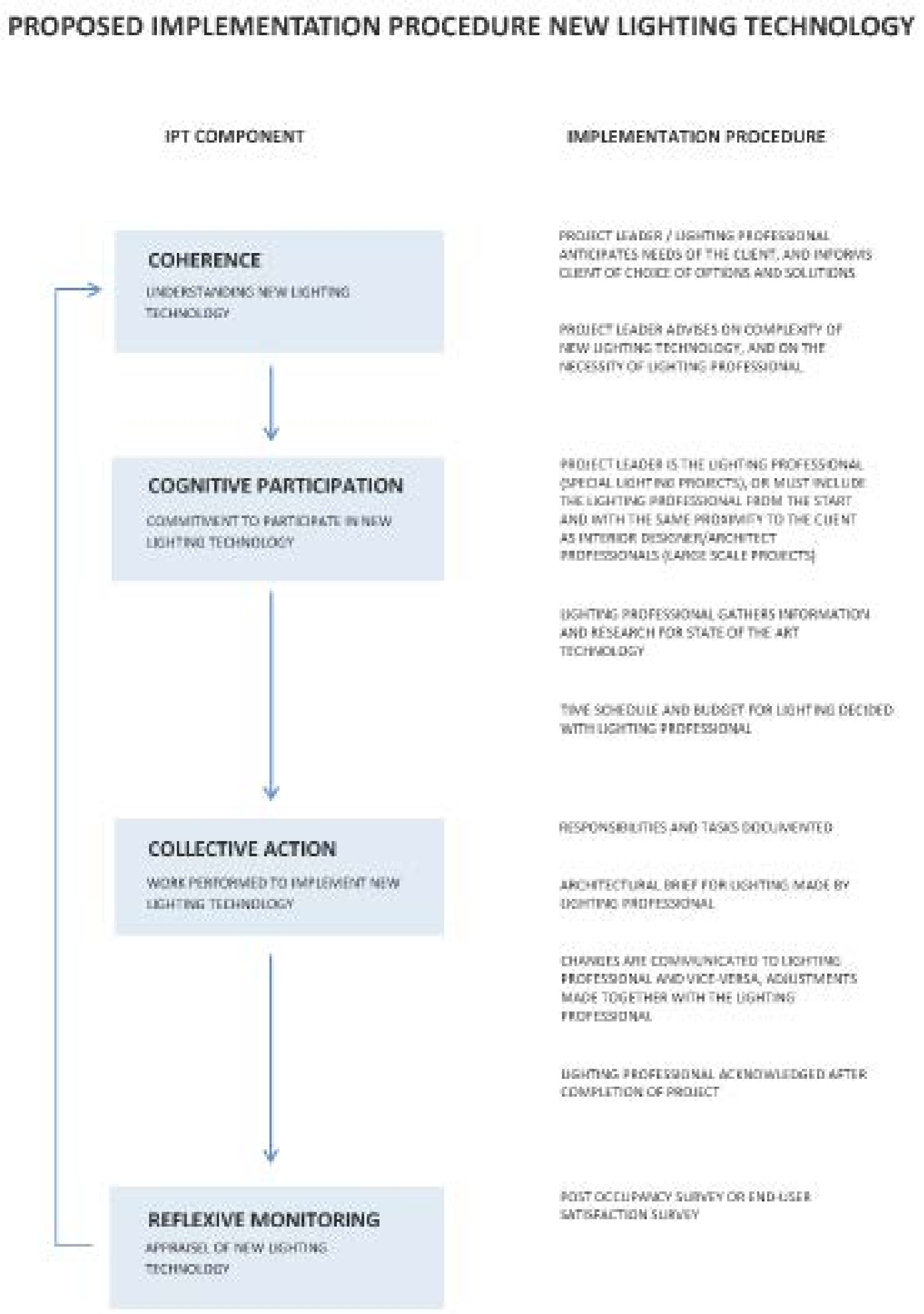

PROPOSED IMPLEMENTATION PROCEDURE NEW LIGHTING TECHNOLOGY
IPT COMPONENT
IMPLEMENTATION PROCEDURE
COHERENCE
UNDERSTANDING NEW LIGHTING TECHNOLOGY
PROJECT LEADER / LIGHTING PROFESSIONAL ANTICIPATES NEEDS OF THE CLIENT, AND INFORMS CLIENT OF CHOICE OF OPTIONS AND SOLUTIONS
PROJECT LEADER ADVISES ON COMPLEXITY OF NEW LIGHTING TECHNOLOGY, AND ON THE NECESSITY OF LIGHTING PROFESSIONAL
COGNITIVE PARTICIPATION
COMMITMENT TO PARTICIPATE IN NEW LIGHTING TECHNOLOGY
PROJECT LEADER IS THE LIGHTING PROFESSIONAL (SPECIAL LIGHTING PROJECTS), OR MUST INCLUDE THE LIGHTING PROFESSIONAL FROM THE START AND WITH THE SAME PROXIMITY TO THE CLIENT AS INTERIOR DESIGNER/ARCHITECT PROFESSIONALS (LARGE SCALE PROJECTS)
LIGHTING PROFESSIONAL GATHERS INFORMATION AND RESEARCH FOR STATE OF THE ART TECHNOLOGY
TIME SCHEDULE AND BUDGET FOR LIGHTING DECIDED WITH LIGHTING PROFESSIONAL
COLLECTIVE ACTION
WORK PERFORMED TO IMPLEMENT NEW LIGHTING TECHNOLOGY
RESPONSIBILITIES AND TASKS DOCUMENTED
ARCHITECTURAL BRIEF FOR LIGHTING MADE BY LIGHTING PROFESSIONAL
CHANGES ARE COMMUNICATED TO LIGHTING PROFESSIONAL AND VICE-VERSA, ADJUSTMENTS MADE TOGETHER WITH THE LIGHTING PROFESSIONAL
LIGHTING PROFESSIONAL ACKNOWLEDGED AFTER COMPLETION OF PROJECT
REFLEXIVE MONITORING
APPRAISEL OF NEW LIGHTING TECHNOLOGY
POST OCCUPANCY SURVEY OR END-USER SATISFACTION SURVEY

Figure 73.

Proposal for assessment questionnaire new lighting technology

Understanding the effects of new lighting technology, i.e. what works and what does not, is essential for the proposed implementation model. New lighting technology is more complex than older technologies in that it implies the ability to efficiently control more parameters of light, and in addition use these to affect changes in human behaviour. Because research on this topic is still ongoing, there is no ultimate consensus over the precise details of how illuminance and CCT should be changed as a function of time, and under what conditions.

