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Published in:
IOP Conference Series: Earth and Environmental Science

DOI (link to publication from Publisher):
10.1088/1755-1315/1099/1/012028

Publication date:
2022

Document Version
Publisher's PDF, also known as Version of record

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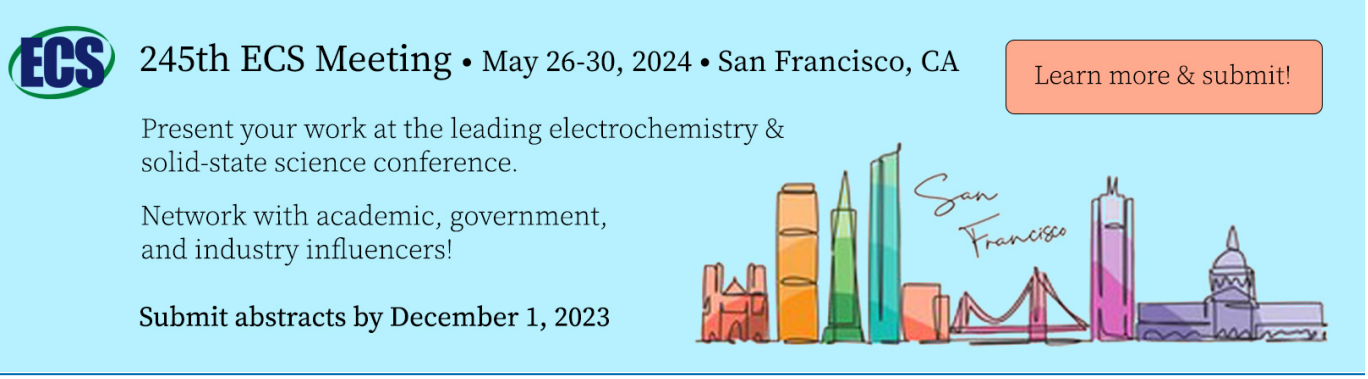

Evaluating an integrative lighting design for elderly homes – a mixed methods approach

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Abstract. The experience of light in a space and the physiological effect of light combined is complex to study. Methods which combine parameters from the fields of the biological, visual and atmospheric effects of light through a combination of both qualitative and quantitative data collection on site, seem more important than ever to validate the potentials of integrative lighting. A case study, conducted in two elderly homes in Copenhagen and Aarhus, in Denmark, is used to evaluate a mixed methods approach, assessing an integrative lighting design solution. Luminaires with circadian settings are implemented as a supplementary lighting with the aim of supporting various objectives, including biological stimulation and a homely atmosphere in the elderly homes. To evaluate the implementation of the lighting, a convergent mixed methods approach is used, collecting quantitative and qualitative data. In parallel to collecting quantitative measurements, such as melanopic equivalent daylight illuminance (mEDI) and photopic lux, semi-structured interviews based on questionnaires and card-sorting, on the same subjects, are carried out. To evaluate the approach for evaluating the implementation of this integrative lighting design, three criteria are introduced: a) integration, b) flexibility and c) validity. The integration of results enabled to compare the different methods and findings to identify and study correlations, differences or contradictions. That was conducted across the three topics: biological, visual, and atmospheric effects of the integrative lighting design solution. A framework for a holistic approach for evaluating lighting in elderly homes was defined, with an indication of the need for further development in an iterative process.

1. Introduction

A holistic lighting design evaluation requires the inclusion of multiple effects of light. The complexity how light affects people both physically and physiologically makes it particularly difficult to conduct studies. The multidimensionality of lighting design has been investigated with different methodologies to evaluate and identify the most important factors. According to the current state of science, the biological effect of light on humans, such as melatonin suppression, should be considered in particular [1], as well as factors such as visual comfort [2] and perceived atmosphere [3]. However, studies on the effect of light are often investigated one factor at a time and primarily in laboratories [4]. This study is therefore intended to help assess the multidimensionality of a lighting design solution based on the factors related to the biological, visual and atmospheric effects of light. In this context, conflicting factors pose a particular challenge for evaluation. How can this be dealt with if two of the factors produce conflicting results? Is a scoring of the factors necessary and if so, how can this be achieved?

