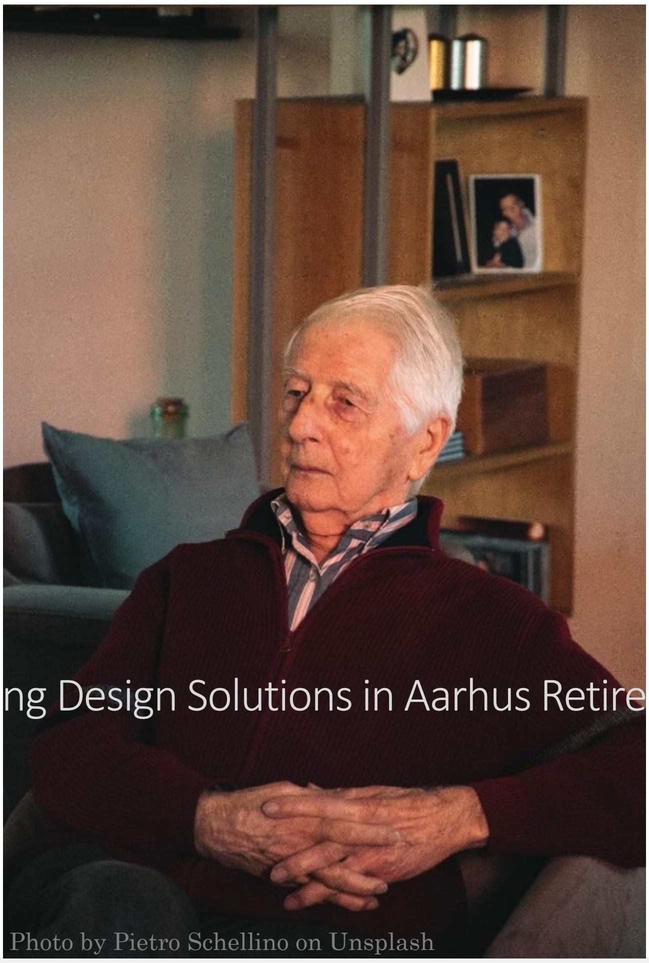

Electric Lighting Design Solutions in Aarhus Retirement Homes

Photo by Pietro Schellino on Unsplash

Student project at Aarhus University,

Department of Civil & Architectural Engineering

Course: Electric Lighting

May 26th, 2021

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Content

1 Introduction

Elderly people living in nursing homes spend the majority of their time indoors. Combined with age-related changes in the visual system, it points to the need for working with the electrical lighting design. The apartments in nursing homes are often one- or two-room apartments, meaning that the rooms are multi-purpose rooms used by the elderly for several different activities with different needs when it comes to lighting. Additionally, the apartments in a nursing home are not only homes for the elderly people living there, but they are also workplaces for the staff members. This adds another dimension to lighting design as numerous conflicting criteria for visual comfort arise.

This report documents the work on a student project on electrical lighting design solutions in a reference apartment in the retirement home Plejehjemmet Kildevang located in Mårslet, Aarhus. Only the apartment is included and simulated in the lighting design software DIALux evo. Lighting conditions in common areas in the retirement home have not been a part of the work and are considered outside the scope of the project. The first part of the report serves as a summary of the starting point for the design task. That includes an outline of age-related changes in the visual system, a summary of relevant work with the topic in Aarhus Kommune, and a summary of relevant legal design boundaries. All these areas are relevant and used in the design task and discussions. The reference apartment is then presented along with an evaluation of the daylight performance in it. The next part concerns the design phase and includes relevant discussions on methods and results. Finally, the learning outcomes from the design phase are combined into one discussion with suggestions for electrical lighting design.

Acknowledgement
Special thanks to Søren Pallesen from Aarhus Kommune who provided feedback and valued insights into some of the problems related to electrical lighting design in Aarhus retirement homes.

2 Lighting for elderly people: A review

As people become older, many changes happen to the body. The eye is not any different, but as the visual system is the part of the body which is responsible for the most important of the senses, the decreasing effectiveness becomes more noticeable. All these changes happen in the optics and retina of the eye, as well as in the neurological pathways sending signals from the eye to the brain. In *Figure 1* on the next page, the different changes occurring with age are summarised as the causes. The consequences of these causes are also presented.

Many of the negative consequences presented in the figure affect the amount of light which can reach the retina, and thereby impact the perception of the light. The structural changes in the eye and the pathway to the brain also increase the scattering of the light which results in an increasing glare. And as the dark adaptation is also slowed down with age, the contrasts between the dark and the light become more important. Another consequence is the loss of blue light which stimulates the circadian rhythm. Normally, a large amount of blue light is gathered from the daylight, but since many elderlies also have mobility issues, they do not come outside often, and therefore they do hardly get any outdoor light exposure. This has severe consequences for the circadian rhythm since the low variations in the illuminance levels indoors do not support the biological clock, and since the typical electrical light does not vary in colour temperature.

Thereby, the body does not as easily understand when it is night-time and when it is daytime, which worsens an already decreasing sleep quality and shorter sleep length. (van Bommel, 2019).

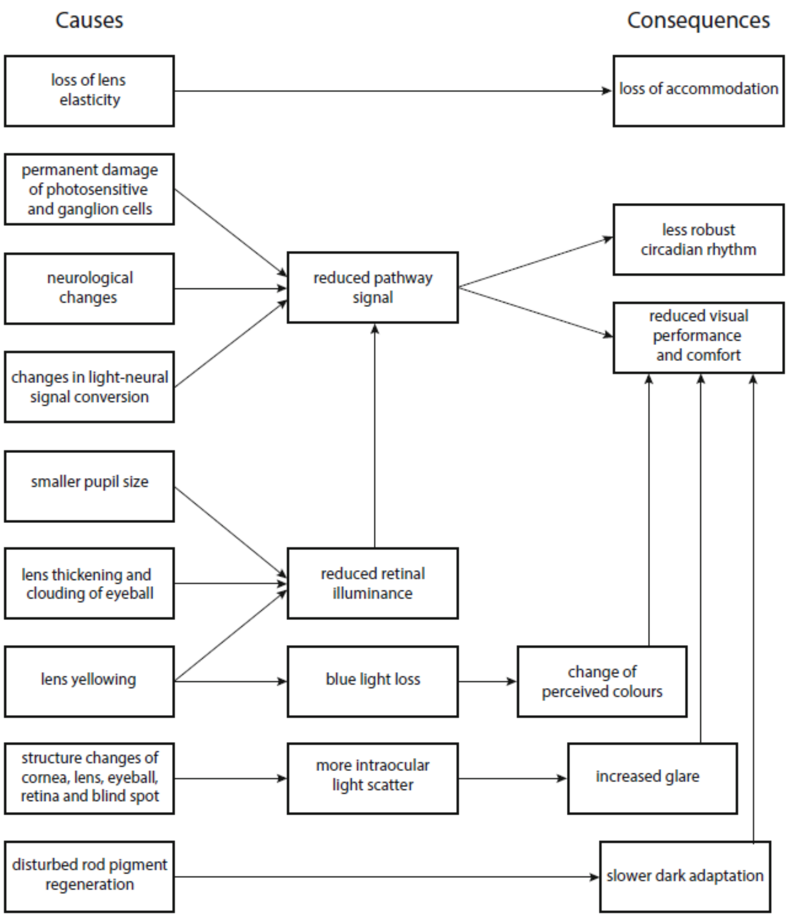


Figure 1 - The causes of the impaired vision and consequences (van Bommel, 2019)

All these changes end up affecting the visual performing and thereby the visual comfort for the elderly. And as these physiological changes occur for all people, it is important to find ways to support the elderly. But in addition to the general decrease in visual performance, many senior citizens also suffer from eye diseases. For instance, it is assumed that one third of the American population aged 65 years and above suffer from an eye condition. The four predominant diseases are glaucoma, cataracts, macular degeneration and diabetic retinopathy. (Sollitto, n.d.). A well-considered lighting design can increase the quality of life for the senior citizens, both for those suffering from eye diseases and for those that do not.

2.1 Target groups

As mentioned in the previous section, the physiological changes happen for all people. But not all elderly can fit under one category since other factors can also induce different needs. This issue is something that Aarhus Kommune and Københavns Kommune have been working on for some years. (Lauridsen, Pallesen, Jelnes, Skriver, & Jensen, 2021). They have therefore already divided the senior citizens into 17 categories and five overall target groups with different lighting needs:

1. Severe disturbances in sleep and circadian rhythm. Unrestful physically and mentally, depressive, visually and walking-impaired
2. Immobile and requires care
3. Night wandering
4. Lowered appetite
5. Mild disturbances in sleep and circadian rhythm

The specific needs for each one of the target groups were defined during workshops, where different solutions for each of the groups were made by a team of experts in different areas. All these solutions were made to support the different needs of the residents. (Tofteberg et al., 2020).

3 Legal design boundaries

Legal design boundaries were only briefly considered in the report from the workshop. The nursing staff spend a lot of time in the different apartments, and legally, the home is defined as a workplace, which means that the apartment must comply with the Danish Working Environment Act ("Plejeboliger og ældreboliger," 2021). In this act, it is a condition that the requirements from the building regulation is fulfilled as well as the standard DS/EN 12464-1 and national annex. (Beskæftigelsesministeriet, 2002).

In this standard, several tables are listed with the requirement for different kinds of work tasks. However, there is not one specific table applicable for staff in retirement homes. The tables where the tasks are considered close to those of nursing staff in a retirement home were therefore examined. Since most of the work that is done in the residents' own apartments are based around health care, the most relevant tables to look at in this standard are the ones regarding the health work. Two tables are particularly relevant: table 5.37 and table 5.47. One of those tables can be seen in *Figure 2*.

Table 5.47 — Health care premises – Intensive care unit

Ref. no.	Type of area, task or activity	$\bar{E}_m$ lx	UGR_L –	U_o –	R_a –	Specific requirements
5.47.1	General lighting	100	19	0,60	90	Illuminance at floor level.
5.47.2	Simple examinations	300	19	0,60	90	Illuminance at bed level.
5.47.3	Examination and treatment	1 000	19	0,70	90	Illuminance at bed level.
5.47.4	Night watch	20	19	-	90	

Figure 2 - Table 5.47 ("DS/EN 12464-1 Light and lighting – Lighting of work places – Part 1: Indoor work places," 2011)

4 Presentation of reference case

The work with electrical lighting in retirement homes in this project took a starting point in a reference apartment at Plejehjemmet Kildevang in Mårslet, Aarhus. It is a two-room apartment containing a living room with a kitchenette, a bedroom and a bathroom. The floorplan of the apartment can be seen in *Figure 3*.

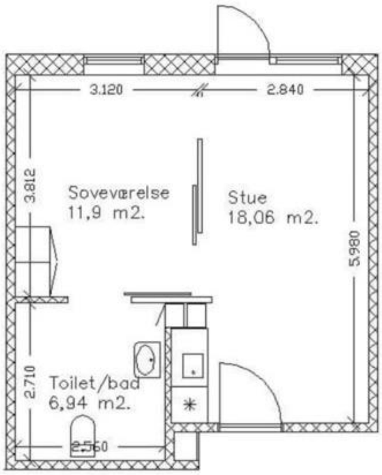


Figure 3 - Floorplan of the two-room apartment

The apartment is placed at the ground floor, and the windows are facing south/south-west and oriented towards the train tracks. The location of the apartment and the facade can be seen in *Figure 4*.

Figure 4 - Pictures of the retirement home

4.1 Expected room layout

The apartment was modelled in DIALux evo to be able to evaluate the design proposals. To adapt the light design to the expected use of the apartment, the following assumptions are made for furniture:

- The sanitary installations in the bathroom is located as seen on *Figure 3*. The elderly do not have a specific shower area with walls, but the shower in the model is used to indicate the area where it is expected that the elderly will shower in their bathchair.
- The bed will be placed next to the window, with space around the bed for the staff to care for the elderly.
- The bedroom will contain a wardrobe and a bedside table, placed between the bed and the bathroom.
- The dining table is placed across the room from the kitchenette.
- There is a sofa and an armchair placed next to the window in the living room, to make it possible for the residents to enjoy the natural light and look out the window. The sofa is turned towards the wall where it is assumed that a TV will be mounted.

The expected placement of the furniture can be seen in *Figure 5* below:

Figure 5 - Expected room layout, modelled in DIALux evo. Furniture from DIALux evo catalogue

4.2 Model assumptions

In the DIALux evo model of the apartment, the following assumptions are made:

- Room height: 2.5 m
- Double glazed windows (LT=82%)
    - Bedroom window:
        - Height: 1.7 m
        - Width: 1.03 m
        - Windowsill height: 0.8 m
        - Frame width: 0.06 m
    - Living room window:
        - Height: 2.5 m
        - Width: 1 m
        - Frame width: 0.06 m
    - Living room glass door:
        - Height: 2.5 m
        - Width: 1 m
        - Frame width: 0.06 m
        - Height of cross post: 2.0 m
        - Width of cross post: 0.1 m
- The reflectance values of the room surfaces are:
    - Ceiling: 70 %
    - Floor: 20 %
    - Walls: 50 %

4.3 Daylight

Daylight and electrical lighting should ideally be designed together. Before designing electrical lighting for the reference apartment, the daylighting performance of the space is therefore evaluated. According to the building regulations, daylight performance can be documented in two ways. Either the glass/floor-ratio must be at least 10%, or the illuminance levels at the floor must be at least 300 lux in half the room in half of the daylight hours. ("Bygningsreglementet," 2018). The simulation software used in this project, DIALux evo, allows for illuminance simulations, so the rooms are evaluated based on the second option. This requirement is tested for the living room and the bedroom, and without any furniture. The date of the calculations is chosen to be the 21st of April at 11:38 am which is the time when the Median External Diffuse Illuminance is close to the reference value. (*DS/EN 17037:2018 : Daylight in buildings*, 2018).

Bedroom

In *Figure 6,* visualisations of the bedroom from two corners of the room can be seen, and *Figure 7* shows an illuminance map.

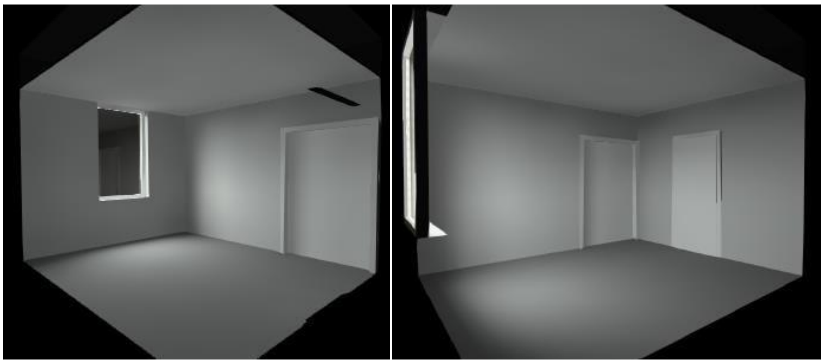


Figure 6 - Visualisations of daylight in bedroom

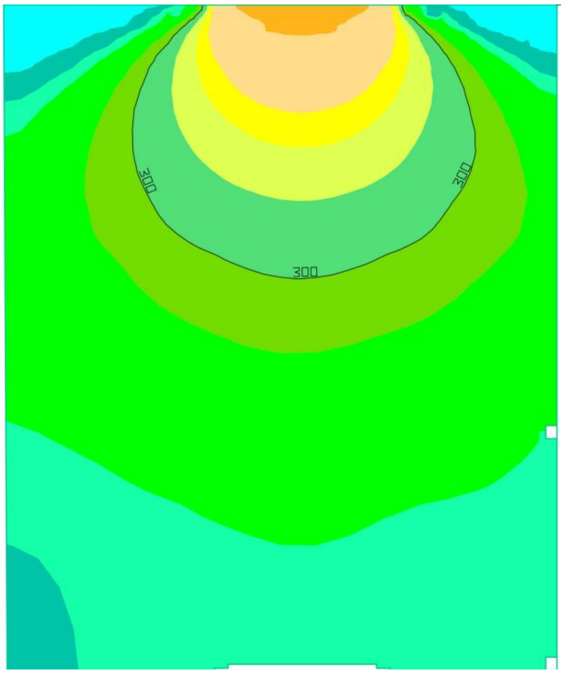


Figure 7 - Daylight results for the bedroom from DIALux evo

In the bedroom, the requirement of the 300 lux is only met in a small part of the room. However, the bed is placed in the end where the requirement is met. In the back of the room, the closet and different doors are placed. This means that this area is not where the resident or the staff will linger, and therefore the necessity for daylight is not as high. Ideally, the window should be made larger, because this could lower the high demands for electrical lighting. And if the building was built today, the window would have been larger. If the window was replaced to be longer horizontally, then more daylight comes into the bedroom. The visualisation of this new window can be seen in *Figure 8*.