As was argued in the previous chapter, the implementation process is by necessity a cycle which requires feedback from the end-users for adjustment of the lighting conditions. As such understanding the end-user experience is a necessary step in the implementation process cycle. The assessment however must be based on a number of parameters which are inherent to new lighting technology. Besides illuminance and CCT, questions must equally relate to the temporal aspects of this technology. In other words, appreciation of illuminance levels and CCT values must be related to the question of time.

The following is an example of how this may be set up using the case study of Dansk Metal as an example. As discussed in the Methodology chapter, this is most efficiently done with closed ended forced choice questions in the form of a questionnaire. In addition, the option of a neutral response has been omitted. This was done to nudge the respondents to think more critically of the lighting situation, and the questions.

The questions are based on the results of fieldwork, in this case for the case study of Dansk Metal. One of the challenges of the building are the two different facades which flank the open office areas. The building has much smaller single pane windows on the darker façade with a larger space between them, whereas the façade facing the sun has double pain windows with less spacing between them. This reduces the amount of daylight that can enter the dark side more than that for the sun facing side. Daylight factoring equally shows the impact this has on the space, where the light reaches almost twice the distance into the building on the sun facing side of the building, than on the dark side.

This situation is exacerbated by the automatic blinds which tend to come down at odd times. As such, it is assumed that any dissatisfaction with the illuminance levels will be related firstly to the position of the work station in relation to the façade, and window type. Secondly it is assumed that this dissatisfaction is mostly related to the automatic blinds. In other words, it is expected that there is some dissatisfaction by office staff who work on the dark side of the building, closest to a single pain window, and when the blinds are down.

There is however a second issue related to the interior decoration of the office spaces. Similar to the case of the window types, the workstations located on the dark side of the offices consist in some sections of high closed shelves which are places perpendicular to the façade wall, and run the full length of two desks in some cases. These block the already sparse light coming through the small windows, and create dark working conditions for the office staff in these areas. It was observed that also in the summer, staff members used desk lighting particularly on the dark side of the building and in the middle. Finally, the CCT levels were noted to be somewhat high. They had already been turned down after initial informal feedback by office staff. As this process of adjustment was still ongoing, some dissatisfaction with respects to high CCT levels is expected.

The lighting situation for Dansk Metal is complex. The concept is based on supporting the circadian cycle of the office staff, and at the same time stimulating conditions for concentration and for informal communication at the office. In addition, the lighting was made to vary to provide a more optimal peripheral view of the office staff. The topography of the lighting thus shows a dotted layout, where some areas are static, with low CCT and illuminance levels, whereas other areas are a variety of higher and lower CCT and illuminance levels. In addition, the light changes not only throughout the day, but equally along two slightly different schedules: a summer and a winter schedule.

The question of end-user satisfaction thus revolves around the illuminance and CCT levels of the light, and how these either change or remain static over time. The first step is to understand how end-users rate the illuminance levels and CCT. The choices of answers are presented in the form of a Likert scale, where the options are presented descriptively (tab.9):

Satisfaction rating
Very satisfactory
Satisfactory
Somewhat satisfactory
Somewhat unsatisfactory
Unsatisfactory
Very unsatisfactory

Table 8.

The next step is understanding how they experience the illuminance and CCT levels. Similar to the previous question, the answers are presented in a Likert scale form. The illuminance levels and CCT however each require a different type of answer, i.e. a different description. In the case of the illuminance levels, the choices presented related to brightness, and for the CCT values the choices related to the warmness and coldness of light (tab.10), albeit with an additional explanation in the questionnaire that warm light was reddish in colour and cold light bluish:

Illuminance levels	CCT values
Too bright	Too warm
Bright	Warm
Somewhat bright	Somewhat warm
Somewhat dark	Somewhat cold
Dark	Cold
Too dark	Too cold

Table 9.

The third step is relating each of these questions to the factor of time, which relates both to the time of day as well as the season. The time of day is related only to the time frame when the office staff is working at the office, and is split up in to morning, lunch time, and afternoon. Respondents are given the option to fill in a combination of these choices in an open answer box equally listed in the choice of answers. The seasons are split between summer and winter (tab.11), which is based on the two different lighting programming schedules that are used by Dansk Metal. Because the questionnaire is filled out in the summer period, the memory of how the light was in the previous winter may not always be clear. As such, the options fo answering with respects to the winter period include an additional ‘ I can’t remember’ box:

Summer period	Winter period
All day	All day
Morning	Morning
Lunchtime	Lunchtime
Afternoon	Afternoon
Other	Other
	I can´t remember

Table 10.

The lighting system at Dansk Metal relied on daylight harvesting and automatic blinds to regulate illuminance levels. In addition, during the preliminary fieldwork it was firstly noted that the amount of daylight that entered the office spaces differed greatly due to the position of the building and the size of the windows, the latter of which was different for each façade. Secondly it was noted that also in the summer period office staff still used desk lighting in certain areas of the office space. Finally, during informal conversations with the office staff, it was revealed that the automatic blinds would sometimes make the office space too dark.

The next question that is thus asked relates to the location of the work stations. This is done by presenting a respondent with a plan drawing of their floor, and asking them to indicate where they are located based on a number of zones either close to one of the facades or in the middle. These zones derive from the fieldwork and notes made on where the workstations are located.

To understand the impact and relationship between the automatic blinds, the window size and the orientation of the building, additional questions are asked relating to the effectiveness of the automatic blinds, and the type of windows closest to the respondent´s work station.

The question of the effectiveness of the automatic blinds related to a simple yes/no choice as to whether or not they were thought to function adequately. If the respondent thought the blinds were not functioning well, this was followed up with a question on whether the conditions they produced were too bright, too dark or confusing (tab.12). This was equally asked for both the summer and winter period, and included an option for the earlier mentioned ´I can´t remember´ choice for the winter period:

Summer	Winter
It gets too dark	It gets too dark
It gets too bright	It gets too bright
Sometimes it´s too dark, and sometimes too bright	Sometimes it´s too dark, and sometimes too bright
Other	Other
	Can´t remember

Table 11.

Again, due to the dynamic lighting system, this question is equally related to the question of whether the experience is time or seasonally dependent, and formulated in the same way as for the questions on the experience of the general illuminance and CCT levels.