Lighting design that encompasses these considerations is described as integrative lighting, defined by CIE [5]. Integrative lighting is an essential topic for the AAU Lighting Design Research Group. It also touches upon the core idea of the master's program – designing with lighting transdisciplinary, across multiple fields of knowledge and expertise to understand light as a multidimensional design element [6]. It is hypothesized, that an integrative approach, which includes the areas of biological, visual and atmospheric effects of light can form a holistic evaluation, applying methods from quantitative and qualitative research. This leads to the first criterion against which the approach will be tested: *(1) Integration. The methods must integrate the various effects of light. The methods should incorporate biological, visual, and atmospheric effects of light, as well as allow for integrative data analysis.*

Due to the similar interest in light and health and its effect on humans in a holistic sense, the AAU Lighting Design Research Group was invited to be part of the project and evaluate a new integrative lighting solution for eldercare homes. While the lighting solution in question had already been tested in lab settings by other parties, AAU participated in the project as a conductor of a case study. Studies have demonstrated, that case studies can be important for evaluating a lighting design solution, as knowledge can be drawn from setting up tests in *"specific spaces under specific lighting conditions"* [4].

Designing lighting for eldercare homes bears a significant responsibility, as light is known to influence health and well-being, for instance the effect on the circadian rhythm [5]. Residents of eldercare facilities are especially susceptible for disturbances in circadian rhythm, since many of them are physically restricted, and therefore have limited access to daylight, which is known to be a zeitgeber of circadian regulation [7]. Similar to the research mentioned, the municipalities in Copenhagen and Aarhus had also found in their preliminary studies, that there is a need for supporting the well-being of residents in eldercare facilities by supporting the circadian rhythm with biological stimulation, and by creating visually pleasant atmospheres in their homes. Together, the two municipalities created a tender in which the needs of the elderly residents and the staff working in these facilities were described [8]. Thereafter the tender was released, and the bids of different lighting design companies were assessed. Lyhne Design with their product *SolMate* [9] was chosen and a detailed evaluation of their suggested integrated lighting design solution, further referred to as ILD solution, was planned.

Referering to Schledermann et al. [10] an evaluation in nursing homes is not without challenges. The complexity and heterogeneity of the facilities make it hard to conduct research in the nursing home itself, due to the great complexity of dealing with residents in sensitive situations. Implementing the new lighting can also present challenges related to acceptance, adaptation and usability of the technology, as Schledermann et al. discovered. Lastly, the number of samples depends on the condition of the participants, especially the residents. It is often necessary to rely on the residents' contact person(s) from the given facility to reflect on certain behaviours. To ensure that the evaluation takes into account these needs for flexibility, the second criterion was established. *(2) Flexibility. The methods should offer a high degree of flexibility in their application and design. The methods must be able to be carried out in an eldercare facility and allow valid data collection in different locations, circumstances and/or lighting conditions.*

A combination of both, qualitative and quantitative methods, seems more important than ever to validate the potentials of integrative lighting. For instance, the study conducted by Schledermann et al. demonstrates the value of applying mixed methods to a case study in the field of healthcare, a nursing home [11]. According to Creswell and Plano Clark [12], mixed methods can be defined as different designs, which can be included in a specific framework as a core design. It is of particular value in the field of lighting design to combine different methods and to draw conclusions from them, as *"[a] mix of qualitative and quantitative studies, each chipping away at a single point, can start to provide answers"*, as Albers [13] states. An approach including multiple methods can help to reinforce, understand, or question the data collected. Defined by Creswell and Clark, *"[i]ntegration is the point in the research procedures where qualitative research interfaces with quantitative research"* [12]. Though the integration differs depending on the type of mixed methods design, four key considerations can generally be made to enable the integration of data analysis and interpretation of the chosen topics, as

proposed by Creswell and Clark: integration intent, integration data analysis procedures, representation of integration results, and interpretation of integration results [12]. Another advantage of mixed methods is the possibility to include not only quantitative and qualitative methods, but also multiple different factors. As the evaluation of experiments in the Double Dynamic Lighting innovation project [4] shows, the diversity of mixed methods designs [12] allows for the inclusion of a wide range of factors. Depending on the design, the factors can stand next to each other and be evaluated simultaneously or sequentially build on each other.