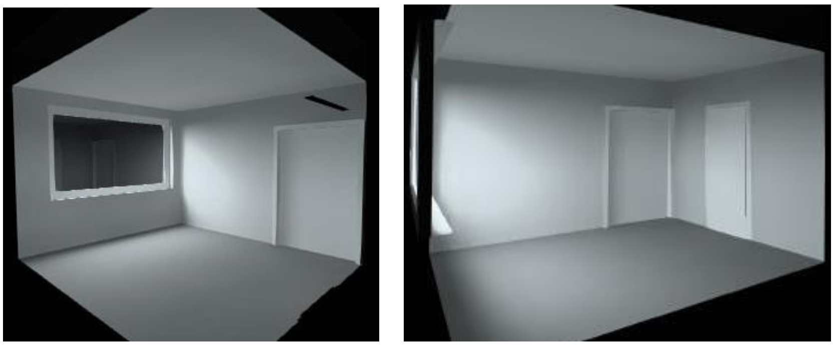


Figure 8 - Visualisation, window replaced

The illuminance map for replacing the window can be seen in *Figure 9*. This change has fulfilled the requirement, and more than half of the room now has 300 lux.

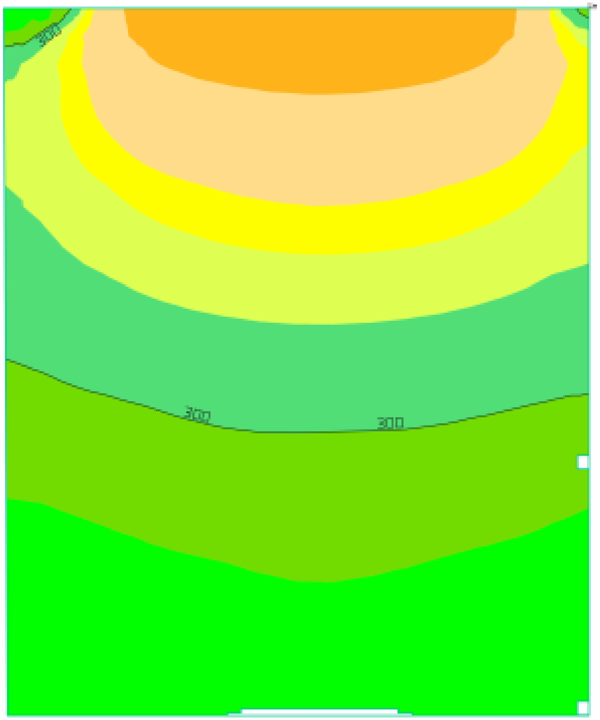


Figure 9 - Result from DIALux evo for the bedroom with the new window

Another reason for replacing the window to a larger one is that some of the elderly people spend most of their time in bed. Therefore, it becomes even more important that they can have a view out of the room to follow the world around them. For example, the train station is placed nearby, and many elderly residents could enjoy looking at the trains. The wider window would also be beneficial for the residents' circadian rhythm, something that will be further explored later in the report.

However, since this reference apartment is already built and in use, this change is not practical, and it would be expensive. And the reference apartment is considered to be representative for many other retirement homes. Therefore, it is chosen to keep the original window in the design investigations in this project. But for future projects it would be a recommendation to implement larger horizontal windows for increased visual comfort and wellbeing.

Living room

In *Figure 10*, visualisations of the living room from two corners of the room can be seen, and *Figure 11* shows an illuminance map.

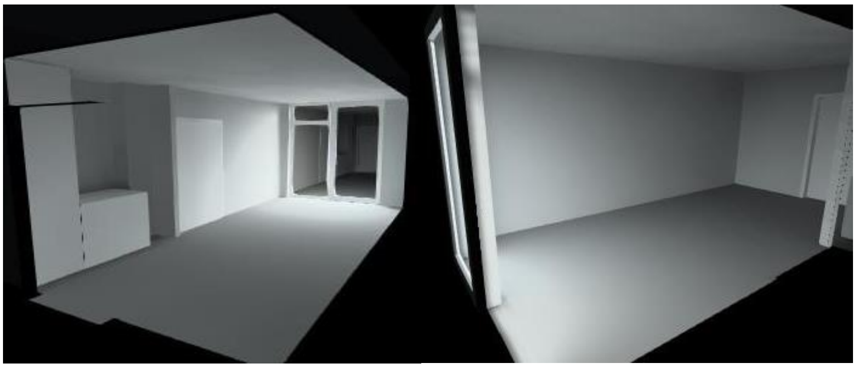


Figure 10 - Visualisations of living room

Figure 11 - Result for the living room from DIALux evo

In the living room, the requirement of 300 lux in half of the floor area is almost fulfilled. In *Figure 11,* it can be observed that where the sofa will be placed, the illuminance is above 300 lux. Therefore, it is assumed that the residents will spend most of their time in this area and thereby they will receive a lot of daylight. It should be noticed that the kitchen area is included, but the building regulation states that only relevant floor area should be included in the calculation. ("Bygningsreglementet," 2018).

Since the daylight performance for both rooms is now known, the development of the electric lighting concepts can be continued. To sum up, daylight conditions are not optimal, but they are probably representative for many retirement homes.

5 Design phase

This section presents some of the overall steps and ideas from the design phase. The first part of the design phase did not have a clear focus or method but consisted of many relevant discussions and investigations. It ended up with three well-defined and thoroughly prepared tables describing the expected use of the rooms that were used later in the process. These tables were followed by sketches showing ideas for luminaire placement and lighting directions that could fulfil the need for lighting in each of the situations described in the tables. These sketches can be seen in *Appendix B: Initial lighting scene design*.

Later in the process, we came to the realisation that we were not able to balance all the influencing parameters and contradicting goals at once. It was decided to work with a radical design method where different problem areas were treated separately. The end product will be presented in section 6, where learning outcomes from the radical design investigations will be combined and discussed.

5.1 Initial design phase: Scenarios and expected use of the rooms

Relevant for all design investigations is to understand the use of the space. The three tables below present the work of some of the first steps that were made in the design phase. The tables summarise for each of the rooms in the reference apartment what important scenarios that the lighting design should function for.

Bedroom

Time	Activity
Night	Resident in bed, waking up
Night	Resident in bed, staff entering to help
Day	Resident in bed. Reading, sleeping, talking
Day	Cleaning. Resident not present

Living room

Time	Activity
Afternoon, direct sunlight entering room	Watching TV/Reading/Talking
Evening	Watching TV/Reading/Talking …
Morning	Staff preparing medicines. Resident not in room or sitting in couch area.
Day	Cleaning
Afternoon	Resident (and guests) at dinner table

Bathroom

Time	Activity
Night	Resident just woke up, using toilet
Day	Staff and resident present (bathing, diaper change)
Day	Resident or guest using toilet/mirror
Day	Cleaning

Each row in the tables was followed by a sketch showing ideas for lighting that could support the specific activity. The picture below, in *Figure 12*, shows such a sketch for the activity "Resident in bed, staff entering to help" in the bedroom. All remaining sketches are provided in *Appendix B: Initial lighting scene design*.

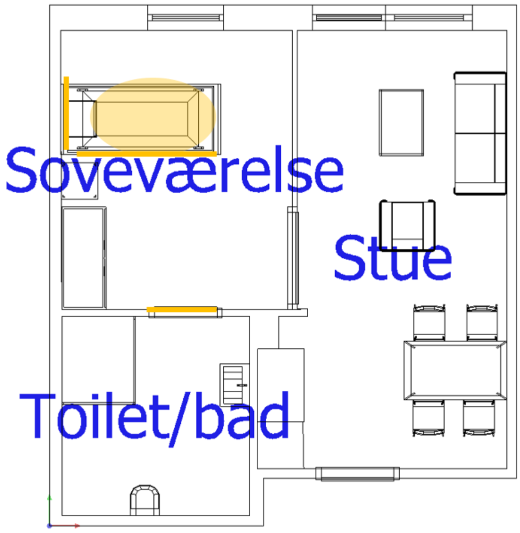


Figure 12 - Example of a sketch from the initial design process

5.2 Radical design investigations

In this section, we present the work with three different radical design suggestions. Based on group discussions, and inspired by a presentation by Søren Pallesen (Pallesen, 2021), five focus areas were detected that would possibly influence design decisions in different ways.

1. Human centric lighting
   Covering how the rhythm of daylighting could support the residents' daily rhythm
   Goal: Support the circadian rhythm of the residents
2. Resident comfort
   Covering the ability for the residents to perform their visual tasks without experiencing glare
   Goal: Design that concentrates on residents' needs
3. Staff comfort
   Covering the staff members ability to perform their visual tasks, including illuminance levels and the degree of shadows disturbing their work
   Goal: Design that concentrates on staff members' needs
4. Low expected LCC
   Covering expected costs for initial installations, maintenance and energy use
   Goal: Low price design that comply with standards
5. Traditional control technology
   Covering the possibility to install a simple and recognisable control system
   Goal: Lighting that is easy to control for both staff members and residents

The second and third focus areas were combined into one radical design investigation targeting conflicting comfort criteria. The fourth and fifth focus areas were combined into one radical design investigation targeting simplicity. Thereby, three radical investigations were made, called "Human Centric Lighting", "Conflicting Comfort Criteria" and "Simplicity". These investigations will be described separately in the following sections. Detailed information on all luminaires used in simulations, including references, can be seen in *Appendix A: Luminaires*.

5.2.1 Human centric lighting

The goal of this design investigation was to make a design that would support the residents' circadian rhythms. That is not a simple task, because elderly people must be exposed to higher illuminance levels than younger adults in order to experience the same circadian effect. The eye illuminance should be above 500 lux, preferably up to 1,000 lux, and exposure times up to two hours to influence the circadian system of the elderly (Rossi, 2019, section 4.3). Because of that, design decisions should be made carefully, taking the expected behaviour and daily routines of the residents in the different rooms into account.

Several case studies and manufacturer catalogues were examined in order to decide on which colour temperatures and dimming settings to implement. The final decision was to implement colour temperatures as used at Plejecentret Albertshøj. Dimming settings are only partially adapted from that project (Ascanius, 2019). The figure below shows four colour temperature settings from the Albertshøj project:

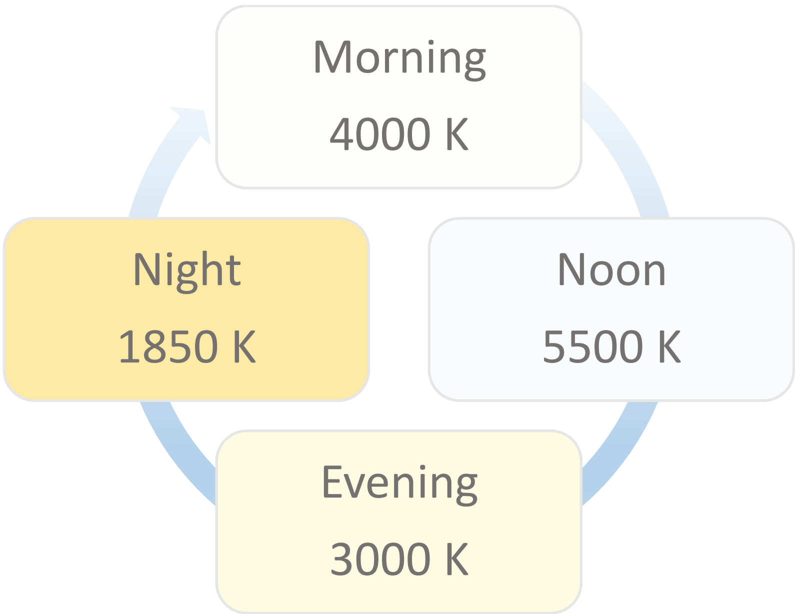


Figure 13 - Implemented colour temperatures. Based on ref: (Ascanius, 2019)

It is important to notice that the four settings should be considered as extreme settings or turning points. For instance, the noon setting with 5500 K is only for when natural daylight peeks. Between the four settings, a very slow graduation should happen, but only the extreme cases are investigated, meaning that the proposed design is based on these four settings.

The figure below shows how the four colour configurations look when adapted in a DIALux evo model:

Figure 14 - Four colour figurations in DIALux evo. From left: Morning, Noon, Evening, Night

Since previous research showed that high illuminances and long exposure times will be necessary to gain a circadian effect, it is important to consider where in the apartment that the elderly will spend most of their time during the day. For the residents that are confined to their beds, the bedroom is of course very important. For other residents, the bedroom may be important in the morning hours, but the living room is more important. Many of those residents will most likely spend several hours a day in common areas. In order to gain a circadian effect, both the access to daylight in common spaces, and circadian lighting in common spaces, will increase the level of success. These aspects are however not examined further in this project.

Bedroom

Daylight from the window will stimulate the circadian system, and the bed is placed near the window. But as shown in section *4.3* about daylight, it is necessary to enlarge the area with high illuminances if eye illuminances between 500 and 1,000 lux shall be possible. Many different options were considered. When the resident is awake and in bed, the bed will probably be elevated so the resident is in a halfway sitting position. Thereby, both the ceiling and opposite wall to the bed will be in the resident's primary field of vision. It was finally chosen to benefit from illuminating both of these surfaces as part of the design. Counting on the wall surface opposite to the bed is a risk. In order for this to be successful, it is necessary to have a large and bright surface as assumed in the simulations presented later on. The resident is in his or her own home, of course, allowed to decide on how to furnish. But if the wall is highly decorated, or shelves are placed in front of the wall, the luminance will likely be much lower than anticipated. Aware of the risk, this option was chosen anyway. As an important supplement, it was chosen to install a bedside table lamp to further increase the illuminance at the eye.

Both ceiling mounted lighting directed at the wall and wall mounted lighting was considered the purpose of wall-washing the wall opposite to the bed. Floor mounted lighting was also considered, but it was not seen as a good solution. The reasons were both a concern that the installations would not last as long, that furniture would destroy the intention, and that poor cleaning could destroy the function. Ceiling mounted lighting was chosen, and the primary argument for that was flexibility for the resident. For general lighting and luminating the ceiling, the goal was to find a type of luminaire that would fulfil both functionalities.

Luminaires were found using the DIALux evo catalogue LUMsearch. For the ceiling mounted wall-washing, the goal was to find luminaires with light distribution curves that showed angled downlighting that were not spotlights but more diffuse lighting. For the combined general and ceiling luminaire, the goal was to find symmetrical light distribution curves with both upwards and downwards lighting. For the bedside table lamp, the goal was to find a lamp with a distribution curve showing multidirectional and rather diffuse lighting, though most table lamps proved to be for downwards or directional, concentrated lighting.

Many sizes, shapes and extra functions were considered. The final choices for luminaires were:

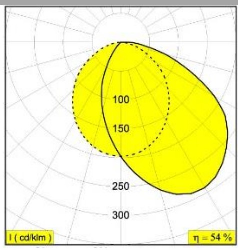
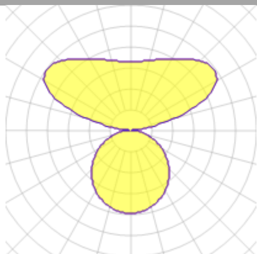
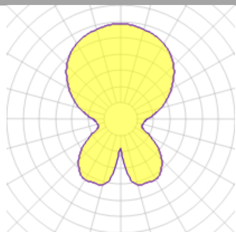
Primary function	Wall wash wall opposite to bed	General lighting and ceiling illumination	Bedside lighting
Light distribution curve			
Photo			

Table 1 - Bedroom luminaires, Human Centric Lighting design. See detailed references in Appendix A: Luminaires

The figure below is a visualisation of the luminaires in the bedroom.