To understand what type of window is located closest to the respondent, a photograph of both types are presented in the questionnaire with the question which one is closest. A third option is presented for the staff located in the middle of the building, who can check a box indicating they are equidistant from both types of windows, i.e. both facades.

The next question relates to the time of day the respondents are filling out the question. This is broken up into three periods as with the previous questions involving the time of day, with the options of morning, lunchtime and afternoon.

Finally, because the physical condition of the respondent determines the efficiency and efficacy of photoreception, photo-transduction and processing of light stimuli, questions relating to gender, age and visual acuity are asked.

The questionnaire is concluded with an optional open comment box so that any additional comments can be written. An example is included in the appendix.

Conclusion

The thesis aimed at answering the following questions:

- How efficient are current implementation processes for new lighting technology in offices?
- How can we increase the efficiency of current implementation processes for new lighting technology in offices?
- How can the efficacy of new lighting technology in offices be assessed?

Overall, the standard implementation process for current projects involving new lighting technology varies depending on the size of the project. For smaller more specialized lighting projects, the lighting professional is involved early in the project, mostly as project leader. Budget and time frame are estimated by the lighting professional, and the implementation process is fairly efficient. Much of the elements in this process which contribute to its efficiency are due to the appreciation of the complexity of new lighting technology, and the necessity of a lighting professional to be in charge of its implementation. This seems to be the opposite for large scale projects, where lighting is but one part of the project. In these bigger projects, this process seems to be cumbersome and ineffective. The crux of the problems is an under appreciation of the complexity of light at the highest levels of the project. This has a knock on effect with respects to informing the client of this complexity, involving a lighting professional early in the project, as well as allocating enough budget and time for the lighting aspect of the project.

Whereas the more efficient smaller lighting projects succeed in implementing new lighting technology, the end-result for the less efficient larger projects is more than often a less complex lighting system, where the original concept for new lighting technology is adjusted to technology that merely has to meet the meet the minimum requirements.

The case studies on the other hand show that it is possible to efficiently implement new lighting technology in large scale projects.The implementation process for the case studies was similar to that of smaller more specialised lighting projects, and followed similar steps. As such this implementation model, i.e. one that appreciates the complexity of new lighting technology, and the importance and necessity of the lighting professional, can be taken as a template. Yet, due to the lack of end-user or post occupancy surveys, this implementation process is still inefficient, and results in continued adjustments of the new lighting technology after installment, and over longer periods of time.

The lack of post occupancy surveys equally impacts the progress of research and industry in new lighting technology. In practice many applications of new lighting technology are still unpredicatble, and without feedback proper understanding of this technology will be slow.

As such, the efficiency of current implementation processes can be increased by adding the assessment of end-user satisfaction after installment as a step within the process. Based on this, this thesis has proposed an implementation model to increase the efficiency of current implementation processes for new lighting technology, by adding the aspect of post occupancy surveys, or assessment of end-user satisfaction as a final step in the process.

The proposed implementation model stresses the need for feedback to advance knowledge on new lighting technology, and increase end-user satisfaction. The assessment of new lighting technology however is fundamentally different from that of older lighting. New lighting technology is dynamic and not static, and both the CCT and illuminance can be controlled as a function of time. In other words, the assessment will have to account not only for the illuminance and CCT levels, yet equally for their changes over time.

By using one of the case studies as a testbed, this study has equally proposed an approach to the assessment of end-user satisfaction for cases where dynamic lighting has been implemented. Besides questions about age, gender, location of the work station etc, respondents are asked to rate and describe the CCT and illuminance levels, and in addition indicate whether or not their experiences are dependent on the time of day, or the season.

By analyzing the efficiency of current implementation processes for new lighting technology, and by proposing both an alternative implementation model to increase the efficiency of this implementation, as well as a model of approach for the assessment of end-user satisfaction for this new technology, this thesis contributes in three ways to the study of lighting, and the building and lighting industry in general. Firstly it contributes to the management of lighting projects by presenting an analysis of current implementation procedures, and as such an analysis of which factors contribute to its efficiency, and which do not. Secondly, the proposed more efficient implementation model contributes by resolving issues which hamper current implementation precesses. Finally, it contributes to reducing proposes an alternative implementation process model to resolve some of the issues which hamper the efficiency of current implementation processes for new lighting technology in office environments. Finally, the proposed assessment method for new lighting technology contributes to research and development of new lighting technology, and help to increase end-user satisfaction.

Discussion and final remarks

The proposed implementation process model, as well as the proposed assessment scheme for new lighting technology remains untested. The model therefore needs to be applied and scrutinized in other cases. One of the greater challenges in this is the behaviour of the project leader. Due to the competitive nature of the building industry, project leaders are pressured by budget constraints, which in turn are dictated by their clients. A change in attitude towards new lighting technology can probably only happen if the industry drives this in unison at a grass-root level. Because of this, implementing the proposed model will therefore remain challenging. Yet as the cases of Dansk Metal, COWI and DTU demonstrate, there are some companies that are willing to invest and try out new lighting technology. This makes cases like Dansk Metal, COWI and DTU important for both industry and research.

Unlike the proposed implementation model, the proposed end-user assessment scheme for new lighting technology will be used for Dansk Metal to understand end-user satisfaction. The analysis of this is expected to be used to further adjust the lighting. This in effect will be a testbed for the proposed scheme.

Because the interviews were anonymous, the recordings of the interviews as well as personal notes are not included in the appendix.

Bibliography

Baron, Rea and Daniela. (1992). Effects of Indoor Lighting (Illuminance and Spectral Distribution) on the Performance of Cognitive Tasks and Interpersonal Behaviors: The Potential Mediating Role of Positive Affect, *Motivation and Emotion*, Vol. 16, No. L 1992

Van den Beld, G.J. (2002). Healthy Lighting, Recommendations for Workers. Presented at the *Symposium healthy lighting at work and at home*, SOLG, University of Technology, Eindhoven, The Netherlands

Boivin, James.(2002). Circadian adaptation to night-shift work by judicious light and darkness exposure, *J Biol Rhythms,* 17:556-567.

Bryman, A. (2012). *Social Research Methods*. 4 ed., Oxford University Press, New York

CELMA TF. (2011). *Apples and Pears, CELMA Guide standardisation of performance LED luminaires,* Retrieved on June 1st, 2017 from https://www.led-professional.com/technology/standardization/standardization-of-performance-criteria-for-led-luminaires/celma_tf_apples_pears-kr

Choi K, Suk J. (2016). Dynamic lighting system for the learning environment: performance of elementary students. *Optics Express,* 24(10):A907-A916

Creswell, J., & Clark, V. (2011). *Designing and Conducting Mixed-methods Research*. Sage Publishing, Los Angeles, Singapore, New York.