Lastly mixed methods can provide validity, even where topics occur where *"it has been a challenge [...] to quantify the thing which cannot be measured through conventional measurement techniques"* [14]. Often described as an issue [15], the quality in mixed methods approach can still be discussed, e.g., based on the criteria from O'Cathain [16]. Building on the Good Reporting of a Mixed Methods Study (GRAMMS) [17] O'Cathain provided a set of evaluation criteria, from which, four key criteria can be derived to ensure the validity and quality of the study: rigorous data collection and analysis, intentional integration, organisation into specific research design and framing within theory [12]. This leads to the final criterion for the evaluation of an integrative light design - the validity of the conducted study. *(3) Validity. The methods must demonstrate their validity for scientific research. The methods must ensure the quality and thus the validity of the study conducted.*

Consequently, the following question is asked: *How can a mixed methods approach be applied for a holistic evaluation of an integrative lighting design in elderly homes?* To evaluate the mixed methods approach, three criteria have been formulated, about the topics of *(1) integration*, *(2) flexibility* and *(3) validity* of the methods.

2. Method

To evaluate the integrative lighting design solution, a case study, using a convergent mixed methods approach, is carried out. The case study is part of the phase 2 of the evaluation design process to evaluate and develop the ILD solution for elderly homes as illustrated in **Figure 1**. As the different phases of this study unfold, active integrated conclusions, about the ILD solution and the use of the mixed methods approach, can be drawn based on the results previously obtained.

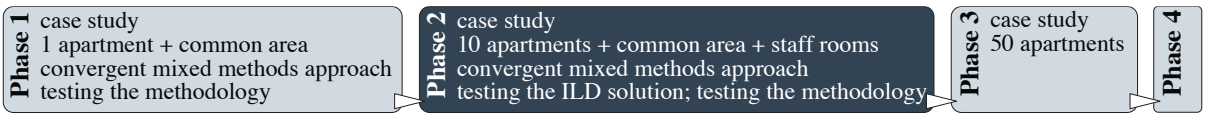


Figure 1. Evaluation design process – Integrated Lighting Design

As *"[…] in areas such as education and nursing, the phenomena studied are complex and tensions arise over the efficacy of both qualitative and qualitative research"*, stated by Gilbert [18], the simultaneous collection of quantitative measurements and qualitative data on the same subject, allows to compare these data and gives an overview of whether correlations, differences or contradictions exist. While the scope of the case study is to study integrative lighting [5], metrics for both visual and non-visual effect are applied. Although non-visual effects could refer to a large variety of biological human responses [19], in this paper the measurements of non-visual effects of light are focused on the qualities of light that would have an effect on circadian rhythm and sleep [7]. The chosen metric for studying the non-visual effects of light is melanopic daylight illuminance (mEDI), as it is based on an expert scientific consensus [7] and recommended by CIE [20]. The visual effect of light could refer to a vast array of perceived qualities of light, such as colour, light distribution, spatial pattern and contrast ratio [4]. In this study, as the lighting design solution to be evaluated takes place in an indoor workplace, the chosen approach for quantifying the visual effect is to study the illuminance on horizontal planes of the relevant task areas, with a reference to the standard, DS/EN 12464-1-1:2021. For ensuring a valid quantitative data collection professional equipment is used and calibrated. Further, measurement points are decided to be similar that the resulting data will be comparable between each other by limiting the amount of measurement heights and directionalities.

As the perceived atmosphere of light is not straightforward measurable [14], qualitative methods are introduced. Semi-structured interviews are a key element towards grasping the participants' experience. This type of interviews offer the possibility to ask questions of different types, depending on the nature of the participants and the context [21]. The interviews are based on questionnaires using the tool SurveyXact [22] in order to enable precise and standardized data collection. This tool also provides the flexibility to send the questionnaires online, if interviews with the healthcare workers on-site due to the unpredictable conditions in the nursing homes is not possible [18]. To verify and expand the collection of the data, contact persons interviews are introduced additional to the interviews with the residents. As a projective technique for the interviews, card sorting is used to help the participants to elaborate the queried topics [21].