Figure 15 - Visualisation of luminaires in bedroom

A calculation object resembling a person sitting slightly elevated in bed was modelled in DIALux evo, see the figure below:

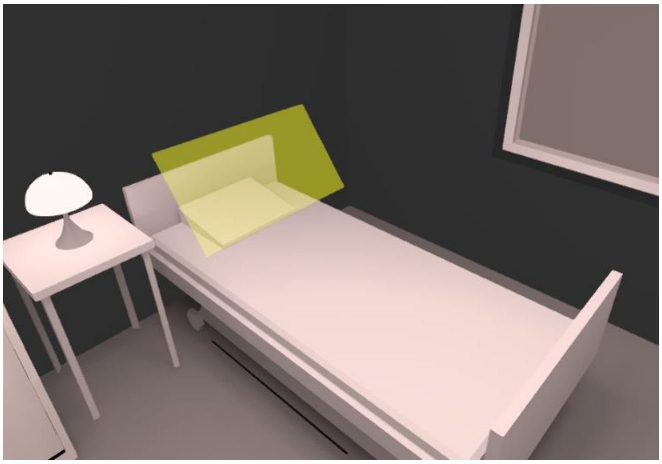


Figure 16 - Calculation object for HCL investigation

Lumen values for the luminaires were determined by considering the noon situation as a reference situation, since highest illuminance levels are required here. Based on examined literature, the target value was chosen an eye illuminance of 700 lux, shown as an average perpendicular illuminance for the calculation object shown in *Figure 16*.

Daylight configurations, lumen values and resulting eye illuminances are reported in the table below.

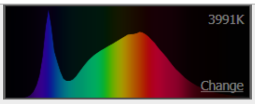
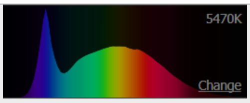
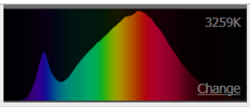
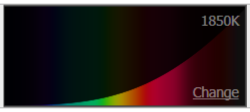
	Morning	Noon	Evening	Night
Daylight conditions for investigation	Daylight Reference sky type: Overcast Sky Date and time: 21-03-2021 08:00 Location: Arhus	Daylight Reference sky type: Overcast Sky Date and time: 21-03-2021 12:00 Location: Arhus	Daylight Reference sky type: Overcast Sky Date and time: 21-03-2021 18:00 Location: Arhus	Daylight Reference sky type: Overcast Sky Date and time: 21-03-2021 21:00 Location: Arhus
CCT [K]	4000	5500	3000	1850
Spectrum				
General lighting/ceiling lamp [lm]	1,000 x 8 = 8,000	1,200 x 8 = 9,600	600 x 8 = 4,800	0
Ceiling lamps for wall illumination [lm]	1,100 x 2 = 2,200	1,500 x 2 = 3,000	900 x 2 = 1,800	0
Table lamp [lm]	800	800	400	200
Eye illuminance [lux]	475	708	261	5

Table 2 - Simulation configurations

The figure below contains visualisations from the four scenarios in DIALux evo.

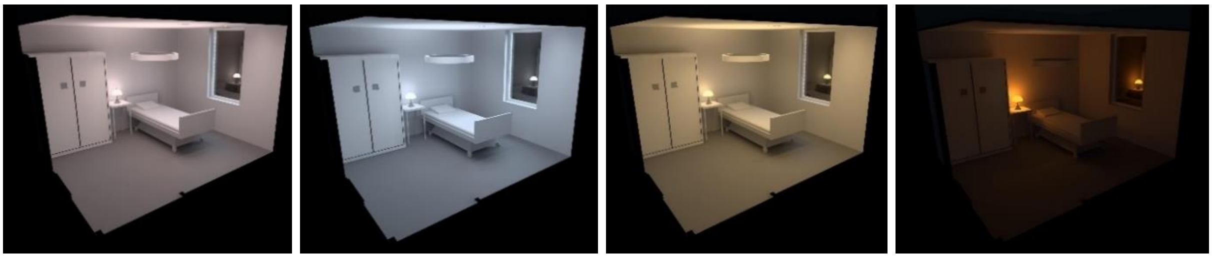


Figure 17 - Visualisations from DIALux evo

Living room

For the residents that are not bedridden, circadian stimulus from the living room lighting will be important. It is expected that they will spend most time at the sofa area, but the dinner table will probably also be used frequently. In this room, the direction of the vision is not as obvious as it was the case in the bedroom. Two calculation objects were modelled in DIALux evo, and the goal was to reach an eye illuminance of above 700 lux at the noon colour setting for both these calculation objects. The first calculation object was modelled to resemble a situation where the resident is in the couch watching TV. The second calculation object was modelled to resemble that the resident is at the dinner table looking slightly downwards, for instance sitting and talking.

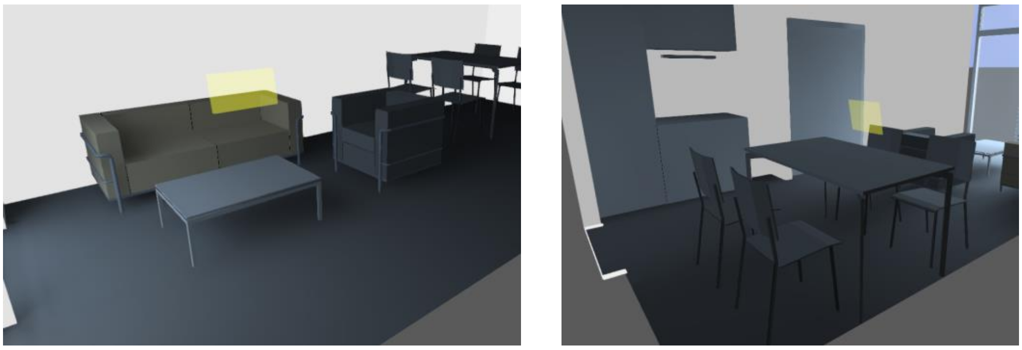


Figure 18 - Calculation objects for HCL investigation

If the resident was instead doing tasks such as reading or knitting, the direction of the vision would be more downwards, and even higher illuminances may be needed. Since this radical design investigation centres on circadian stimulation, which may be disturbed by task lighting in 'wrong' colours or lumen values, the task lighting has not been a focus. Considering the expected direction of the vision in the living room, illuminating the wall surfaces will help achieving the intended eye illuminance values.

For the dinner table situation, both direct and indirect lighting could be useful. At first, it was considered to use one luminaire that could satisfy both the direct lighting needs and illuminate the wall surfaces. But after implementing several different luminaires, it was concluded that it was difficult to control the direct and indirect lighting simultaneously, without creating a spotlight effect on the wall surfaces. Therefore, two types of luminaires were used at the dining area. The goal was to find a recessed ceiling mounted luminaire with an asymmetrical distribution curve and a pendant with a symmetrical, wide, downwards lighting.

It was much more difficult to design for a situation where the resident is watching TV. Fluctuating lumen values from the TV makes it difficult to truly count on using the wall opposite to the couch for wall washing. Luckily, there will be a circadian effect from daylighting entering the window near the sofa, but ceiling lighting must be used to enhance the circadian stimulus. It could not be a low-hanging pendant luminaire, since that could disturb the view from the sofa to the TV or the view to the outside. The goal was to find a ceiling mounted luminaire with a wide and symmetrical distribution curve showing mostly direct lighting.

The LUMsearch catalog was used, and the final choices for luminaires are shown in the table below.

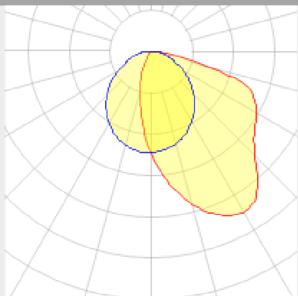
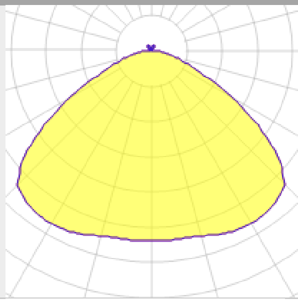
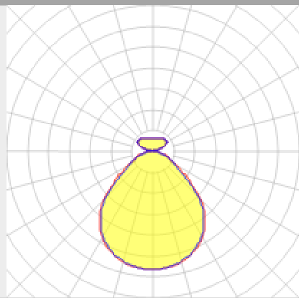
Primary function	Wall-washing, dinner table	Direct lighting, dinner table	General lighting, sofa area
Light distribution curve			
Photo			

Table 3 - Living room luminaires, Human Centric Lighting design. See detailed references in Appendix A: Luminaires

Daylight configurations, lumen values and resulting eye illuminances are reported in the table on the next page.

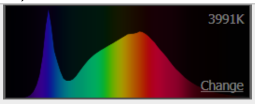
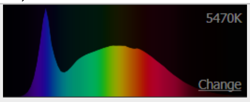
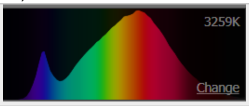
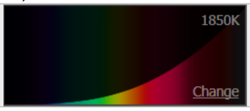
	Morning	Noon	Evening	Night
Daylight conditions for investigation	Daylight Reference sky type: Overcast Sky Date and time: 21-03-2021 08:00 Location: Arhus	Daylight Reference sky type: Overcast Sky Date and time: 21-03-2021 12:00 Location: Arhus	Daylight Reference sky type: Overcast Sky Date and time: 21-03-2021 18:00 Location: Arhus	Daylight Reference sky type: Overcast Sky Date and time: 21-03-2021 21:00 Location: Arhus
CCT [K]	4,000	5,500	3,000	1,850
Spectrum				
Direct lighting, dinner table [lm]	2,000	3,600	1,800	400
Ceiling lamps for wall illumination [lm]	4,000 x 2 = 8,000	5,600 x 2 = 11,200	1,800 x 2 = 3,600	0
Direct/indirect lighting, sofa area [lm]	2,200 x 2 = 4,400	2,800 x 2 = 5,600	1,600 x 2 = 3,200	200 x 2 = 400
Eye illuminance, sofa [lux]	439	736	249	23
Eye illuminance, dinner table [lux]	420	694	297	48

Table 4 - Simulation configurations

The figure below contains visualisations from the four scenarios in DIALux evo.

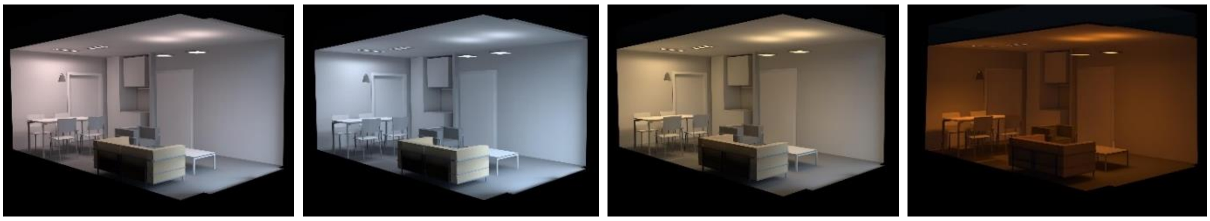


Figure 19 - Visualisations from DIALux evo

Conclusion on the Human Centric Lighting Design proposal

The goal with this radical investigation was to propose a lighting design that could support the circadian rhythm. Research showed that high illuminances and long exposure times were necessary. This was taken into account by focusing on places where the residents would likely stay for long periods. Overall, the design proposal is considered to be successful in fulfilling the intentions behind, and it will be further discussed and compared with other radical suggestions in section 6.1.

5.2.2 Conflicting comfort criteria

The goal of this design investigation was to make an overall concept for the entire apartment where the comfort for the resident is in focus. This is done based on the expected use of the different rooms during the day as described in section 5.1. Using this overall concept, it is explored where the comfort of the residents and the requirements for the staff are counteracting each other, causing conflicting criteria. This is a critical aspect to investigate, since in some of the spaces in the apartment, it is important for the staff to have visual comfort so their job can be done well. However, these requirements can affect the comfort of the residents in a negative way. So, the goal for this investigation was to reach the best possible comprise between the two user groups.

The bathroom

For the bathroom, three different scenarios were defined: General use, shower, and night-time use. The overall placement of the chosen lamps can be found in *Figure 20*.

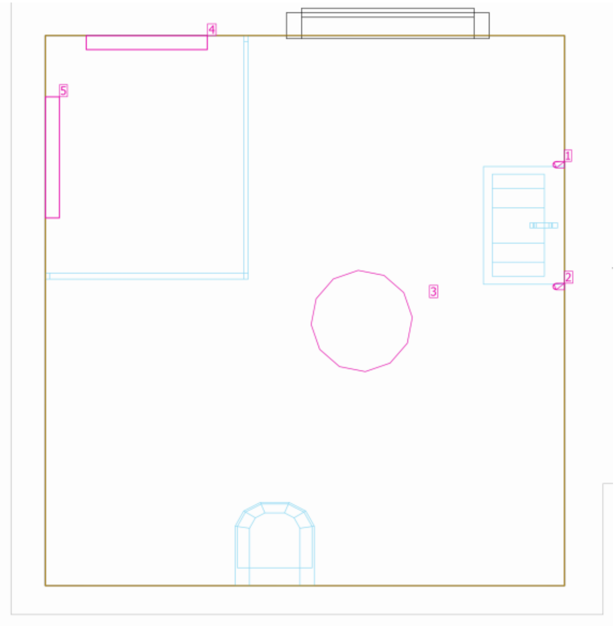


Figure 20 - The placement of the lamps, marked with pink, in the bathroom

The three different scenarios are shown in *Figure 21* below. The one for general use of the bathroom is on the left, the one where the resident is taking a shower is in the middle, and the one for when the resident needs to use the bathroom at night-time is on the right.

Figure 21 - Visualisation of the three different scenarios in the bathroom

For general lighting in the bathroom, a ceiling lamp which is placed in the centre of the room between the toilet and the mirror is used. This lamp is on whenever the bathroom is in use. However, when it is night, the lux-level and the colour temperature of the light is lowered. This is to ensure that when the residents use the bathroom at night-time, they do not wake completely up, and they feel safe. It is also possible to implement LED-strips around the bathroom door to guide the resident back to the bed. These specific set-ups have been tested by Københavns Kommune and Aarhus Kommune which showed promising results. (Lauridsen et al., 2021).

To illuminate when using the mirror, two lamps of the same kind is used. These lamps are placed vertically along the mirror, and by placing them in this direction, a more even distribution of light is emitted. Therefore, the face of someone who looks in the mirror will look natural. The last two lamps in the bathroom are placed in the shower, and their functions will be explained more in a separate section about conflicting criteria below.

The chosen lamps can be found in *Table 5*. All the selected luminaires have at least the IP-class of 44 as it is a must for lamps placed in bathrooms. ("Viden om tæthedsgrad (IP)," n.d.).

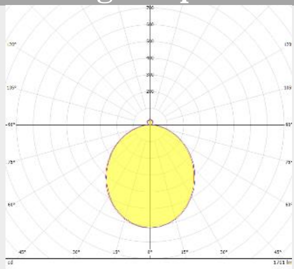
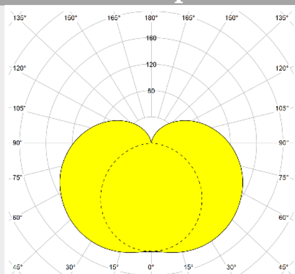
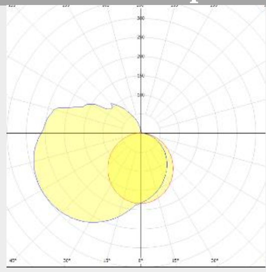
Primary function	Ceiling lamp	Mirror lamps	Shower lamps
Light distribution curve			
Photo			

Table 5 - Bathroom luminaires, Conflicting comfort criteria design. See detailed references in Appendix A: Luminaires

Area with conflicting criteria

In the bathroom, an area where two comfort criteria can come into conflict with each other is in the shower situation. This could occur when the resident takes a shower and needs assistance from the staff. The resident probably sits on a bath chair. This means that the resident could cast shadows onto him or herself which could complicate the work for the staff. To solve this issue, proper lighting from multiple directions is necessary. It should however not feel like a spotlight on the residents, as it could feel intimidating and make them feel uncomfortable.

To find a solution to this problem area, a small case study was made. Below are some of the inspiration pictures found.

Figure 22 - Inspiration pictures for a solution in the shower ("Bathroom Remodel," n.d.; Cornwell)

In these pictures, it can be seen that integrating the lamps in the wall, by using a shelf or in the ceiling, is a modern way to get a stylish shower. By integrating the luminaries, the light is distributed more evenly in the shower by using the walls or the ceiling as a reflector. Thereby, the light is coming from multiply directions. However, all these solutions can be very expensive to make in a retirement home. So, the suggested solution is to have two light panels in the shower which emit light from two sides. In this way, the walls and the ceiling in the show are used as reflectors without integrating the luminaires into the construction.