Crowley S.J, Lee C., Tseng C.Y., Fogg L.F., Eastman C.I. (2003).Combinations of Bright Light, Scheduled Dark, Sunglasses, and Melatonin to Facilitate Circadian Entrainment to Night Shift Work*, J Biol Rhythms*, Dec;18(6):513-23

Deutsches Institut für Normung. (2013). Biologisch wirksame Beleuchtung - Planungsempfehlungen (DIN SPEC 67600:2013 - 04)

Dansk Standard. (2011). Belysning ved arbejdspladser (DS/EN 12464 2011). Charlottenlund

Eastman CI, Stewart KT, Mahoney MP, Liu L, Fogg LF. (1994). Dark Goggles and Bright Light Improve Circadian Rhythm Adaptation to Night-shift Work. *Sleep,* 17:535–43

European Commission Staff Working Document. (2016). EU GPP Criteria for Office Building Design, Construction and Management, Retrieved on June 1st, 2016 from http://ec.europe.eu/environment/gpp/pdf/swd_2016_180.pdf

Eldred.(1992). Optimal Illumination for Reading in Patients with Age-related Maculopathy, *Optometry and Vision Science : Official Publication of the American Academy of Optometr*y, Jan 69(1):46

Ekirch, A. Roger. (2001). Sleep We Have Lost: Pre-industrial Slumber in the British Isles, *American Historical Review*, Oxford University Press on behalf of the American Historical Association, 106 (2): 343–386.

Ellis, E.V., Gonzalez, E.W., Kratzer, D.A., McEachron, D.L., Yeutter, G. (2013). , Auto-tuning Daylight with LEDs: Sustainable Lighting for Health and Wellbeing, Presented at ARCC 2013 | The Visibility of Research Sustainability: Visualization Sustainability and Performance, Charlotte

EU Green paper.(2011).Lighting the Future Accelerating the deployment of innovative lighting technologies, Retrieved on June 1st, 2017 from https://ec.europa.eu/digital-single-market/en/news/public-consultation-lighting-future-accelerating-deployment-innovative-lighting-technologies

EU Interreg.(2016). Dynamic Lights—Towards Dynamic, Intelligent and Energy Efficient Urban Lighting, Retrieved on June 1st, 2017, from file:///C:/Users/Sen/Downloads/Dynamic%20Light%20Project%20Summary.pdf

Figueiro, M.G. (2008). A proposed 24 h lighting scheme for older adults. *Lighting Res Technol*; 40:153–160

Fotios.(2017). A Revised Kruithof Graph Based on Empirical Data, *LEUKOS*, 13:3–17

Geerz, C. (1973). *The interpetation of cultures,* (1st ed.). Basic Books. New York

Goven, Laike, Pendse, Sjöberg.(2007). The Background Luminance and Colour Temperatures Influence on Alertness and Mental Health, Presented at the nordic LIGHTING + DESIGN conference - October 2008

Hanford, N., Figueiro, F. (2013). Light Therapy and Alzheimer´s Disease and Related Dementia: Past, Present and Future. *J Alzheimers Dis*, Jan 1; 33(4): 913-922

Hawes B.K., Brunyé T.T., Mahoney C.R., Sullivan J.M. (2012).Effects of Four Workplace Lighting Technologies on Perception, Cognition and Affective State, *Int J Ind Ergon,* 42:122-128

Jeffrey S. Heier,David M. Brown,Victor Chong, Jean-Francois Korobelnik, Peter K. Kaiser, Quan Dong Nguyen, Bernd Kirchhof, Allen Ho,Yuichiro Ogura,George D. Yancopoulos,Neil Stahl, Robert Vitti,Alyson J. Berliner,Yuhwen Soo, Majid Anderesi, Georg Groetzbach, Bernd Sommerauer, Rupert Sandbrink, Christian Simader, Ursula Schmidt-Erfurth. (2012). Intravitreal Aflibercept (VEGF Trap-Eye) in Wet Age-related Macular Degeneration, *Ophthalmology,* Volume 119, Number 12, December

Knez I.(1995). Effects of Indoor Lighting on Mood and Cognition, *Journal of Environmental Psychology,*15, 39-51

Kruithof, Arie Andries (1941). Tubular Luminescence Lamps for General Illumination, *Philips Technical Review*, 6 (3): 65–96.

Küller R, Ballal S, Laike T, Mikellides B, Tonello G. (2006). The Impact of Light and Colour on Psychological Mood: a Cross-cultural Study of Indoor Work Environments, *Ergonomic,* Nov 15;49(14):1496-507

Lack L, Wright H, Kemp K, Gibbon S.(2005). The Treatment of Early-morning Awakening Insomnia with Two Evenings of Bright Light, *Sleep,*28(5):616–23.

Lincoln, Y., Guba, E., & Pilotta, J. (1985). Naturalistic Inquiry, *International Journal Of Intercultural Relations*, *9*(4), 438-439

Logadóttir, Á., Hvass, M., Bay, A., Møjen, J. (2016). Brugertilfredsstillende og Energibesparende Reguleringsstrategier for Belysning. Afslutningsrapport PSO 346-034. Statens Byggeforskningsinstitut

Lucas, R.J., Peirson, S., Berson, D.M., Brown, T.M., Cooper, H.M., Czeisler, C.A., Figueiro, M.G., Gamlin, P.D., Lockley, S.W., O'Hagan, J.B., Price, L.L.A., Provencio, I., Skene, D.J., & Brainard, G.C. (2013). Measuring and Using Light in the Melanopsin Age, *Trends in Neurosciences,* January, Vol. 37, No. 1

May C, Finch T, Mair F, Ballini L, Dowrick C, Eccles M, et al. (2007). Understanding the Implementation of Complex Interventions in Health Care: the Normalization Process Model, *Implement Sci*, 7:148

McClaughan, Aspinall, Webb. (1999). The Impact of Lighting on Mood, *Lighting Research and Technology*, Vol 31 no.3, 81-88

Timothy I. Morgenthaler, Teofilo Lee-Chiong,Cathy Alessi, Leah Friedman, R. Nisha Aurora, Brian Boehlecke, Terry Brown, Andrew L. Chesson, Jr., Vishesh Kapur, Rama Maganti, Judith Owens, Jeffrey Pancer, Todd J. Swick, Rochelle Zak. (2007). Practice Parameters for the Use of Actigraphy in the Assessment of Sleep and Sleep Disorders: an Update for 2007, *Sleep,* 30:519–29.