In addition, observations are planned during data collection to better compare data sets later and to account for possible irregularities or open issues that may arise due to the dynamics of daylight and possibly differentiated lighting situations [4]. The data sets are first analyzed separately and then compiled in a joint display [12]. The combination of the data based on the three selected subjects allows the reinforcement, understanding and questioning of the results. The previously described methodology is illustrated in **Figure 2.**

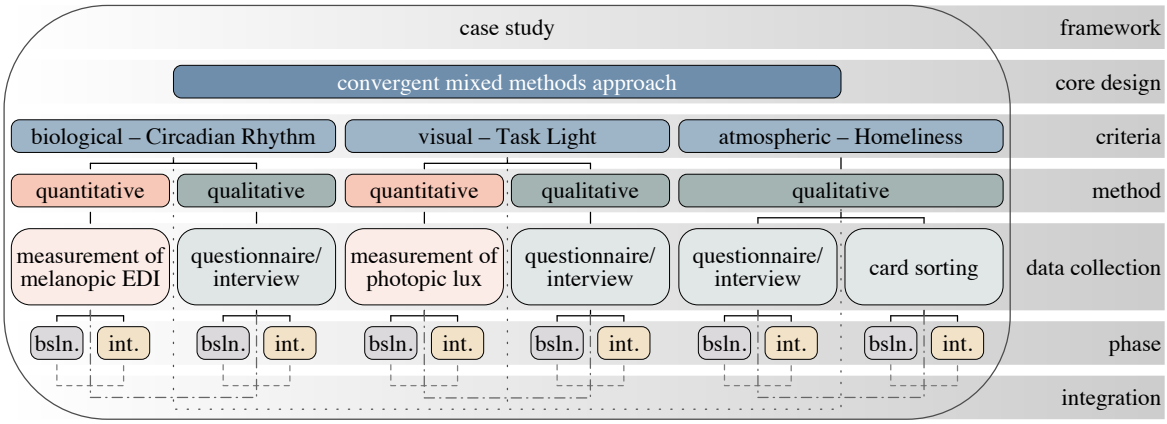


Figure 2. Methodology chart based on Creswell & Plano 2018

3. The Case Study

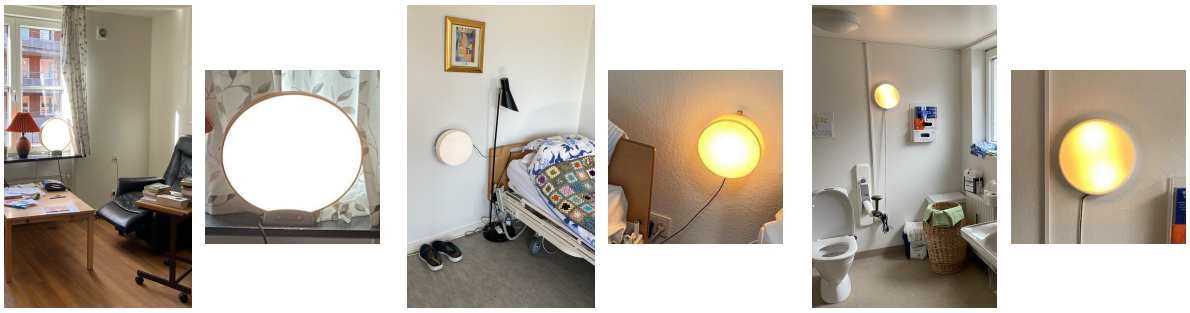
The evaluation process of the new ILD solution was designed in co-operation between AAU, Lyhne Design, and the municipalities of Copenhagen and Aarhus. Regarding the tender materials from the municipalities, the main approach in developing the new ILD solution has been to design the lighting for eight defined target groups or areas [8], in the eldercare facilities.

Based on the defined target groups and their needs, and the introduced criteria of biological, visual and atmospheric effects of light, three topics and their research questions have been introduced to evaluate the ILD solution. The first topic, corresponding with the theme of biological effects, is the effect of the ILD solution on the circadian rhythm: Does the ILD solution support the circadian rhythm of the participants? Second topic, considering the theme of visual effects, is task lighting: Does the ILD solution provide sufficient light for (healthcare) tasks? And thirdly, the feeling of homeliness, for evaluating the perceived atmosphere of the new lighting design, is discussed: Does the ILD solution support the participants' feeling of homeliness?

The resulting data of the quantitative and qualitative methods will be evaluated against the targets listed in the municipalities tender material [23]. The case study was conducted in Danish and translated to English for this research paper.

3.1. The Integrative Lighting Design Solution

The new ILD solution consisted of three different types of light fixtures, presented in **Figure 3**, which were designed to be used as complementary lighting, supporting the lighting that existed prior to the implementation of the new fixtures. These existing luminaires consisted of varying types of light fixtures, both residents' personal fixtures, as well as several types of luminaires from the facilities.