In *Figure 23*, the light distribution at floor level without the shower lamps is shown to the left, and with the lamps in the shower to the right. As mentioned in section 3, the illuminance level for a so called 'simple examination', which helping with a shower is assumed to be, must be at least 300 lux at bed-level. However, as the staff is assisting the resident with a shower, and thereby working at a different height than in the bed, it is determined that the requirement of 300 lux should be fulfilled at floor-level.

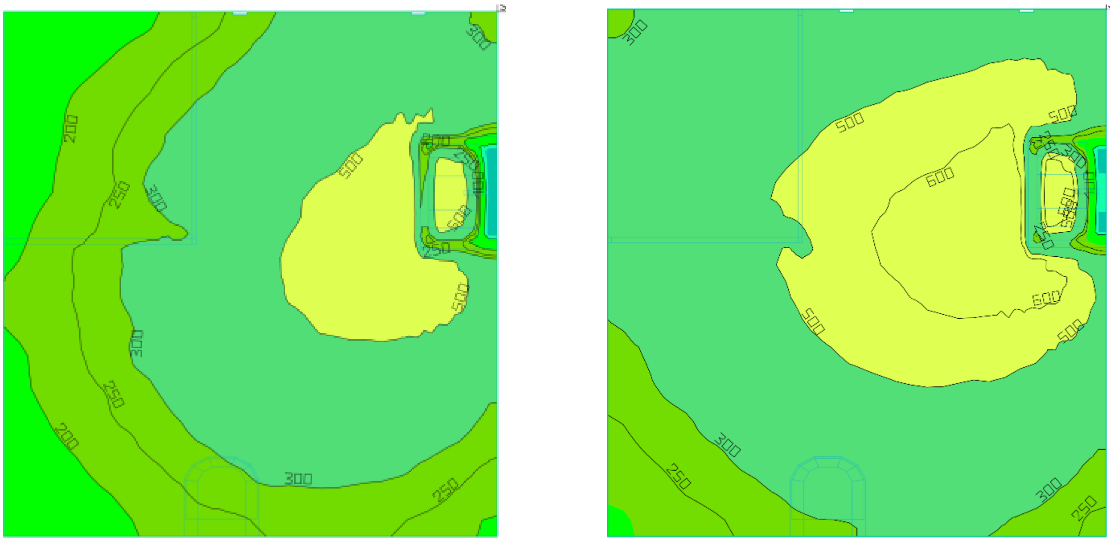


Figure 23 - Illuminance map of the bathroom without (left) and with (right) lamps in the shower

It can be observed here that the lux-level on the floor is now 400 lux in all the area for the shower. Therefore, the requirement of at least 300 lux is fulfilled, and it will be easier for the staff to do their work. In *Figure 24,* visualisations of the shower without the lamps and with the lamps are shown. Here it can be observed that the light is spread using the walls and the celling, and there is no intimidating spotlight feeling.

Figure 24 - Visualisations with and without shower lamps

It should be noted that the residents in many retirement homes only shower once a week, and often it is only a 'sink bath'. For example, if the resident is in a wheelchair, they cannot get up and onto a bath chair. However, the suggested design will still have benefits for the staff, as the higher illuminance levels would make it easier to assist the resident. Another positive aspect of using the shower lamps is that the light is also useful for the cleaners, since the requirement for cleaning is 200 lux on the floor level in table 5.37. ("DS/EN 12464-1 Light and lighting – Lighting of work places – Part 1: Indoor work places," 2011).

The luminaires in this room are controlled by a motion sensor which, based on the time of the day, turns the luminaires on at the colour temperature and lux level that is preinstalled. However, the shower lamps are suggested to be controlled by an on/off switch, as this will save energy.

Bedroom

The overall suggested placement of lamps and the resulting light distribution at the floor level can be found in *Figure 25*.

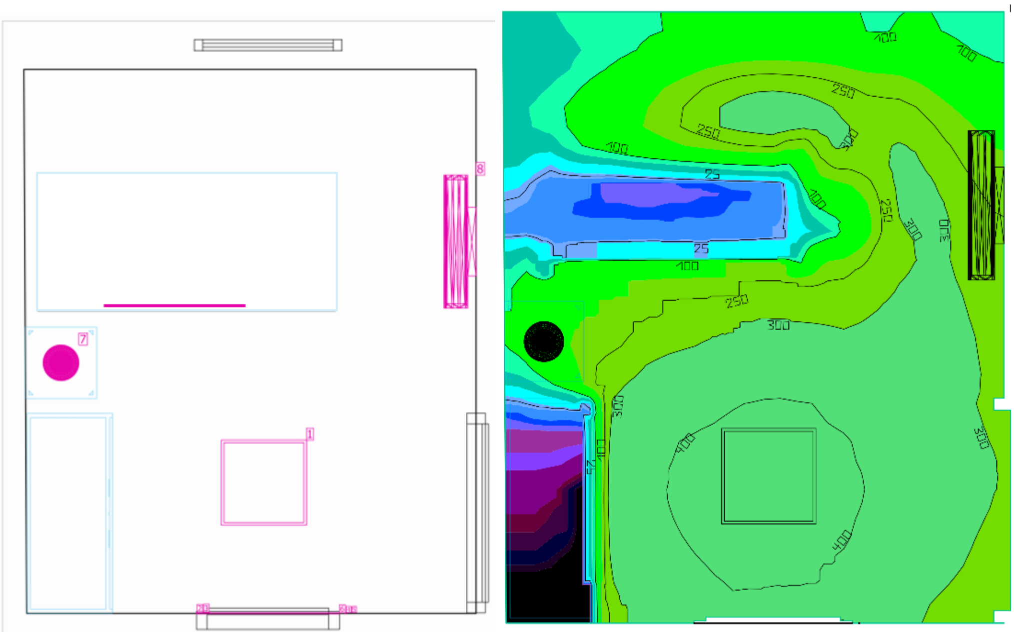


Figure 25 - Placement of lamps and illuminance map

For the bedroom, two different scenarios are visualised and can be seen in Figure 26. The first two visualisations from the left are for the same scenario with all the lamps turned on, showed from two different corners of the room. The last visualisation to the right is for night-time when the resident gets out of bed to use the bathroom.

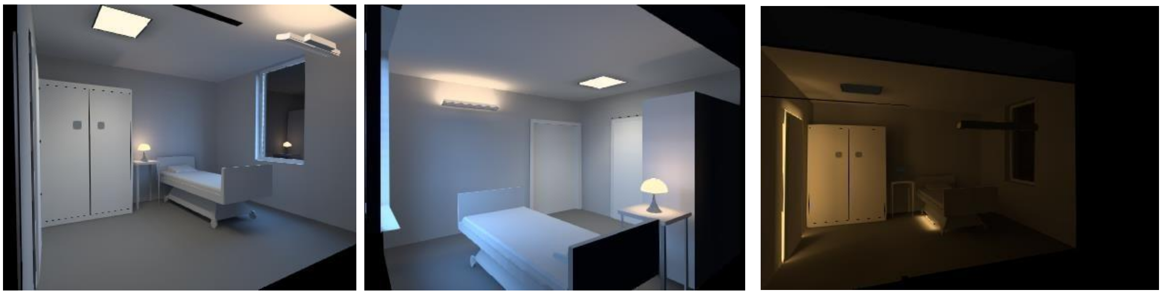


Figure 26 - Visualisations from DIALux evo

For both the bedroom and the living room where there are windows, it is important to involve daylight, and therefore, all day-time simulations include daylight. The placement of the lamps and lumen values also took daylight into consideration. For the general lighting, a luminaire which is integrated into the ceiling is suggested. This lamp can also change colours and thereby be a part of a human centric system if requested. The lamp is placed close to closet, so when residents and/or staff choose clothes, it becomes a good and effective experience. The general lighting is supported by a wall washer which is placed on the wall opposite the bed. The function of this luminaire is explained more in a separate section, since this is an area where comfort criteria are conflicting.

On the table beside the bed, a table lamp is placed. The chosen lamp is placed here as an example, since the idea is that the resident themselves could bring a lamp from home to make the room feel homier. Either way, a lightbulb which can give an output of 500 lumen or more should be chosen. Otherwise, it would not be possible for the elderly person to read in the bed, since there is a need for a high lux-level. It was not possible to find a lamp that could satisfy this requirement and be imported into DIALux evo. So, the lamp used in the simulations is there to show an example of the placement, but a table lamp with a higher lumen output is suggested.

The last luminaires in the room are only turned on during the night. These luminaires are the LED-strips that are placed under the bed and around the door to the bathroom. They are turned on by a sensor placed under the bed that monitors if the resident is going out of the bed. Normally, when the residents go out of bed during the night, it is because they need to go to the bathroom. These strips will help the residents find the door to the bathroom and back to the bed when they are done. The strips all have a low colour temperature, so the residents do not wake completely up or experience any glare. This solution is specifically good for elderly who wander at night, since the light will guide them towards a specific direction. If the staff needs to check on the resident during the night, they could use a flashlight. Thereby, the resident does not wake up by the light turning on.

The specific chosen lamps can be seen in *Table 6* on the next page.

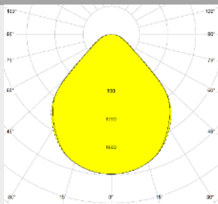
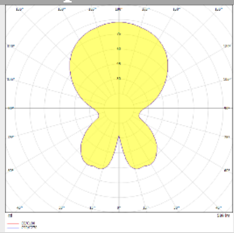
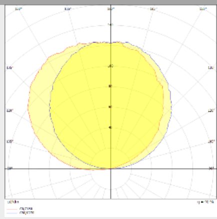
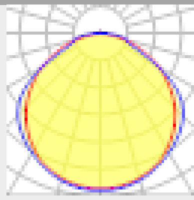
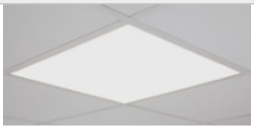
Primary function	Ceiling lamp	Bedside table lamp	Wall washer	LED-strips
Light distribution curve				
Photo				

Table 6 - Bedroom luminaires, Conflicting comfort criteria design. See detailed references in Appendix A: Luminaires

Area with conflicting criteria

In the bedroom, a problem area can be the bed. Because when the staff members help the resident to get into bed or if the resident is bedridden, the bed can be seen as a workspace. Therefore, the requirement of the 300 lux for the staff needs to be fulfilled. However, the resident must not find this uncomfortable, so glare should not occur. An inspiration for a solution for this problem can be seen below in *Figure 27*.

Figure 27 - Inspiration picture for a solution for the bed (Fagerhult, n.d.)

In this inspiration picture, a fictional room in a hospital is used. Here it can be seen that a ceiling lamp and a wall washer is placed over the bed. However, since this is a room in a hospital where the patient will not stay for a long time, the glare that a person lying in the bed will experience is not considered well. In this project, a glare investigation was conducted for a person who is lying in the bed with a wall washer over his or her head.

When the wall washer used in this figure was tested, the unified glare rating (UGR) was 44 when the bed was placed right under the wall washer. And when the wall washer was moved to the wall opposite the bed, the UGR was 22. Both results are unacceptable. The reason behind this high UGR was caused by the wall washer's ability to emit light in two directions, towards the ceiling and towards the bed, as well as the ceiling light being placed right over the bed.

Based on this initial investigation, the ceiling light was moved towards the closet, and another wall washer was chosen. This luminaire is placed close to the top of the wall, so the ceiling can work as a reflector, and the light distribution becomes indirect. Thereby, the wall surface becomes free so the resident can decorate the wall with pictures or other things. A visualisation of the view that a person lying in bed experiences can be seen in *Figure 28.*

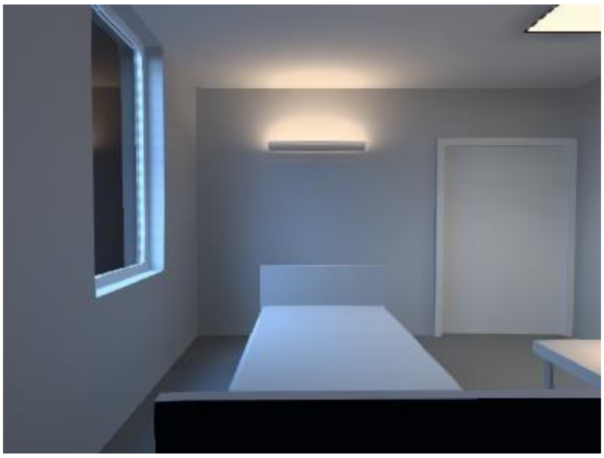


Figure 28 - The view of the wall washer from the bed

As seen in *Figure 29,* when the wall washer is not incorporated in the design, the illuminance level on the bed is not reaching the target level all over the bed. At the same time, the light distribution is not as even as wished. But as it can be observed in *Figure 30,* when the wall washer is incorporated, the area which is below 300 lux is significantly smaller, and the distribution is more even.

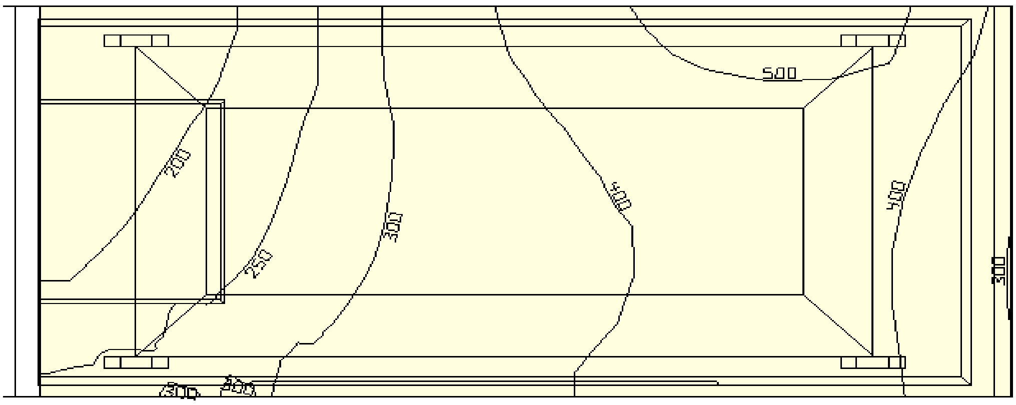


Figure 29 - The illuminance levels at the bed without the wall washer

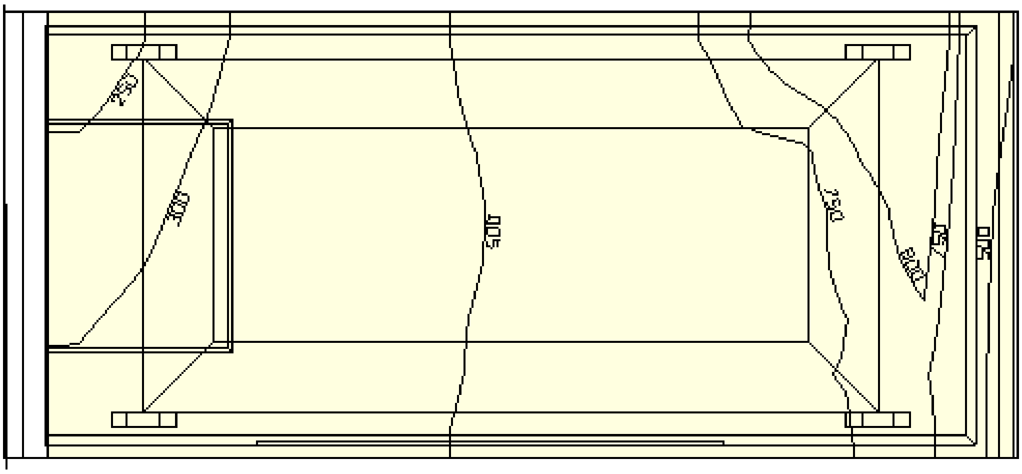


Figure 30 - The lumen level at the bed with the wall washer

The important part is that the resident will not experience any glare from the chosen wall washer. Therefore, a glare analysis is conducted based on two different scenarios: One where the resident is lying down in the bed, as seen in *Figure 31*, and one where the head is raised to a 45-degree angle as seen in *Figure 32.* For these two positions, the UGR from the bed is evaluated for the case when the resident is most likely to experience glare, which is when the ceiling light, wall-washer and the table lamp are turned on.