Murray, E., Treweek,S., Pope,C., MacFarlane, A., Ballini, L.,Dowrick,C.,Finch, T.,Kennedy, A.,-Mair, F.,O'Donnell, C.,Ong, B.N.,Rapley, T.,Rogers.,May, C. (2010). Normalisation Process Theory: a Framework for Developing, Evaluating and Implementing Complex Interventions, *BMC Med*, 8:63.

Nilsen. (2015).Making Sense of Implementation Theories, Models and Frameworks, *Implementation Science*, 10: 53

Norris. (1997). Error, Bias and Validity in Qualitative Research, *Educational Action Research*, Volume 5, No. 1

Rajendran.(2001).Dealing With Biases in Qualitative Research: a Balancing Act for Researchers, Presented at Qualitative Research Convention 2001, Kuala Lumpur

Risen, C. (2016). Seeking Compatibility in the LED Era, *Architectural Lighting Technology*, Retrieved on June 1st, 2017 from http://www.archlighting.com/technology/seeking-compatibility-in-the-led-era_o

Rosenthal, Vanderpool, Levendosky, Johnston, Allen, Kelly, Souetre, Schultz, Starz. (1990). Phase-shifting Effects of Bright Morning Light as Treatment for Delayed Sleep Phase Syndrome, *Sleep*,13(4):354–61

Rothstein, Sutton, Borenstein (Ed).(2005). *Publication Bias in Meta-Analysis Prevention, Assessment and Adjustments,* Wiley

Schlangen, Lang, Novotny, Plischke, Smolders, Beersma, Wulff, Foster, Cajochen, Nikunen, Tähkämö, Bhusal, Halonen. (2014). *Lightning for Well-being in Education, Work Places, Nursing Homes, Domestic Applications, and Smart Cities*, SSL-Erate Consortium. (http://lightingforpeople.eu/2016/wp-content/uploads/2016/03/SSLerate-3.2-3.4-v4.pdf)

Shenton.(2002). Strategies for Ensuring Trustworthiness in Qualitative Research Projects, *Education for Information,* 22; 63–75

Sust, Dehoff, Lang, Lorenz. (2012). *More Light! Improving Well-being for Persons suffering from Dementia,* Presented at the International Conference on Human Aspects of IT for the Aged Population 2015, Toronto

Terkildsen, M. (2004). Indretning af plejecentre – for svage ældre og mennesker med demens. Styrelsen for Social Service, ISBN 87-91247-35-7

Terman M, Terman J.S., Quitkin, F.M., McGrath, P.J., Stewart, J.W., Rafferty, B.(1989). Light therapy for seasonal affective disorder. A review of efficacy, Neuropsychopharmacology, Mar;2(1):1-22

Turner, Mainster. (2008). Circadian photoreception: ageing and the eye's important role in systemic health, *British Journal of Ophtalmology, Volume 92, Issue 11*

US Department of Energy.(2015). Led Lighting, Retrieved on June 1st, 2017 from https://energy.gov/energysaver/led-lighting

Viola, Schlangen, Dijk. (2008). Blue Enriched White light in the Workplace Improves Self-reported Alertness, Performance and Sleep Quality, *Scandinavian Journal of Work, Environment & Health.* 34(4): 297-306

Walmsley,L., Hanna, L.,Mouland, J.,Martial, F.,West, A.,Smedley, A.R.,Bechtold, D.A.,Webb, A.R.,Lucas, R.J.,Brown, T.M. (2015). Colour As a Signal for Entraining the Mammalian Circadian Clock, *PLOS Biology*., April 17; 13(4)

Yamagishi, M., Yamaba, K., Kubo, C.,Nokura, K., Nagata, M. (2008). Effects of LED lighting Characteristics on Visual Performance of Elderly People*, Gerontechnology,* 7(2), 243

Yoon, In-Young, Do-Un Jeong, Ki-Bum Kwon, Sang-Bum Kang & Byoung-Gun Song (2002). Bright Light Exposure at Night and Light Attenuation in the Morning Improve Adaptation of Night Shift Workers. *Sleep*, May 1;25(3):351-6

Appendix

Kære forsøgsdeltager,

Sammen med Dansk Metal vil Statens Byggeforskningsinstitute, Aalborg Universitet dokumentere brugererfaringer om lysinstallationer som er installeret i jeres bygning. Spørgeskemaet er en del af et projekt støttet af ELFORSK om brugeroplevelse af nye lysinstallationer.

Spørgeskemaet er opdelt I tre dele, den første del dækker din oplevelse af det visuelle miljø, anden del omfatter dagslysforholdene i lokalet og tredje del indeholder generelle spørgsmål.

Vi håber du vil bruge 5 til 10 minutter på at svare på vores spørgsmål om dine oplevelser. Dine svar bliver behandlet fortroligt og din organisation modtager resultater anonymt.

I tilfælde af spørgsmål, venligst kontakt:
Ásta Logadóttir (asl@sbi.aau.dk)

På forhånd tak for hjælpen

I tilfælde af spørgsmål, venligst kontakt:
Ásta Logadóttir (asl@sbi.aau.dk)

På forhånd tak for hjælpen

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

Afsnit , Det visuelle miljø

Denne del omfatter det visuelle miljø som et resultat af lysanlægget i dit arbejdslokale, vi sætter pris på at du svarer så godt som muligt på efterfølgende spørgsmål:

Hvordan oplever du belysningsniveauet i dit arbejdslokale?

- ☐ Meget tilfredsstillende
- ☐ Tilfredsstillende
- ☐ Nogenlunde tilfredsstillende
- ☐ Nogenlunde utilfredsstillende
- ☐ Utilfredsstillende
- ☐ Meget utilfredsstilllende

Hvordan vil du beskrive lyset i dit arbejdslokale?

- ☐ For lyst
- ☐ Lyst
- ☐ Nogenlunde lyst
- ☐ Nogenlunde mørkt
- ☐ Mørkt
- ☐ For mørkt

Er din opfattelse af lyset i lokalet afhængig af et specifikt tidsinterval?

- ☐ Nej, det samme gælder for hele dagen
- ☐ Ja, generelt er der kun tændt i morgentimerne
- ☐ Ja, generelt er der kun tændt omkring frokosttid
- ☐ Ja, generelt er der kun tændt om eftermiddagen
- ☐ Andet__________

Hvordan oplever du lysfarven i dit arbejdslokale?