SolMate NightMate BathMate

Figure 3. The new light fixtures implemented in the ILD solution

One of the new fixture types, SolMate, had a predefined circadian lighting setting built in. SolMate was programmed for a dark setting (<3mEDI) from 9p.m. to 6:30a.m. From 8:45a.m. until 3:30pm the setting was at its brightest. In between these times, the light was dimming gradually from bright setting to dark setting during the evening and vice versa in the morning. SolMates were designed not only as tabletop version, but also as wall mounted, ceiling recessed and hanging pendants. In the apartments only the tabletop version was used, while in the common and staff areas all four types were installed. The other two fixtures, NightMate and BathMate, were intended for use only during evening and night-time, and had no circadian profile settings.

3.2. Experimental Set-up

The total experiment period took place from the 5th until the 29th of April 2022. Baseline study, prior to the implementation to the new ILD solution was carried through from the 5th to the 8th of April 2022 both in Aarhus and Copenhagen. After the baseline study, the new ILD solution was implemented, and the intervention study took place from the 26th to the 29th of April 2022. The new lighting was implemented 18 days before the intervention study in Aarhus and for nine days before the intervention study in Copenhagen. Five residents in Copenhagen and five in Aarhus participated in the study, as well as four healthcare workers from Copenhagen and six from Aarhus.

For the intervention period, SolMates were implemented in two resident apartments in Aarhus and Copenhagen, resulting in four apartments in total. Two staff rooms in Aarhus and one staff room in Copenhagen were equipped with SolMates, as well as one common area per each city. The number and placement of the SolMates varied in each space. NightMate was implemented in three apartments in Aarhus and two apartments in Copenhagen, the placement of the fixture being in close proximity to the bed. BathMates were installed in four toilets in total, with two in Aarhus and two in Copenhagen. Overall, the ILD solution was implemented minimum of one and maximum of four rooms per floor. In detail set-up of the study has been documented, however excluded due to the length of the paper.

3.2.1. Quantitative Methods. The mEDI was always measured from the field of view of the observer, with a 180° hemisphere sensor, the main direction of gaze being the angle 0 [20]. The measurement device was a spectrometer by GL Spectis (1.0 touch + flicker). In case of seated position, the measurements were taken from the vertical plane in the height of 1.2m, and in the case of a standing, from the vertical plane in the height of 1.6m [7]. The measurements for the scenario of a resident laying in a bed were taken from the height of 1.2m in an angle of 45° during daytime, referring to a typical view angle from a raised hospital bed [24]. In the night-time, the measurements from the beds were

taken from the horizontal plane facing upwards in the height of 1.0m. In the apartments where SolMate fixtures were installed, the measurements were taken five times a day (at 9am, 12am, 3pm, 6pm and 9pm). In the baseline period the measurements were taken with daylight only and with daylight and the house lighting combined. In the intervention period, the lighting was measured both with daylight only and with daylight and the new lighting combined. In the apartments, where the ILD solution consisted only of fixtures intended to be used at night, the mEDI value was recorded only at 9pm, once with the luminaire turned off and once with the luminaire turned on. Task lighting was measured as illuminance on relevant task areas, using Voltcraft lux meter MS-200. All the task lighting measurements were taken at 9pm, as it was in the interest of the case to provide task lighting at evening and night. For the measurement, all the other light sources were turned off, except for the fixtures implemented in the ILD solution. With the light fixtures that were dimmable, the value was recorded both with dimmed down and dimmed up settings.