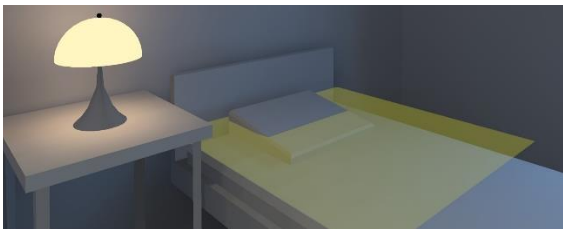


Figure 31 - The calculation surface for a person lying in bed

Figure 32 - The calculation surface for a person sitting in bed

The results from the two positions showed that the UGR became the largest at the upper corner next to the bedside table. In *Figure 33* and *Figure 34* it can be seen where the primary direction the reason for glare was coming from. When a person was lying in the bed, some glare could be experienced from the direction of the wall washer, which is probably the reflections from the ceiling. But at this position, the primary direction for the glare was coming from the ceiling light. At the 45-degree angle, the primary source of glare was shifted to be the bedside table lamp.

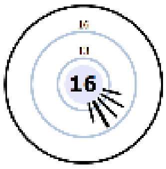


Figure 33 - UGR near bedside lamp for a person lying in bed

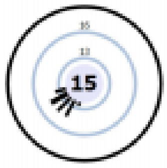


Figure 34 - UGR near bedside lamp for a person sitting at a 45-degree angle

From this investigation, it can be observed that the main object which is causing the glare is coming from the ceiling light and not the wall washer. Therefore, it can be recommended to place a wall washer, which illuminates the ceiling opposite the bed.

However, it should be noticed that the wall washer should not be placed too close to the ceiling since this will cause more glare from the reflection.

In this room, the ceiling lamp and the wall washer are controlled by the same on/off switch which is placed beside the door to the living room. In this way, the resident and the staff can easily control the light when they enter or leave the bedroom. The bedside table lamp is also control by an on/oof switch. But this one is placed right beside the bed so the residents can control the light themselves when they are lying in the bed.

Living room

The overall view of all the luminaires can be seen in *Figure 35*. And the light distribution at floor level can be seen in *Figure 36*.

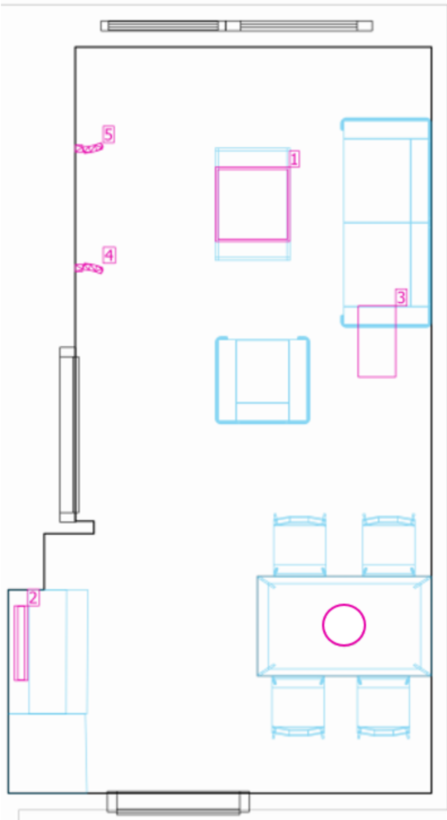


Figure 35 - The placement of the luminaires, marked with pink, in the living room

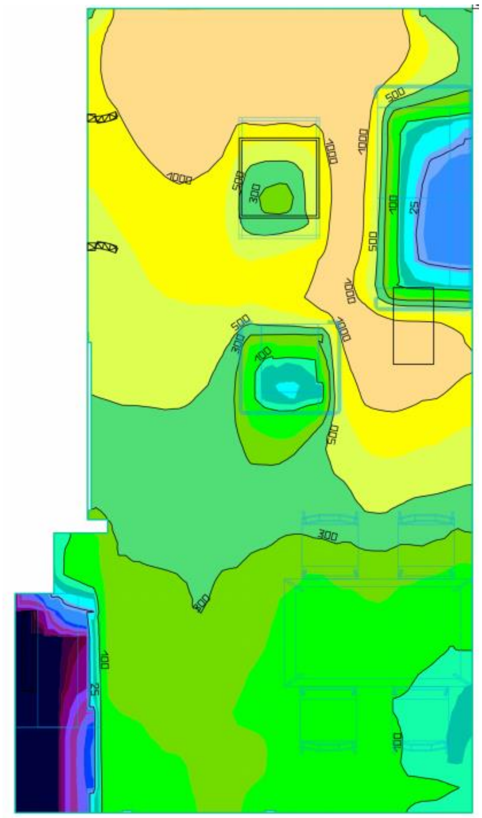


Figure 36 - The light distribution at floor level in the living room

This room can be used for many different activities, so in *Figure 37,* it is chosen to show all the lights being on, from two different directions.

Figure 37 - Visualisation of the living room

As it can be seen in the visualisations, this room has many different lamps. However, the ceiling lamp and the wall washers, which are placed where the TV is assumed to be mounted, are the same as in the bedroom.

The ceiling lamp is placed over the sofa table to distribute an even lux-level over the table. The ceiling light is not placed more towards the middle since the dining table is lighted up by a pendant. The table is an area of possible conflicting interests, so this pendant will be discussed more in a separate section below.

Beside the dining table, the kitchen is placed. In the kitchen, a lamp is placed underneath the kitchen cabinets. This luminaire has a high lumen-value so the kitchen space is well lit, and the elderly can see when they make coffee and tea. On the other hand, the staff will also be able to see well if they need to give out medicine to the resident. This lamp has an on/off switch which is simple for the elderly to use.

Beside the sofa, a floor lamp is placed. As in the bedroom, this lamp is only shown as an example of where a luminaire should be placed. This lamp is one that the resident can bring from home, but, as in the bedroom, this lamp must have the ability to have a light-bulb installed that can emit 500 lumen. For when the resident is sitting in the sofa, reading, knitting and so on, they must be able to see what they are doing. A floor lamp is ideal since it can be moved around by the staff if they need more light elsewhere.

The last lamps in this room are the wall washers beside the TV. These luminaires are placed beside the TV to counteract the contrast between the TV and the surroundings. Especially during the evenings, this contrast is bad for the elderly since their eyes are slow to adapt to the dark. In *Figure 38,* a visualisation of the view from the sofa can be seen, and in *Figure 39,* the light distribution is shown.

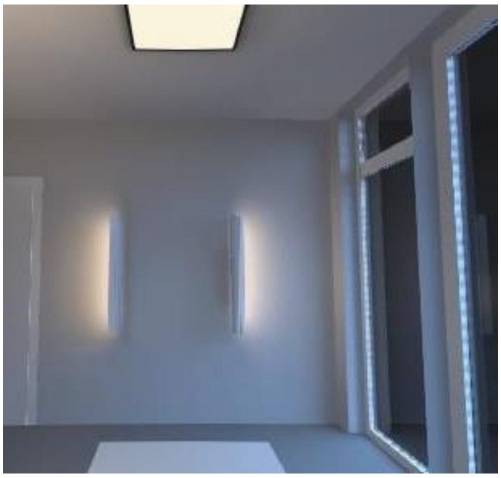


Figure 38 - Visualisation of the view from the sofa

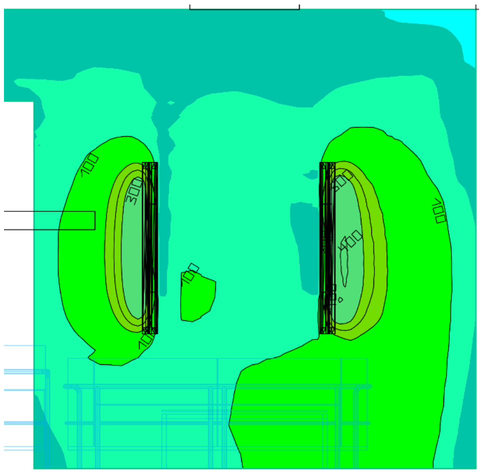


Figure 39 - Light distribution on wall

And to ensure that there is no glare caused by these luminaires, a glare analysis is conducted. The calculation area is placed as a person who is sitting in the sofa with their head at 1,2 meters as shown in *Figure 40* and without daylight.

Figure 40 - The calculation area for UGR from the wall washers

From the glare analysis it can be observed that the primary source of glare is caused by the floor lamp beside the sofa. Therefore, it can be concluded that glare is not caused by the wall washers and therefore it is recommended to implement them in the design.

The chosen luminaires that are new for the living room is listed in *Table 7*.

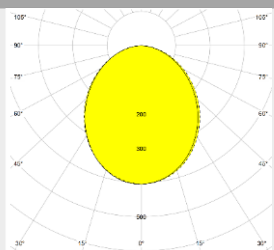
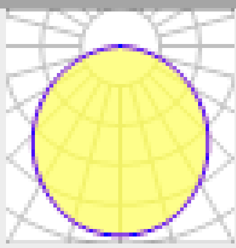
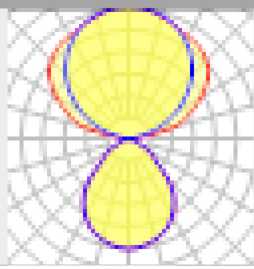
Primary function	Kitchen cupboard	Dining table pendant	Floor lamp
Light distribution curve			
Photo			

Table 7: Living room luminaires, Conflicting comfort criteria design. See detailed references in Appendix A: Luminaires

Area with conflicting criteria

In this room, the area where different comfort criteria can come into conflict is the dining table. But in this case, it is not comfort criteria for staff members that conflict with comfort criteria for the residents. On the contrary, a dinner table is an area where both staff members and residents each have contradicting comfort criteria: They want high illuminance levels for performing their tasks, they do not want to experience glare, and finally they prefer to be able to see other people sitting at the table or standing near the kitchen.

For the staff, the table can be seen as a worksurface. This is also the place where residents sometimes eat and they need to be able to see the food. This means that the luminaire should be placed close to the table so a lux level between 300 and 500 lux can be reached. Therefore, a pendant is chosen as the lamp. But when the lamp is placed close to the table, it can be difficult to maintain eye contact over the table, which is a wish from both users.

An investigation of three different mounting heights is presented below.

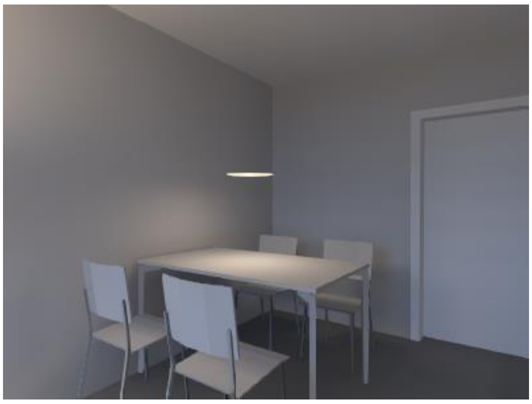


Figure 41 - Pendant close to the table at 1.4 m

Figure 42 - View from eye level. Pendant at 1.4 m

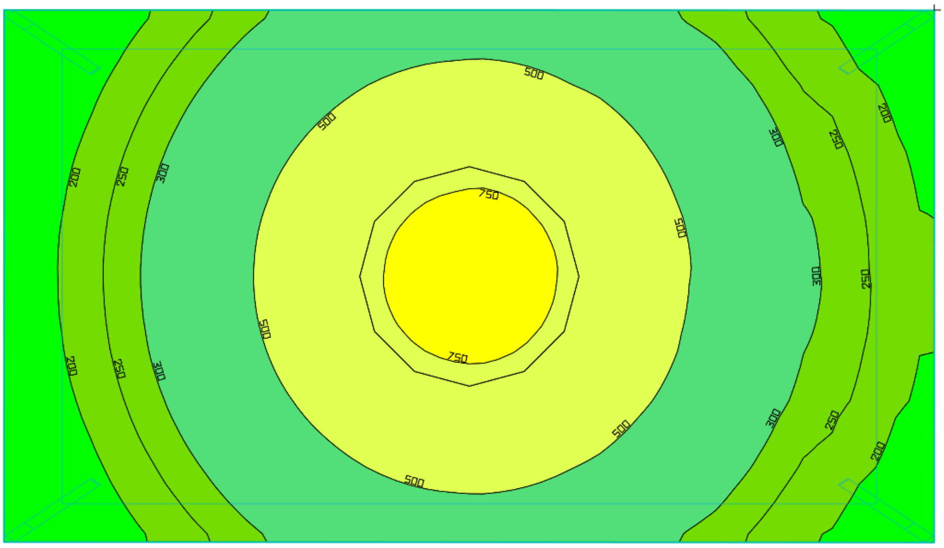


Figure 43: Light distribution with the pendant at 1.4 m

In *Figure 41* above, a visualisation of the lamp placed at 1.4 m and thereby close to the table can be seen. In *Figure 43,* the distribution of light on the surface can be seen, and it is focused and directional and close to 500 lux which is needed for the residents.

However, in *Figure 42,* in the visualisation from eye height, it can be seen that it can be difficult to maintain eye contact. Especially if the lamp had a lampshade as well.

On the other hand, in *Figure 45* it can be seen that it is easier to maintain eye contact over the table when the pedant is placed closer towards the ceiling as shown in *Figure 44*. But as seen in *Figure 46,* the light distribution gets less focused because of the height of the lamp. And the lux level is also far away from the desired 500 lux.

Figure 44 - Pendant placed closer towards the ceiling at 2 m.

Figure 45 - Eye contact with the pendant close to the ceiling

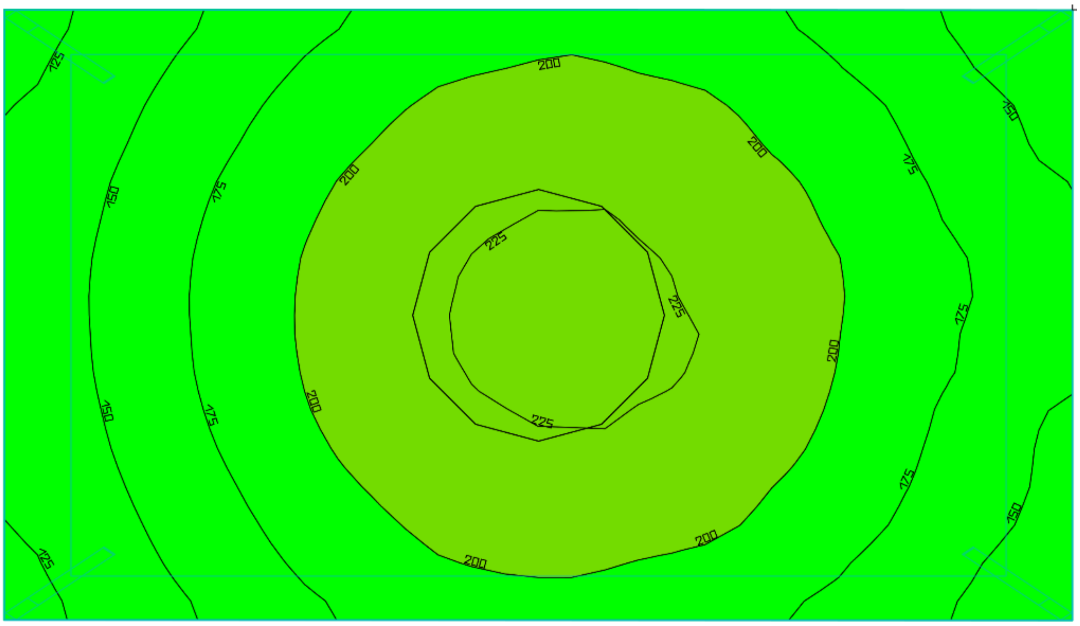


Figure 46 - Light distribution with the pendant at 2 m

Based on this investigation, a compromise is made with the pendant placed between the two extremes at 1.7 meters over the floor as shown in *Figure 47*. As seen in *Figure 49,* the distribution gets more even and is very close to the desired 500 lux. And in *Figure 48,* it can be observed that it would be easier to maintain eye contact.