- ☐ Meget tilfredsstillende
- ☐ Tilfredsstillende
- ☐ Nogenlunde tilfredsstillende
- ☐ Nogenlunde utilfredsstillende
- ☐ Utilfredsstillende
- ☐ Meget utilfredsstilllende

Hvordan vil du beskrive lysfarven? (Varmt lys er gult/orange og koldt lys er blåligt)

- ☐ For varmt
- ☐ Varmt
- ☐ Nogenlunde varmt
- ☐ Nogenlunde koldt
- ☐ Koldt
- ☐ For koldt

Er din opfattelse af lysfarven i lokalet afhængig af et specifikt tidsinterval?

- ☐ Nej, det samme gælder for hele dagen
- ☐ Ja, generelt er der kun tændt i morgentimerne
- ☐ Ja, generelt er der kun tændt omkring frokosttid
- ☐ Ja, generelt er der kun tændt om eftermiddagen
- ☐ Andet__________

Nu er det tid til at tænke tilbage til foregående vintersæson. Du må meget gerne svare generelt for vintersæsonnen som du bedst husker den.

Hvordan oplevede du belysningsniveauet i dit arbejdslokale i vinterperioden?

- ☐ Meget tilfredsstillende
- ☐ Tilfredsstillende
- ☐ Nogenlunde tilfredsstillende
- ☐ Nogenlunde utilfredsstillende
- ☐ Utilfredsstillende
- ☐ Meget utilfredsstillende
- ☐ Det kan jeg ikke huske

Hvordan vil du beskrive lyset i dit arbejdslokale i vinterperioden?

- ☐ For lyst
- ☐ Lyst
- ☐ Nogenlunde lyst
- ☐ Nogenlunde mørkt
- ☐ Mørkt
- ☐ For mørkt
- ☐ Det kan jeg ikke huske

Var din opfattelse af lyset i lokalet afhængig af et specifikt tidsinterval?

- Nej, min opfattelse gælder generelt for hele dagen
- Ja, min opfattelse gælder generelt for morgentimerne
- Ja, min opfattelse gælder generelt omkring frokosttid
- Ja, min opfattelse gælder generelt for eftermiddagen
- Andet__________
- Det kan jeg ikke huske

Hvordan oplevede du lysfarven i dit arbejdslokale i sidste vinter?

- Meget tilfredsstillende
- Tilfredsstillende
- Nogenlunde tilfredsstillende
- Nogenlunde utilfredsstillende
- Utilfredsstillende
- Meget utilfredsstillende
- Det kan jeg ikke huske

Hvordan vil du beskrive lysfarven i dit arbejdslokale i vinter perioden? (Varmt lys er gult/orange og koldt lys er blåligt)

- Nej, min opfattelse gælder generelt for hele dagen
- Ja, min opfattelse gælder generelt for morgentimerne
- Ja, min opfattelse gælder generelt omkring frokosttid
- Ja, min opfattelse gælder generelt for eftermiddagen
- Andet__________
- Det kan jeg ikke huske

Er din opfattelse af lysfarven i lokalet afhængig af et specifikt tidsinterval?

- Nej, min opfattelse gælder generelt for hele dagen
- Ja, min opfattelse gælder generelt for morgentimerne
- Ja, min opfattelse gælder generelt omkring frokosttid
- Ja, min opfattelse gælder generelt for eftermiddagen
- Andet__________
- Det kan jeg ikke huske

Har du en bord lampe?

- Ja
- Nej

I hvilken grad tænder du din bord lampe?

- Aldrig
- Meget sjældent
- Nogen gange
- Ofte
- Altid

Afhænger dit brug af bordlampe af sæsonen?

- Nej, det samme gælder for hele året
- Ja, jeg tænder bordlampen mest i sommer halvåret
- Ja, jeg tænder bordlampen mest i vinter halvåret

Afhænger dit brug af bordlampe af et specifikt tidsinterval på dagen?

- Nej, det samme gælder for hele dagen
- Ja, generelt er der kun tændt i morgentimerne
- Ja, generelt er der kun tændt omkring frokosttid

- ☐ Ja, generelt er der kun tændt om eftermiddagen
- ☐ Andet_________

Afsnit 2, Dagslys

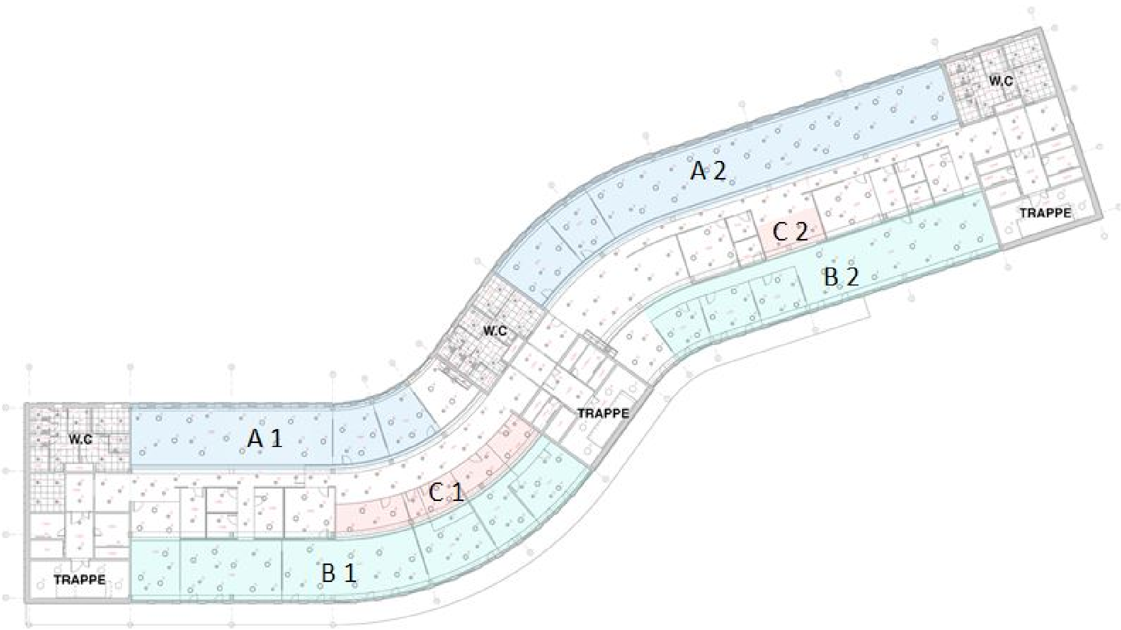
Efterfølgende spørgsmål drejer sig om din placering i lokalet og de dagslysforhold du oplever

På hvilken etage arbejder du?