3.2.2. Qualitative Methods. For the qualitative research, semi-structured interviews were conducted, using card sorting as a projective technique. The interviews were based on questionnaires specific to the topics and target groups addressed. SurveyXact [22] as a data collection platform was utilized to record the interviews. For the card sorting, ten cards were employed in which the ratio between positively and negatively perceived words was balanced. The selected cards were based on previous studies [4,11] on the perception of light in relation to the feeling of homeliness. The chosen cards read as follows: glary, soft, cosy, bright, dark, sharp, sterile, sufficient and insufficient. Each interview lasted 10-20 minutes. All the ten resident participants were planned to be interviewed, but in the test period only six residents were found to be cognitively fit to participate in the interviews. Card sorting could not be applied to any of the resident interviews. In the test period, nine daytime and one night-time healthcare workers were interviewed. In cases of resident interviews in which the resident was estimated to be potentially agitated by the interview situation, a healthcare worker was present to monitor the interview situation. In the cases where the healthcare workers could not be interviewed in person, a questionnaire was sent for them, including the same questions that were included in the interviews. In total four healthcare workers filled out the questionnaire online. In addition to measurements and interviews conducted, observations of the placement of the participants (where and how they were positioned in the room), and light conditions in the space were noted down each time the researchers entered a space to conduct a study. The distances from the observer to the luminaires were measured with a measurement tape, and the direction of gaze and placements of luminaires were noted in a floor plan sketch. Observations of the daylight inflow were noted in text, describing the weather condition, and whether direct sunlight was present in the space. Additionally, for the intervention period, if other lights than the ILD solution were used simultaneously, they were registered in the observations. Additional observations of the interview situations were made regarding the quality of the interview, noting down whether the used techniques seemed to confound the participants or if they were understood in a way appropriate for the research.

3.3. Integration of the Results

Detailed results of the evaluation process have been collected and analysed in the case study, and the summary of the results within each topic is presented in **Table 1**. The summaries are provided both as numerical values regarding how many of the measurement positions reached the target values, and as number and tendency of responses per each interview question. The target values referred to are based on the tender material provided by the Municipalities [23].

The inspection of the summarized results reveals correlations, differences, and contradictions in the data, both within the topics and across. A contradiction within a topic can be found in the results regarding circadian rhythm of the residents, where the measurements point mostly towards positive values, while the interview data shows no positive change. Therefore, the result on the topic of circadian rhythm is inconclusive regarding the residents. The effect of light on the circadian rhythm of staff is as well inconclusive since no qualitative data was collected.

		Circadian Rhythm *Is circadian rhythm supported by the ILD solution?*	**Task Lighting** *Does the ILD solution provide sufficient light for tasks at night-time?*	**Homeliness** *Does the ILD solution support the feeling of homeliness?*	
Residents	Quantitative Results	*Daytime avg. >250 mEDI:* Apartments: 3/4 positions Common areas: 0/2 positions *Night-time avg. <3mEDI:* Apartments: 6/6 positions Bathrooms: 1/2 positions	Numerical target values for the task lighting for residents were not defined in the project.	Qualitative Results	*Fixture design:* 2/6 positive feedback 2/6 unclear 2/6 negative feedback *Experience of the new light:* 0/4 positive experience 4/4 negative experience *Willingness to keep the new luminaires:* 0/5 willing to keep 3/5 don't know 2/5 not willing to keep
	Qualitative Results	*Experience of good night sleep:* 0/4 improvement 3/4 no change 1/4 deterioration *Waking up at night:* 0/7 improvement 5/7 no change 2/7 deterioration *Wandering at night:* 1/1 no change	Residents for whom bathroom lighting was installed did not use bathroom at nights and therefore could not response the questions.		
Healthcare workers	Quantitative Results	*Daytime avg. >250 mEDI:* Staff rooms: 2/5 positions *Night-time avg. <3mEDI:* Staff toilets: 1/2 positions Staff rooms: 5/5 positions	*>5lx for minor tasks:* Resident beds: 3/4 positions Staff rooms: 5/5 positions *>100lx for major tasks:* Resident beds: 0/4 positions Staff rooms: 2/5 positions *>10lx for tasks in bathroom:* Resident toilets: 0/2 positions	Qualitative Results	*Fixture design:* 4/9 positive feedback 4/9 unclear 1/9 negative feedback *Experience of the new light:* 1/7 positive experience 4/9 unclear 2/7 negative experience
	Qualitative Results	Interviews regarding the effect of the light on the circadian rhythm of the staff were not conducted.	Perceived as sufficient. However, the respondent referred to all the apartments in general, and not specifically to the ones with the new ILD solution. It could not be confirmed, how the new lighting solution was perceived.		

Table 1. Joint display of summarized results

The photopic lux measurements on the relevant task areas indicate, that lighting was partially sufficient during night-time for the healthcare workers to carry out healthcare tasks. The qualitative data is inconclusive, and therefore cannot support nor contradict the quantitative results. The integrated results on the topic of task lighting for the residents are inconclusive, since the participating residents did not have need for task lighting at night, and target values for the task lighting for the elderly had not been set.