Figure 47 - Visualisation of the pendant placed at 1.7 m

Figure 48 - Visualisation at eye height with the pendant at 1.7 m

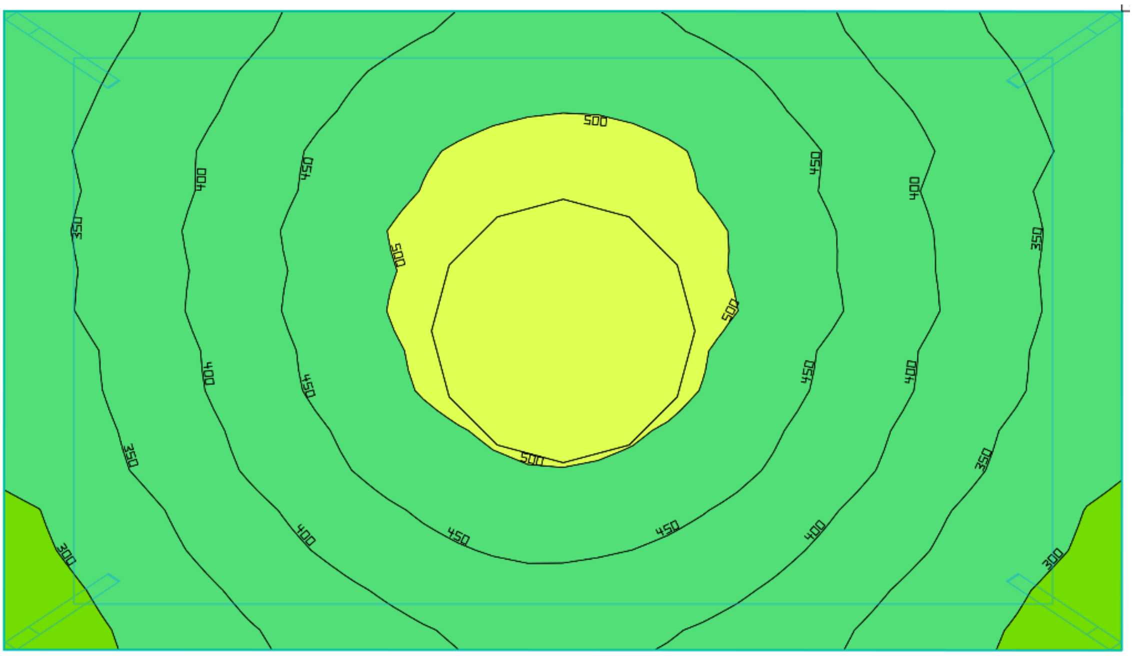


Figure 49 - Light distribution over the dining table with the pendant placed at 1.7 m

The solution was as seen here to place the pendant in between the two extremes. For this situation, a glare analysis is conducted. The calculation area is at 1.2 meters over the floor as seen in *Figure 50*.

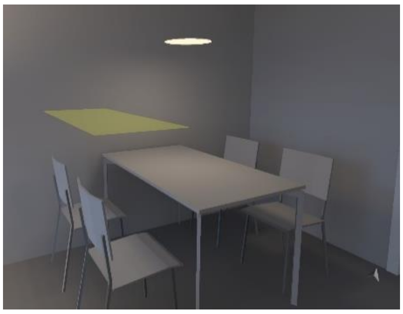


Figure 50 - The calculation area for glare assessment over the dining table

The result of this analysis indicates that the chosen luminaire will cause glare. So instead of this luminaire, a lamp with a lampshade, e.g. as used in the human centric lighting investigation must be incorporated. Thereby, the glare from the lamp becomes less. But the solution for this problem area would still be to have a pendant in the middle of the two extremes.

However, it is suggested to make a more flexible solution. The mounting height of the pendant can be adjustable. By doing this, none of the criteria will come into conflict with each other. And for people with lowered appetite, this solution would be ideal since the light closer to the table could make the food look more appealing, if the luminaire has a good colour rendering. This solution can also be combined with a control system where the light can be dimmed based on what the space is going to be used for. If this control is chosen, the switch could give an audible feed to the user by a clicking sound. Thereby the user knows that the system is working. The ceiling lamp and the wall washers are controlled by the same on/off switch, and the floor lamp is controlled by its own on/off switch.

Sun shading in the bedroom and the living room

For the windows in the living room and the bedroom, it is important to have a shading system when it is sunny, so the elderly do not experience any glare. But at the same time, the elderly should still be able to look out of the windows. Therefore, it is suggested that the windows have automatic sunshade as seen in *Figure 51*.

Figure 51 - Suggestion for shading system for the bedroom and living room (Markisecentralen, 2019)

This system is controlled by the resident so when they press a button, the sunshade will be activated. The sunshade will keep going down until the resident stops pressing the button. Thereby, the residents themselves can decide how much shading they want, and how much of a view out of the window they want. By using this sunshade, glare is prevented, and the resident can still look out of the window.

Conclusion on the Conflicting Comfort Criteria Design proposal

The goal for this radical design investigation was to make an overall design concept and afterwards define areas where the comfort criteria for the two user groups could be conflicting. As expected, the criteria could not be completely fulfilled for either of the user groups in the defined problem areas. It was however possible to reach an acceptable compromise between the two user groups' needs.

5.2.3 Simplicity: Easy to use and low-cost solution

Moving on to the third radical investigation, the goal of this design investigation was to focus on simplicity in the light design. By focusing on simplicity, it is the goal for the design process to find a simple and user-friendly light design. Simplicity in the light design is important because it can both be a way to minimize the cost of installing and operating the light, while also focusing on that the light should be easy to use for the elderly and the retirement home workers to encourage them to use the light. (Ascanius, 2019).

This design investigation will focus on gaining a lux level of 200 at the floor level. This lux level is based on the recommendations to dayrooms at health care premises ("DS/EN 12464-1 Light and lighting – Lighting of work places – Part 1: Indoor work places," 2011). Since the focus in the light design is simplicity and a low-cost solution, it is expected that the elderly will use their own lamps for focused light around the apartment, for example as a reading lamp next to the sofa or the bed and over the dinner table if they need more light that what is provided by the ceiling lamps. Based on this condition, it is accepted that the lux levels, with the proposed light design, will not be high enough for the elderly to do visual demanding tasks like reading and knitting. The simple light design will make it possible to adapt the light design in the individual apartments to the different user needs of the elderly, without needing to redo the entire setup of the lamps in the apartment.

The chosen lamps

The lamps chosen for this solution are the same lamps that are used in the design investigation focusing on comfort for all users. The name of the chosen lamps, and a description of their location, can be seen in the table below.

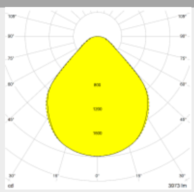
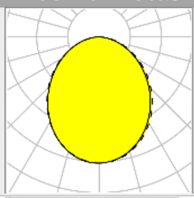
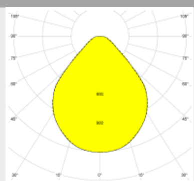
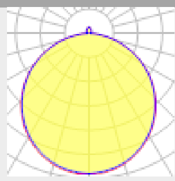
Lamp placement	Living room, ceiling lamp	Living room, lamp below kitchen cabinets	Bedroom, ceiling lamp	Bathroom, ceiling lamp
Light distribution curve				
Photo				

Table 8 - Luminaires, simple light design. See detailed references in Appendix A - Luminaires.

Simulation results

The simulation for the light levels on the floor is performed without a contribution form natural light, because the light design in the apartment must have the ability to achieve the desired lux levels at all times of the day.

The simulation is performed on a furnished apartment to give an insight in where the resident will be using their time, and to make it possible to make the interior design and the light design work together and ensure a satisfying light level at the floor.

As seen in the result of the simulation in *Figure 52,* the lux levels are at least 200 lux at most of the floor in the living room and bedroom. Lamp placements are marked with red. The lux-levels at the floor between the bed and the window in the bedroom is below 100 lux, but that is acceptable since it is not expected that the resident will spend much time in that area.

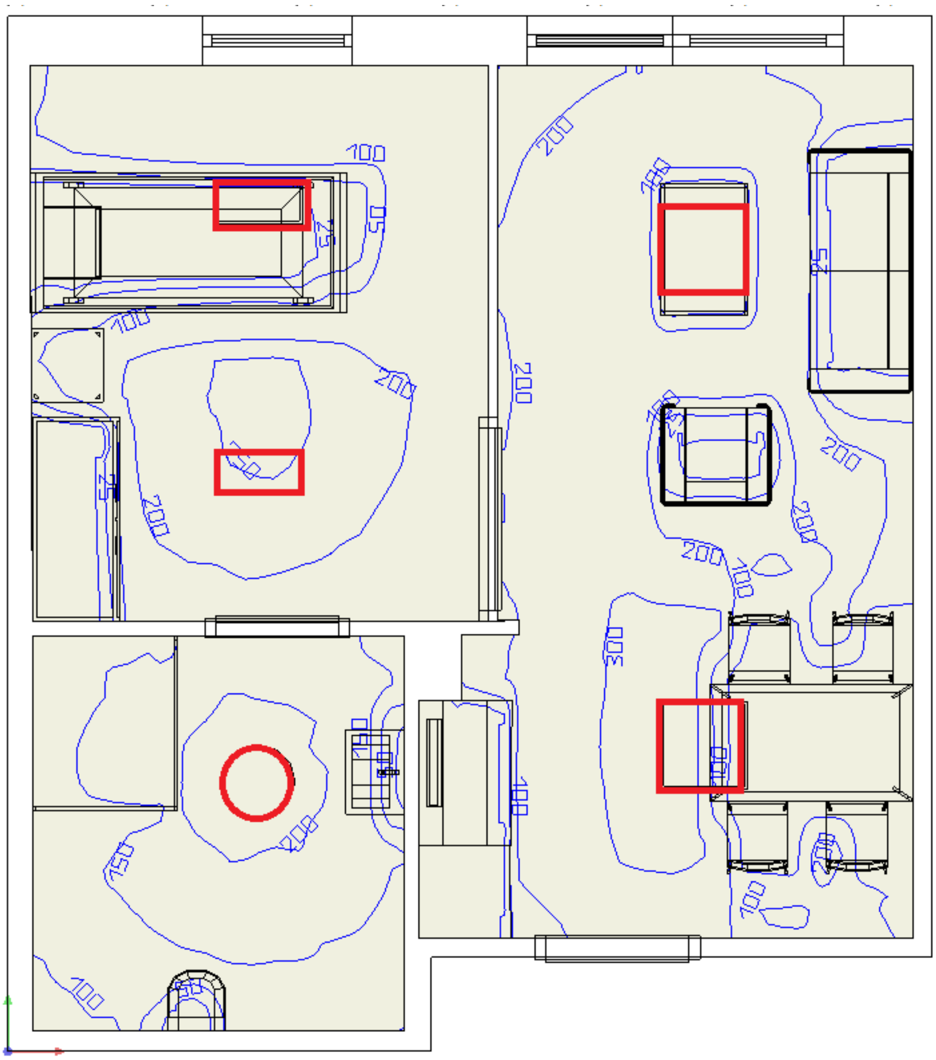


Figure 52 - Lux levels on the floor, simple light design

The lux-levels at the surface of the bed are simulated to determine if there is enough light on the surface for the elderly to read a book in bed and for the retirement home workers to care for an elderly who cannot leave the bed. It is seen in *Figure 53* that the lux levels at the head of the bed is between 150 and 500 lux, which is too low for an elderly person to be able perform visual demanding tasks. To combat the low lux levels, the elderly can be encouraged to bring their own bedside lamp, to reach the necessary lux levels while also giving a feeling of being home and having a say in the home décor. A bedside lamp will also help raising the lux level on the upper part of the bed in general, so it will be possible for the retirement home workers to care for and perform simple examinations on the elderly in bed. The demanded lux level for performing simple examinations is 300 lux ("DS/EN 12464-1 Light and lighting – Lighting of work places – Part 1: Indoor work places," 2011), which is met in the lower part of the bed, and a bedside lamp will raise the lux levels in the upper part of the bed to at least 300 lux. The demand for a higher lux level in the upper part of the bed can be solved by installing a ceiling lamp over this part of the bed, but this solution might cause glare for the resident in the bed.

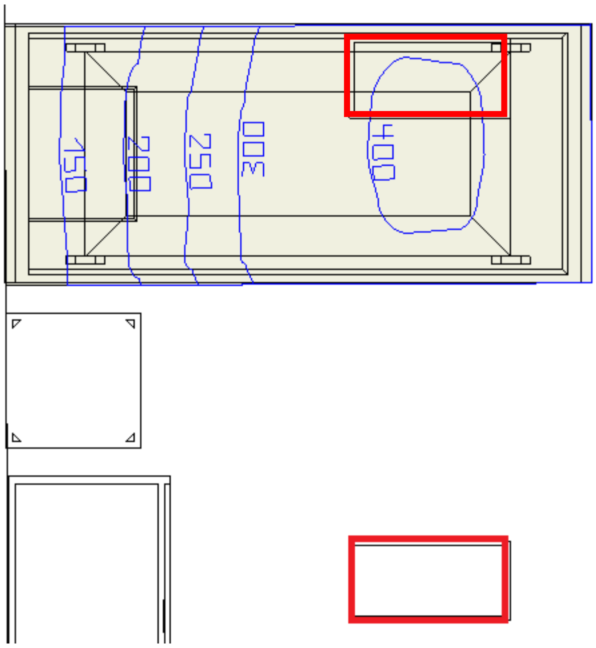


Figure 53 - Lux levels on the bed

To assess the glare that the resident may experience from the lamp when lying or sitting in bed, the UGR is calculated in DIALux using the surface seen in *Figure 54*. The UGR is determined to be 11,8 which is below the recommended value of 19 ("DS/EN 12464-1 Light and lighting – Lighting of work places – Part 1: Indoor work places," 2011), which means that the resident should not experience glare. The average lux level at the eye level is 198 lux, which further supports the recommendation that the resident could have a bedside lamp.

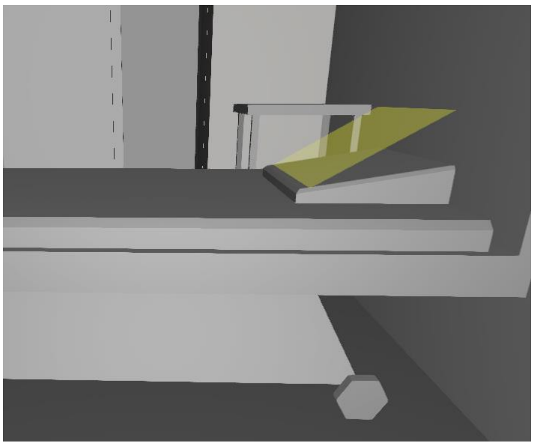


Figure 54 - Calculation object for UGR

In the living room, the lux levels at the dinner table are examined to assess if the chosen light design will be appropriate for eating and more visual demanding tasks without mounting a pendant over the dinner table. Based on the simulation results seen in *Figure 55*, it is clear that there is a difference in the lux levels between the two ends of the table. The light on the table should be enough for eating, but there might be a need for higher lux levels to perform visual demanding tasks, e.g. reading. If it is necessary for the elderly to have higher lux levels, this can be achieved by installing a pendant over the table.

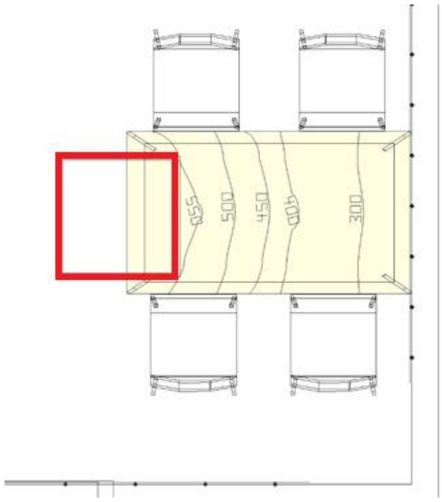


Figure 55 - Lux levels at top of the dining table, simple light design

Light control

It is expected that all the lamps in the apartment will be controlled using a standard Danish light switch, which can turn the light on or off. The lamps in this design concept are not dimmable and are only having an on/off setting. This choice is made to try to make the light design simple and accessible to the residents and the staff, under the presumption that the light only will be used as intended if it is easy to understand and to use.

Conclusion

The goal with this design investigation was to propose a simple light design that could fulfil the basic needs while making it easy for the users to control. This was taken into account when choosing the lamp types, placements, and control. The result is a light design controlled with on/off switches that accommodates the basic lux levels at the floor, but might need to be combined with the residents' own lamps, to gain high enough lux levels to perform visual demanding tasks like reading and knitting. The radical design proposal is considered successful in fulfilling the intentions behind.

6 Discussion and final electric lighting design suggestions

The aim of this section is to discuss the learning outcomes from the radical design suggestions and combine them into final design suggestions. In the first part, the performance of the presented radical investigations will be compared, whereas the next part contains a discussion of how the three radical investigations could be compared in the best possible way, considering the different needs of the elderly people at retirement homes. Finally, the last part contains a discussion on future work.