- ☐ 1. Sal
- ☐ 2. Sal
- ☐ 3. Sal
- ☐ 4. Sal

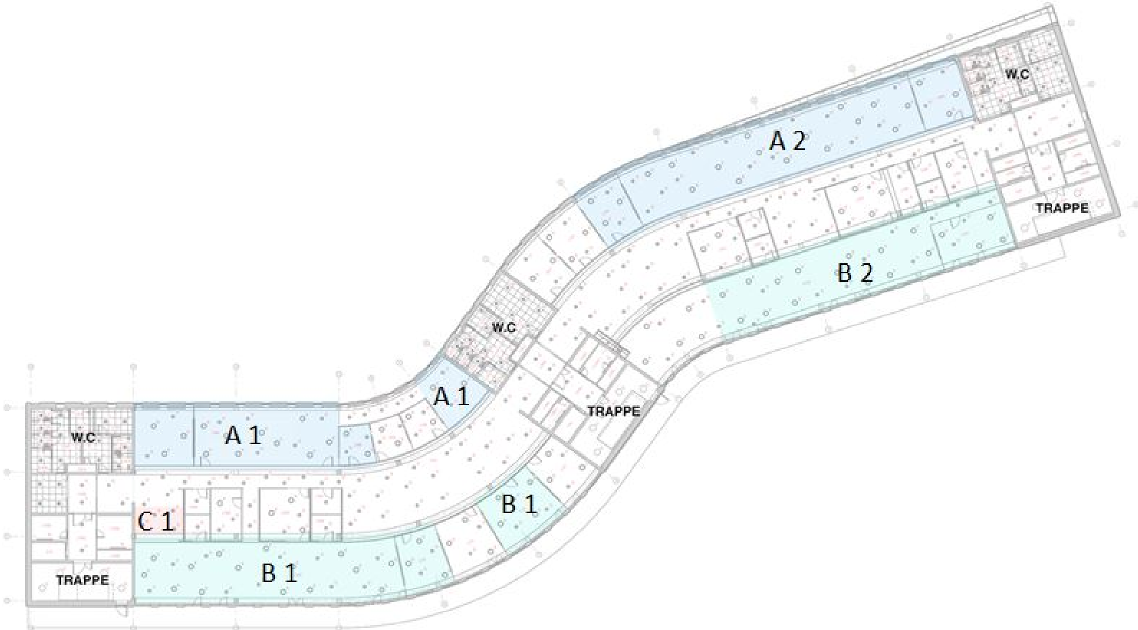
I hvilket område er dit skrivebord?

- ☐ A1
- ☐ A2
- ☐ B1
- ☐ B2
- ☐ C1
- ☐ C2



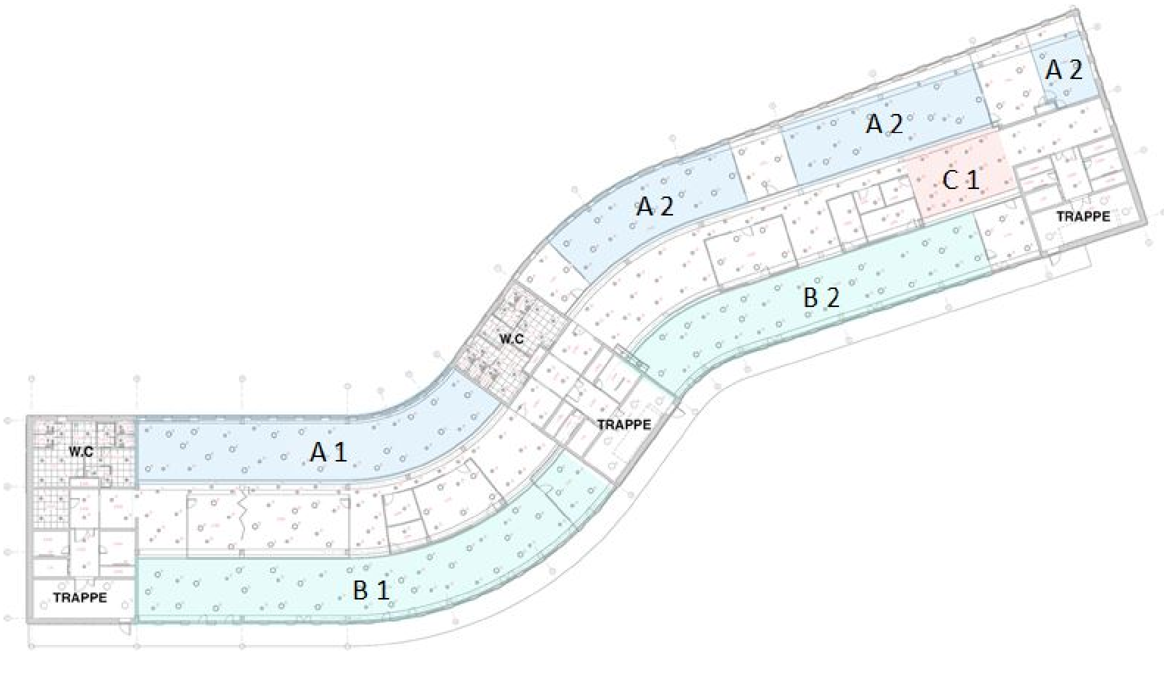
I hvilket område er dit skrivebord?