The topic of homeliness was only ever planned to be studied with qualitative methods, and therefore the conclusion is drawn based on results from the qualitative methods alone. There is no indication in the results that the ILD solution would have supported a feeling of homeliness for the residents. In contrast, the healthcare workers expressed mostly positive feelings towards the new lighting and light fixtures. The interviews indicate, that the ILD solution was supporting the feeling of homeliness for the healthcare workers.

4. Discussion

In this chapter it will be discussed whether the study succeeded in meeting the set criteria of *(1) integration*, *(2) flexibility* and *(3) validity*.

The intentional **integration** of the results in different test phases, methods and topics was partly achieved. Regarding the integration across topics, as an example, the results on the topic of homeliness can be used to reflect upon the results on circadian rhythm and task lighting. For instance, the measured illuminance levels for sufficient task lighting were not met at night for care tasks for the staff, according to the target values set by the municipalities [23]. Similarly, a citizen expressed discomfort of the new lighting, experiencing too low light levels in the evenings. A contradiction and therefore conflict in the results can be found between the measurements of circadian rhythm (mEDI values) for healthcare workers at night-time, where the ILD solution supports the circadian rhythm of the workers, and the task light at night-time, not being sufficient for carrying out the tasks, when the ILD solution runs on the predefined setting. Looking into the integration within one topic a challenge was met regarding the comparability between the quantitative and qualitative data and results. A notable example of this is the data on night-time task lighting for the elderly, where questions were asked about the usage of the bathroom, but no numerical target values for this task or other night-time tasks for the elderly were defined and thus measured. This illustrates the importance of ensuring that comparability between the different methods is maintained in later phases of the study. Successful comparable data from the quantitative and qualitative methods were, however, obtained with regard to the circadian rhythms of the elderly. The interview questions referred to all times of the day and the measurements were taken throughout the day. A deficiency can be found in the comparability regarding the results for the circadian rhythm of elderly in relation to the baseline and intervention periods. The analysed mEDI measurements, due to time restrictions in the analysis process, do not reveal how the light has been before the implementation of the new lighting, while the interview results are based on the change between the baseline and intervention periods.

Having found contradictions in the results, leads to a search for potential explanations. The reason for contradictions might lie in the set target values, methods used for evaluation, or in the lighting design solution itself, such as the programmed light curve over the day. Some of the limitations and challenges mentioned might have been avoided through a simplified evaluation design, for example by focusing the study on a single topic and fewer research questions. With a single focus topic, resources could have been directed more efficiently towards refining the implementation of the chosen method within the short study period, rather than spreading the researchers' attention across multiple topics. If the research had been based solely on one method or topic, however, many opportunities for improvement would have remained undiscovered. Developing methods for transdisciplinary research is commendable, because finding inconsistencies between data sets shows that the design may be functional in one aspect but undesirable in another.

Another option to improve the evaluation design can be an extended implementation period. An indication of an unfavourable design emerged, for example, in the resident interviews on the topic of homeliness, where several residents expressed their discontent with the new design. A plausible explanation for this could be the very short implementation period, as the healthcare staff pointed out that new things are often difficult for the elderly to accept. Therefore, the result led to looking for ways to improve both the design and the evaluation methods.

In terms of **flexibility** by following a mixed-methods approach, the simultaneous collection of quantitative and qualitative data disrupts the everyday life of the participants for a shorter period than

conducting several independent studies. It also allows the number of samples to be reduced as they can be validated with each other in the process of integration. In this study, it was vital to evaluate the lighting situation in the real settings, where the citizens were exposed to the lighting, e.g., measurements were taken from the positions the residents seated themselves. This led to a more open approach comparing different settings on the same topic with each other and allowed a greater sample size.