6.1 Radical design concepts

In order to compare the performance of the radical design suggestions, a radar chart was made based on the five focus areas presented earlier. In the chart, the three designs were graded from 1 (bad performance) to 4 (good performance). The grading was based on the simulation results and group discussions from where the main arguments will be presented below.

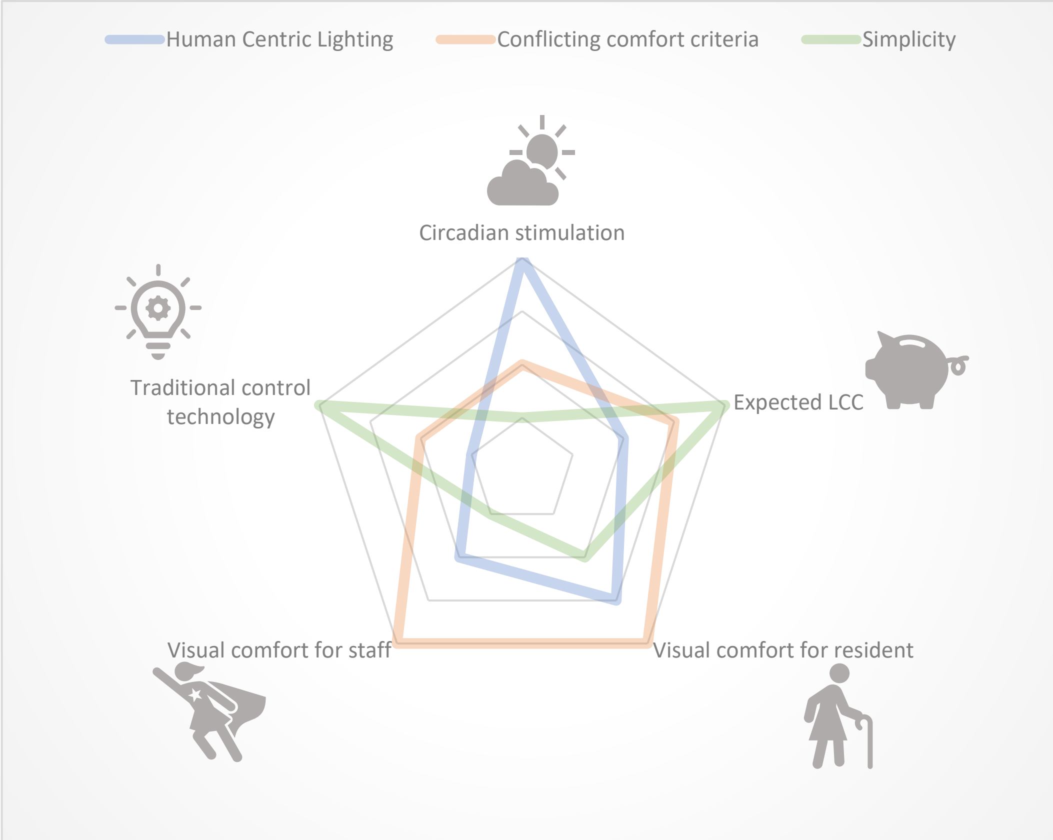


Figure 56 - Comparison of radical design investigations

Starting off with the Human Centric Lighting design, it of course scores well when it comes to circadian stimulation, though it would depend on daylight access and lighting installations in the common areas. No detailed cost estimates were made in this project, so the grading in the Expected LCC category primarily comes from luminous flux needs and number of luminaires, since increasing in these parameters increase the energy use, installation cost and likely maintenance costs. For the Human Centric Lighting, we expect high costs not only associated with energy use, but also a complex installation that should be personalised for the daily rhythm for each of the residents. The comfort is good, but it might be difficult to get used to the fact that at some points of the day, the access to bright task lighting is limited. The visual comfort for night shift workers is poor, but they often visit the apartments shortly for checking if everything is fine. It is also problematic in terms of staff comfort, if common areas do not have circadian lighting installations, since they then have to shift a lot between colour temperatures. Finally, the technology is very new, and we fear that the elderly may be confused or disappointed with the control system, especially if staff members or relatives are frustrated about the technology as well.

Moving on to the conflicting comfort criteria design, we believe that it was successful in dealing with some critical scenarios for both staff and residents. Examples of this are the shower situation and when the resident needs help in bed. Colour temperatures are adapted to the circadian rhythm at night-time, which partly fulfils the circadian stimulation goal. And then there is the Expected LCC, where we believe that installation costs will be slightly lower that for the Human Centric Lighting. There are many different luminaires and dimming options which affects how recognisable the control system will be, affecting the Traditional control technology grade.

The last design investigation targeted a low-cost and easy to use solution. Here we fear that it will have some severe consequences in terms of visual comfort for both the staff members and residents. In particular, the nursing staff may be annoyed by shadows caused by the low number of luminaires, and the residents may find it difficult to perform tasks like reading or knitting. Additionally, it places heavy demands on the residents or their relatives that a good interior lighting design is their responsibility.

6.2 Final suggestions

In the work with combining the radical design investigations to one design concept, the Human Centric Lighting and conflicting comfort criteria investigations were used the most. The work with simplicity was however very valuable as it helped understanding the pitfalls of a too simple solution. The figure below is a visualisation of the final suggestion, which is discussed and described further below. Relevant illuminance levels are also shown.

Surface	Average illuminance [lux]
Living room floor	500
Dinner table surface	1025
Eye level, sitting at dinner table	491
Eye level, sitting in sofa	582
Bedroom floor	250
Eye level, sitting in bed	475
Eye level, lying in bed	385
Bed surface	520
Bathroom floor	285

Figure 57 - Visualisation of final suggestion and illuminance table. Time: Morning.

An important downside of the human centric lighting concept was the lack of task lighting and lack of user involvement in the suggested control system. In the final suggestion, not all the luminaires seen in *Figure 57* are a part of a circadian lighting system, and the user has the opportunity to overwrite preinstalled luminance levels. The visualisation is from the morning hours, but a floor lamp by the sofa has a warmer light.

Indirect lighting solutions are incorporated in the final suggestion because they are considered a very relevant tool for increasing comfort and health for the elderly. There are for instance wall-washers near the dining table and at the TV, and the ceiling is illuminated in the bedroom. Needing high illuminance levels for both the ability to perform visual tasks and for the stimulation of the circadian rhythm, the indirect solutions are means of avoiding severe glare issues. It has however consequences for the expected LCC. More energy will be needed, and more lamps should be installed and maintained. These arguments were the main reason for the poor expected LCC score in the radar chart below, comparing the three radical investigations and the final suggestion.

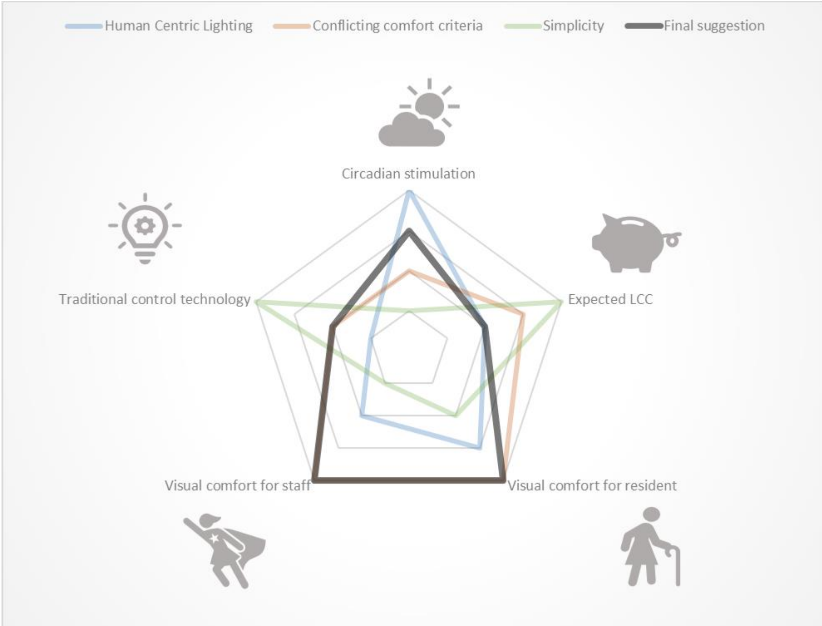


Figure 58 - Radar chart assessment of solutions

It can be seen in the radar chart that in some parameters, the final suggestion is considered successful in combining ideas from the radical investigations. The final suggestion scores well on the comfort criteria since many of the principles from that radical investigation were used. But when it comes to traditional control technology, the final suggestion does not perform well. Some lamps will be controlled by traditional on/off switches on the wall. Some are controlled directly on the lamp itself, but for the lamps included in the circadian lighting system, there is a third way to control. The users should be able to manually set the colour temperatures on a central control panel, even though there is a risk that the full potential of circadian stimulus will not be reached.

Being aware of high costs, it is worth to include some cost/benefit considerations. Not all the senior citizens experience disturbances in their circadian rhythm, so this design concept is suggested for elderly persons within group 1 and 5 who have mild or severe disturbances in the circadian rhythm. (Tofteberg et al., 2020). Learning from research about circadian lighting, the time factor - the time spent in certain circadian stimulating environments - is important. For the mobile elderly people who prefer to spend time in the common areas, the suggested expensive human centric lighting design in the apartments are not expected to have a substantial effect. To sum up, this design is suggested for elderly, immobile people with disturbances in the circadian rhythm.

On the next page, additional visualisations from the final suggestion can be seen.

Figure 59 - Additional visualisations of final suggestion

6.3 Future work

In the retirement homes in Aarhus, it would not be a possibility to install lighting in the bedroom ceiling because the space is occupied by a ceiling hoist. As discussed earlier, indirect lighting is a valuable resource for providing high illuminance levels without causing glare. It is recommended that the effects of ceiling hoists are examined in future work. Could luminaires installed in walls just below the ceiling have the same beneficial effects?

Another important aspect to clarify further relates to expected life cycle costs. This project did not simulate energy use on a yearly basis, which could have been very interesting in the comparison of different solutions. Cost prices and control options should also be discussed with potential lighting suppliers. Is it possible to control the lighting as suggested here? And how could a control panel look that would not cause frustrations for the staff or residents?

Finally, it would be highly relevant to perform a sensitivity analysis. It is expected that the results presented here in this report are dependent of the reflectances in the DIALux model, but it is unknown to what extent. Empirical evidence about the furniture and personal decorations should be gathered by visiting apartments in retirement homes, and this data should be used as basis for new simulations.

7 References

Ascanius, C. (2019). *Forskningsprojekt om døgnrytmelys til skrøbelige ældre og ældre med demens* Retrieved from https://elforsk.dk/sites/elforsk.dk/files/media/dokumenter/2019-06/348-042_slutrapport.pdf

Bathroom Remodel. (n.d.). Retrieved from https://www.homesmartind.com/baths/bathroom-remodel-levittown/

Beskæftigelsesministeriet. (2002). At-vejledning A.1.51 om kunstig belysning. In: Retsinformation.

Bygningsreglementet, §379-§381 C.F.R. (2018).

Cornwell, B. Top 50 Best Shower Lighting Ideas – Bathroom Illumination. Retrieved from https://nextluxury.com/home-design/shower-lighting-ideas/

DS/EN 12464-1 Light and lighting – Lighting of work places – Part 1: Indoor work places. (2011). In. Charlottenlund: Dansk Standard.

DS/EN 17037:2018 : Daylight in buildings. (2018). Kbh: Fonden Dansk Standard.

Fagerhult. (n.d.). PATIENTRUM Komfort og funktionalitet. Retrieved from https://www.fagerhult.com/da/videnscenter/light-guides/sundhedspleje/patientrum/

Lauridsen, I. K., Pallesen, S. H., Jelnes, L. L., Skriver, N., & Jensen, L. V. (2021). Mobilt & personligt lys. In Københavns Kommune & Aarhus Kommune (Eds.).

Markisecentralen. (2019). Guide til udvendig solafskærmning. Retrieved from https://markisecentralen.dk/guide-til-udvendig-solafskaermning/

Pallesen, S. H. (2021). *Aarhus Kommunes lys-rejse*. Presentation at Aarhus University. February 10, 2021. Aarhus Kommune.

Plejeboliger og ældreboliger. (2021, January 13, 2021). Retrieved from https://www.aeldresagen.dk/viden-og-raadgivning/vaerd-at-vide/b/bolig/aeldreboliger/plejeboliger-og-aeldreboliger

Rossi, M. (2019). *Circadian Lighting Design in the LED Era*. Cham: Springer International Publishing.

Sollitto, M. (n.d.). The 4 Most Common Age-Related Eye Diseases. Retrieved from https://www.agingcare.com/articles/the-4-most-common-age-related-eye-diseases-145190.htm

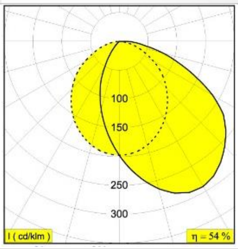
Tofteberg, S., Davodian, M., Sejr, C. H., Jensen, L. P., Petersen, J., Wienke, B., . . . Osterhaus, W. (2020). *Bedre søvn og døgnrytme med rigtigt lys - for beboere på aarhusianske plejehjem*. Workshop.

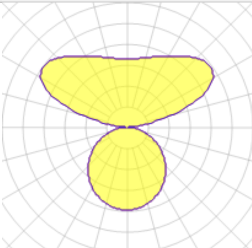
van Bommel, W. (2019). *Interior Lighting: Fundamentals, Technology and Application*. Cham: Springer International Publishing AG.

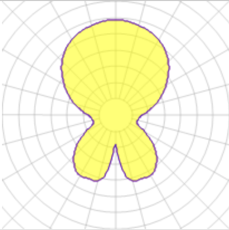
Viden om tæthedsgrad (IP). (n.d.). Retrieved from https://www.lampemesteren.dk/viden-om-taethedsgrad-ip.aspx

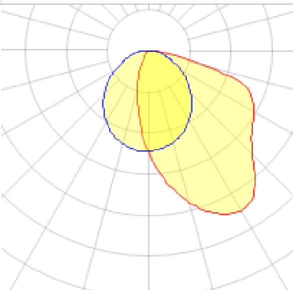
8 Appendix A: Luminaires

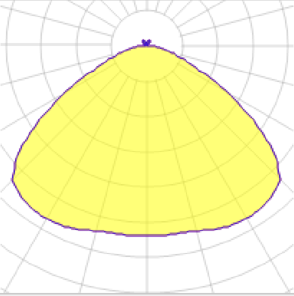
The tables below contain detailed information and references to the luminaires used for simulations in DIALux evo.