- ☐ A 1
- ☐ A 2
- ☐ B 1
- ☐ B 2
- ☐ C 1



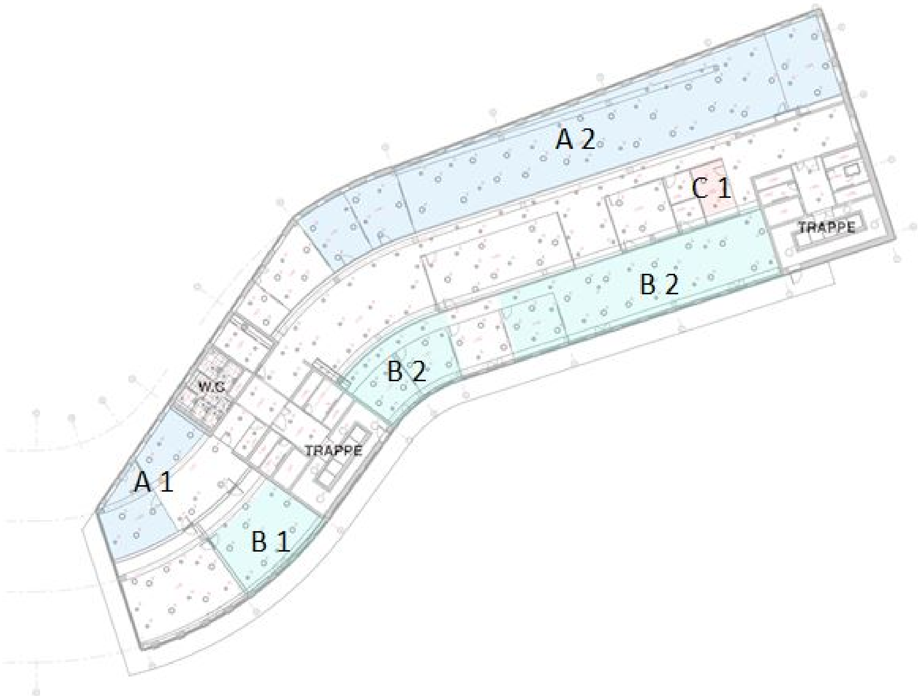
I hvilket område er dit skrivebord?

- A 1
- A 2
- B 1
- B 2
- C 1



I hvilket område er dit skrivebord?

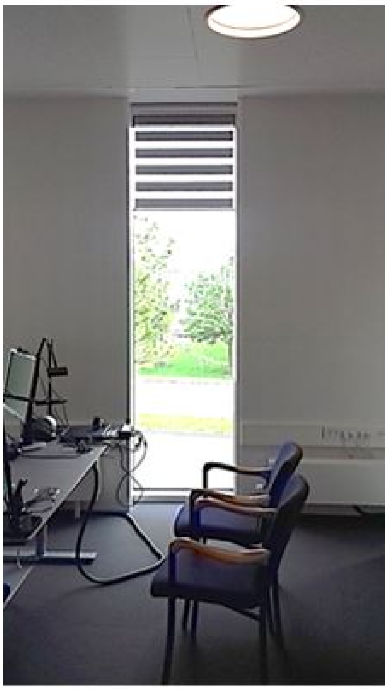
- A 1
- A 2
- B 1
- B 2
- C 1



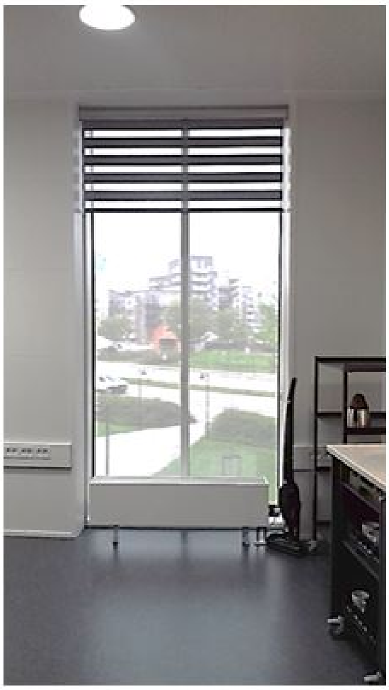
Hvor langt er du placeret fra det nærmeste vindue?

- ☐ Jeg sider ved vinduespladsen
- ☐ andet eller tredje bord fra vindue
- ☐ Jeg sidder omkring midten af bygningen

Hvilke vindues type er tættest på dig?



A



B

- ☐ A
- ☐ B
- ☐ Jeg sidder med samme afstand til begge vinduestyper

Mener du solafskærmningen virker som den skal?

- ☐ Ja
- ☐ Nej

Kryds venligst den udtalelse af som passer bedst til at beskrive solafskærmningens indflydelse på det visuelle miljø.

Den automatiske solafskærmning medfører situationer hvor:

- ☐ Det blev for mørkt
- ☐ Det blev for lyst
- ☐ Nogle gange blev det for mørkt og andre gange for lyst
- ☐ Andet_________

Afhænger din opfattelse af det visuelle miljø af et specifikt tidsinterval på dagen?

- ☐ Nej, det samme gælder for hele dagen
- ☐ Ja, generelt er der kun tændt i morgentimerne
- ☐ Ja, generelt er der kun tændt omkring frokosttid
- ☐ Ja, generelt er der kun tændt om eftermiddagen
- ☐ Andet_________

Nu er det tid til at tænke tilbage til foregående vintersæson. Du må meget gerne svare generelt for vintersæsonnen som du bedst husker den.

Mener du solafskærmningen virkede sidste vinter?

- ☐ Ja
- ☐ Nej

Kryds venligst den udtalelse af som passer bedst til at beskrive solafskærmningens indflydelse på det visuelle miljø sidste vinter.

Den automatiske solafskærmning medførte situationer hvor:

- ☐ Det blev for mørkt
- ☐ Det blev for lyst
- ☐ Nogle gange blev det for mørkt og andre gange for lyst
- ☐ Andet_________

Afhænger din opfattelse af det visuelle miljø sidste vinter af et specifikt tidsinterval på dagen?

- ☐ Nej, min opfattelse gælder generelt for hele dagen
- ☐ Ja, min opfattelse gælder generelt for morgentimerne
- ☐ Ja, min opfattelse gælder generelt omkring frokosttid
- ☐ Ja, min opfattelse gælder generelt for eftermiddagen
- ☐ Andet_________
- ☐ Det kan jeg ikke huske

Afsnit 3, Generelle spørgsmål

Hvilket tidspunkt på dagen er det lige nu?

- ☐ Morgen
- ☐ Frokost tid
- ☐ Eftermiddag

Køn

☐ Kvinde

☐ Mand

Alder

☐ under 30

☐ 31 - 40

☐ 41 - 50

☐ 51 - 60

☐ over 60

Bruger du kontaktlinser eller briller i dit daglige arbejde?

☐ Ja

☐ Nej

Er du farveblind?

☐ Ja

☐ Nej

☐ Ved ikke

Er du blevet diagnoseret med øjensygdomme?

☐ Nej

☐ Ja

Hvad er diagnosen?

____

Har du generelle kommentarer til belysningen på din arbejdsplads?

____

Du er nu færdig med spørgeskemaet, vi takker mange gang for hjælpen.
Fortsat god arbejdslyst!

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