Another hurdle is the number and scope of interviews that could be collected with the residents. Supported by Schledermann [10], this depends on the condition of the residents and can lead to incomplete data sets under certain circumstances. The chosen method allowed to combine data sets of different residents with the same profile. In addition, inspired by the same study, data on the residents could be collected from their contact persons instead, if the resident was not capable on answering the questions themselves, due to cognitive or other limitations. The interviews with the contact persons of the residents were also essential in cases where the resident was able to be interviewed, as this allowed for further validation of the collected data. For example, in an interview a resident expressed having woken up often at night in the study period, and this information was confirmed by the same statement made by their contact person. The collection of valid data is further supported using a mixed-methods approach, in that a baseline interview on the effect of the old lighting on circadian rhythms was compared with the effect of the new ILD solution. The methods chosen also allowed to collect data regardless of the heterogeneous schedules of the health care workers. As the interviews are based on questionnaires, they could be sent online when necessary, as it occurred during the baseline study in Aarhus. The flexibility of the application led to more data and therefore more validity in the overall study. In some cases, losing participants compromised the validity of the results. This happened in the evaluation of the night-time task lighting for the healthcare workers, when only one night-time worker was reached to answer the questionnaire.

The **validity** of the study was ensured by organising the study into the specific research design of a case study as a framework and the convergent mixed methods approach for the core design. The evaluation design is based on state-of-the-art practice and the chosen methods were embedded in theory, the origins of which have been explained in the introduction. Points for further research were noted for some methods regarding their adaptability from theory to real-life situation, although particular attention was paid to the workflow for interviewing techniques, including card sorting, and the rigorous measurement of the mEDI values. During data collection, some situations arose that led to compromises in the implementation of the methods, as illustrated in the following example regarding the measurements of mEDI values. While the theory states that the mEDI is measured from the observer's field of view, it was found that in practice it can be difficult to determine the participant's field of view. Some participants were constantly on the move from one space to another, while others had severe physical restrictions, yet the measurement technique was the same for all. One to three most relevant field-of-view positions were established for each participant, on which the measurements were based. It was found that some measurement positions reflected the participant's actual light exposure well, while in some cases the need for a more accurate method of estimating a particular participant's light exposure in future work became apparent. Other methods that can help with more accurate measurement of mEDI over the course of a period, such as the use of a wearable sensor, can also be considered when evaluating the ILD solution.

As discussed earlier, the evaluation of integration of results shows that it can add to knowledge and increase the validity of the study. However, in this study, discrepancies occasionally occurred that reduced the validity of the results by excluding the possibility of integration. The validity of a study, though, can be judged not only by the results, but also by the possibility of replication. Through careful planning and documentation, similar studies can be repeated. However, due to the special characteristics of a case study in elderly homes with numerous changing factors, such as uncontrollable use of the spaces and artificial lighting by the participants and thus light exposure, it can never be set up exactly the same. This should not be seen as a disadvantage, as case studies, mentioned in the introduction, can provide rich data and new knowledge from real-life environments.

5. Conclusion

In conclusion, through the rigorous collection and evaluation of quantitative, as well as qualitative data in response to the research questions posed on circadian rhythm, task lighting and homeliness, this approach allowed the three topics of biological, visual, and atmospheric effects of the new ILD solution to be combined and evaluated in integration. The joint display demonstrated correlations, differences, and contradictions in the results of the quantitative and qualitative data collected.

The way this study was developed and executed, incorporating the convergent mixed methods design, addressed the needs and challenges involved in conducting the study in the specific context of nursing homes. This approach was framed in relevant theory and therefore took multiple criteria into consideration to demonstrate the validity and quality of the study. The mixed methods approach allowed to evaluate an integrative lighting design, to reinforce, understand and question the collected data and to further develop and adapt the methods in the process to the challenges.

It was found that a mixed methods approach can lead to answering the posed question and help finding correlations, differences, or contradictions. The results led to new knowledge that can be used for the iterative process of developing the ILD solution and evaluation in the next phases that might later lead to answer the overall research question in this specific case and in other cases related to integrative lighting design.

The formulation of the criteria for *(1) integration*, *(2) flexibility*, and *(3) validity* was valuable in the approach to the study and highlighted the most important issues to be considered in the evaluation design. This paper can potentially contribute to other research by presenting an approach that could be applied to other lighting design cases where more than one factor needs to be addressed and investigated in field studies.

6. Acknowledgments

Thank you to our colleagues from the Lighting Design Research Group at AAU, Mimi Ravn, Georgios Triantafyllidis and Kathrine Schledermann for the support in the conduction of the study and sharing knowledge on the methods of evaluating an integrative lighting design solution. Many thanks also to Anita and Morten Lyhne from Lyhne Design, Anders Lundin from Belid, as well as Lene Vad Jensen and Matilde Rodríguez Gammelgaard from the Municipalities of Copenhagen and Aarhus for the opportunity and support with the project.

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