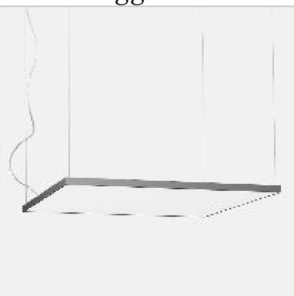
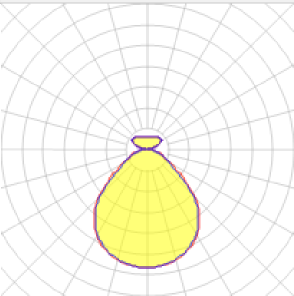
Manufacturer	Deltalight
Product name / number	Dot.com L wallwash
Lamp placement in project	Human Centric Lighting design: Bedroom, Wall washer on wall opposite bed. Final suggestions: Bedroom, Wall washer on wall opposite bed.
Picture	
Light distribution curve	
Link	https://www.deltalight.com/en/products/detail/dot-com-l-wall-wash-02-st-927-ho-424-242-02-92 (Last visited 23/5/2021)

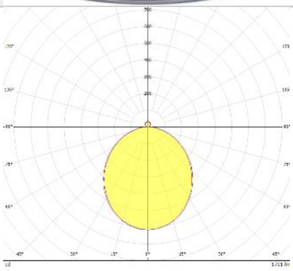
Manufacturer	Lightnet
Product name / number	Ringo Star 60mm
Lamp placement in project	Human Centric Lighting design: Bedroom, Ceiling pendant. Final suggestions: Bedroom, Ceiling pendant.
Picture	
Light distribution curve	
Link	https://www.lightnet-group.com/de/produkt/ringo-star-g3-p3-acoustic-308 (Last visited 23/5/2021)

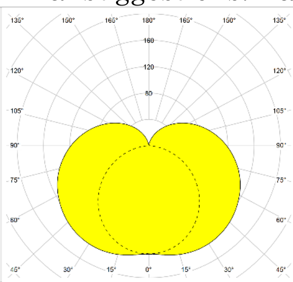
Manufacturer	Louis Poulsen
Product name / number	Panthella mini LED
Lamp placement in project	Human Centric Lighting design: Bedroom, Bedside lamp. Conflicting comfort criteria: Bedroom, Bedside lamp. Final suggestions: Bedroom, Bedside lamp.
Picture	
Light distribution curve	
Link	https://www.louispoulsen.com/da-dk/catalog/privat/bordlamper/panthella-mini-table?v=91684-5744162461-01&t=about (Last visited 23/5/2021)

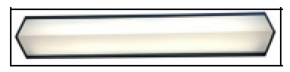
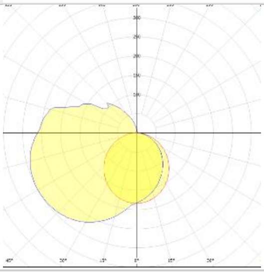
Manufacturer	Ridi Leuchten
Product name / number	EBWE-R1X055/15ND
Lamp placement in project	Human Centric Lighting design: Living room, Wall washer at dinner table. Final suggestions: Living room, Wall washer at dinner table.
Picture	
Light distribution curve	
Link	https://www.ridi.de/de/leuchten-produkte/ebw-ebwe-ebwme/ebwe-r-/ebwe-r-ebwme-r-/ebwe-r1x055-15nd.html (Last visited 23/5/2021)

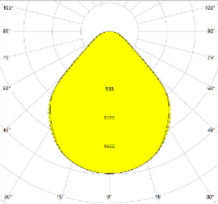
Manufacturer	Louis Poulsen
Product name / number	Above Ø175
Lamp placement in project	Human Centric Lighting design: Living room, pendant above dinner table. Final suggestions: Living room, pendant above dinner table.
Picture	
Light distribution curve	
Link	https://www.louispoulsen.com/da-dk/catalog/privat/pendler-loftlamper/above-pendant?v=91691-5741099362-01&t=about (Last visited 23/5/2021)

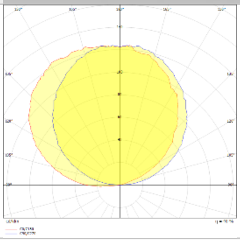
Manufacturer	Lightnet
Product name / number	Cubic Evolution Suspended
Lamp placement in project	Human Centric Lighting design: Living room, ceiling lamp above sofa area. Final suggestions: Living room, ceiling lamp above sofa area.
Picture	
Light distribution curve	
Link	https://lumsearch.com/en/article/E7Qk8RrDTva2pViJ9D6wjA (Last visited 23/5/2021)

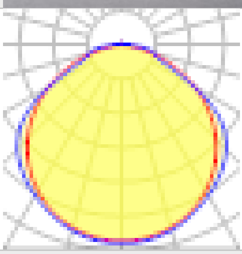
Manufacturer	Solar light
Product name / number	Campus Indbyg
Lamp placement in project	Conflicting comfort criteria design: Bathroom, Ceiling lamp Simple design: Bathroom, Ceiling lamp Final suggestions: Bathroom, Ceiling lamp
Picture	
Light distribution curve	
Link	https://solarlight.dk/produkter/interioer/loft/indbyg/rund/solar-light/campus-indbyg (Last visited 23/5/2021)

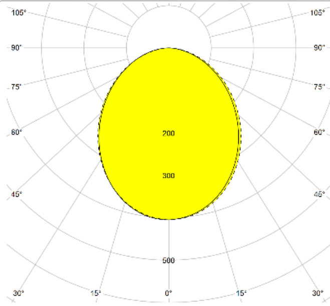
Manufacturer	Fagerhult
Product name / number	Fino LED
Lamp placement in project	Conflicting comfort criteria design: Bathroom, Around mirror Final suggestions: Bathroom, Around mirror
Picture	
Light distribution curve	
Link	https://www.fagerhult.com/da/Produkter/fino/fino-led/ (Last visited 23/5/2021)

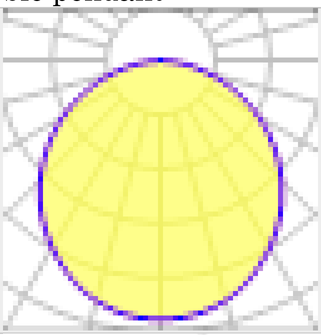
Manufacturer	Solar light
Product name / number	Bano
Lamp placement in project	Conflicting comfort criteria design: Bathroom, Above shower Final suggestions: Bathroom, Above shower
Picture	
Light distribution curve	
Link	https://solarlight.dk/produkter/interioer/vaeg/solar-light/bano (Last visited 23/5/2021)

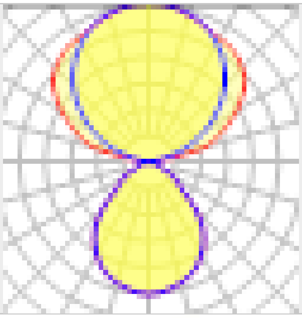
Manufacturer	Fagerhult
Product name / number	Multilume Flat delta
Lamp placement in project	Conflicting comfort criteria design: Bedroom, Ceiling light (600x600 mm) Simple design: Living room, Ceiling light (600x600 mm) and bed room ceiling light (300x600 mm)
Picture	
Light distribution curve	
Link	https://www.fagerhult.com/Products/multilume/multilume-flat-delta/#specifications (Last visited 23/5/2021)

Manufacturer	Disano
Product name / number	Disano 3630 1x39
Lamp placement in project	Conflicting comfort criteria design: Bedroom, Wall washer and Living room, Wall washer Final suggestions: Living room, Wall washer across the room from the sofa
Picture	
Light distribution curve	
Link	LUMsearch - Product data sheet: Disano 3630 1x39 CELL-D white + 354 cover (Last visited 23/5/2021)

Manufacturer	Solar light
Product name / number	LEDstrip
Lamp placement in project	Conflicting comfort criteria design: Bedroom, LED strip around door and below bed.
Picture	
Light distribution curve	
Link	https://www.solarlight.dk/produkter/interioer/skinnesystemer-og-led-baand/ledbaandlyskaeder/solar-light/hidealite/ledstrip (Last visited 23/5/2021)

Manufacturer	Fagerhult
Product name / number	Zest LED Dali
Lamp placement in project	Conflicting comfort criteria design: Living room, Below kitchen cupboard Simple design: Living room, Below kitchen cupboard
Picture	
Light distribution curve	
Link	https://www.fagerhult.com/da/Produkter/zest/zest-basic-led/ (Last visited 23/5/2021)

Manufacturer	Zumtobel
Product name / number	Caela suspended luminaires
Lamp placement in project	Conflicting comfort criteria design: Living room, Dining table pendant
Picture	
Light distribution curve	
Link	https://www.zumtobel.com/dk-da/produkter/caela.html?&GUID=B926FAC8-D365-4ECB-8757-C978F6F8A25A (Last visited 23/5/2021)

Manufacturer	Zumtobel
Product name / number	Capa Plus LED Freestanding Luminaire
Lamp placement in project	Conflicting comfort criteria design: Living room, Floor lamp beside sofa.
Picture	
Light distribution curve	
Link	https://www.zumtobel.com/dk-da/produkter/capa.html?&GUID=34AF79E2-3DC4-489A-B7BD-3945033EE23D#CAPA%20Plus%20LED%20freestanding%20luminaire (Last visited 23/5/2021)

9 Appendix B: Initial lighting scene design - sketches and initial considerations

Overview of bedroom scenarios

Time	Activity
Night	Resident in bed, waking up
Night	Resident in bed, staff entering to help
Day	Resident in bed. Reading, sleeping, talking
Day	Cleaning. Resident not present

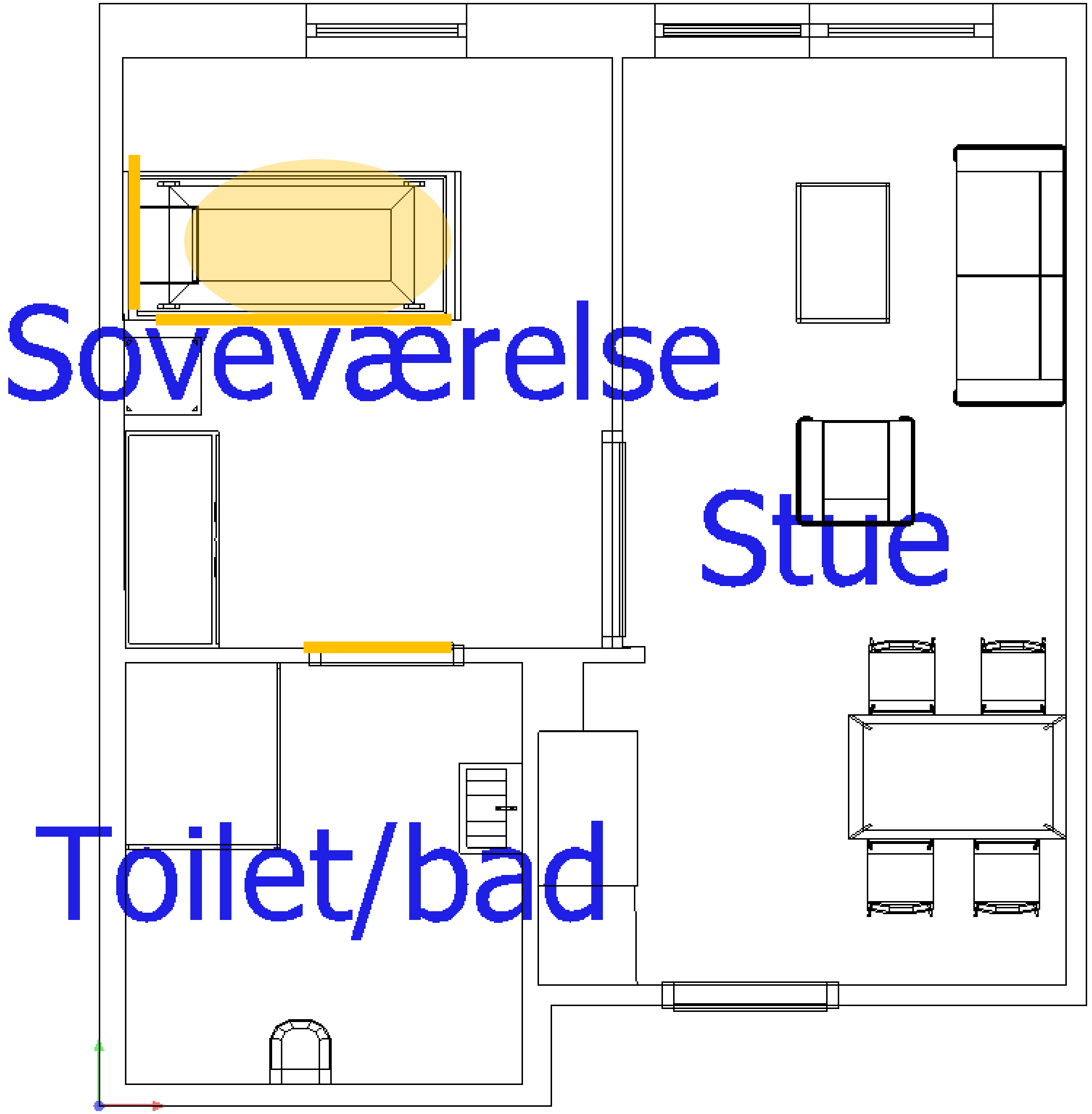
Night: Resident waking up

- When the resident is waking up during the night it is normally to use the bathroom. Therefore a guide light is needed to help them find the way to the bathroom and back to bed.

- To find guide the way LED strips with motion sensor should be used
- They should have a warm light (2000-3000 K) under bed and around bathroom door
- Approx. 200-250 lumen

Photo from:
https://www.werkenmetmerken.nl/nl/led_s_light_led_strip_met_bewegingssensor_1200_cm_1700k/p/78342

Night: Resident in bed. Staff entering to help

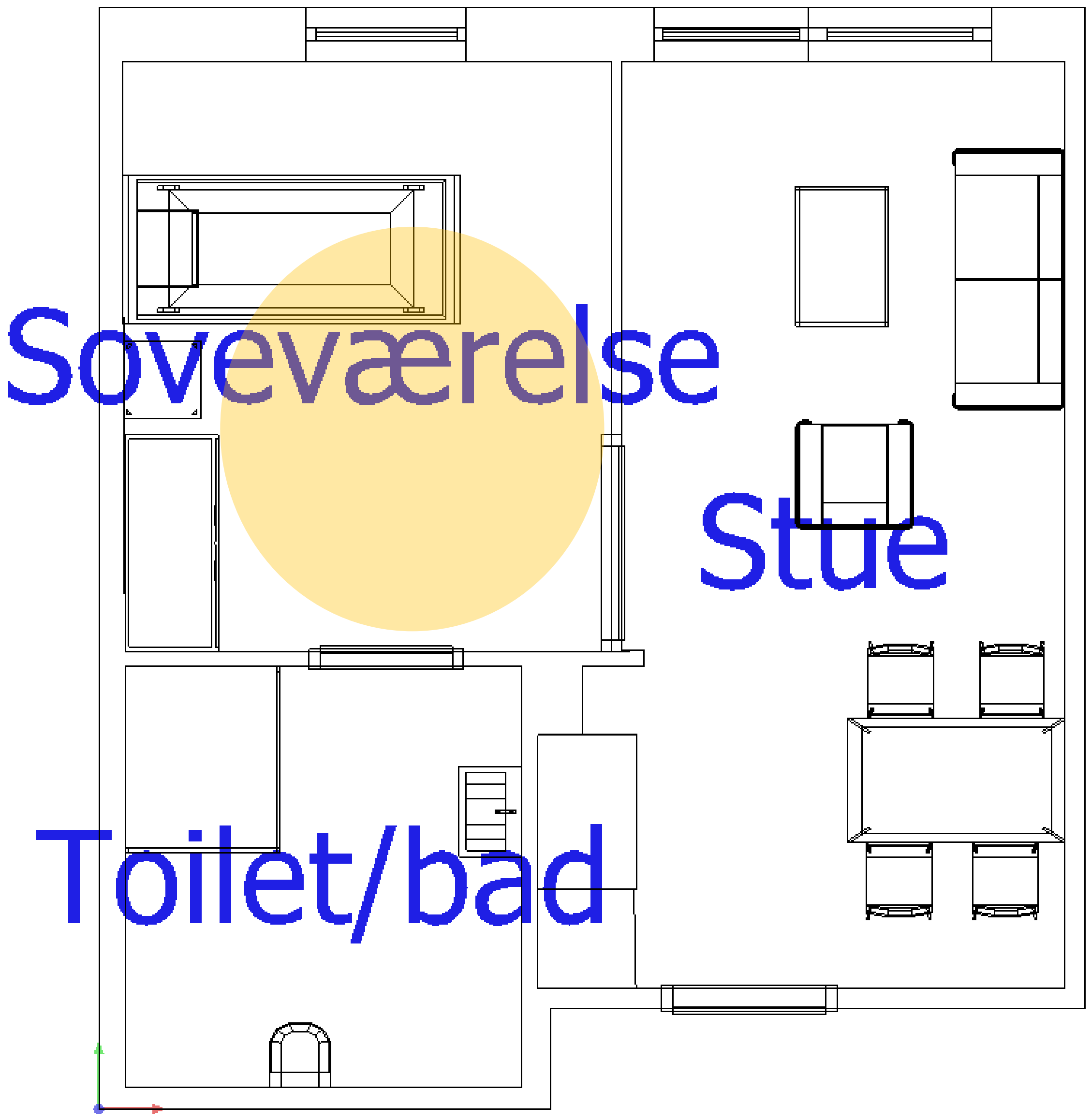


- Now a workplace - Conflict of interests
- The light distribution: Not direct light towards resident's head → glare
- Approx. 20 lux at bed
  - manual switch, turned on gradually
  - 3500-4000 K
- Need for additional light? Wall wash placed on the wall behind resident's head?

Photo from: Belysningsvejledning – Patientrum - Fagerhult (Danmark)

Day: Resident in bed. Reading, sleeping, talking

- Target: Min. 100 lux at floor
- Lamp in ceiling
  - Colour rendering R_a>90
  - No glare experienced from bed
- Bedside table lamp (maybe from home?)
- Consider wall washer for wall opposite to bed?

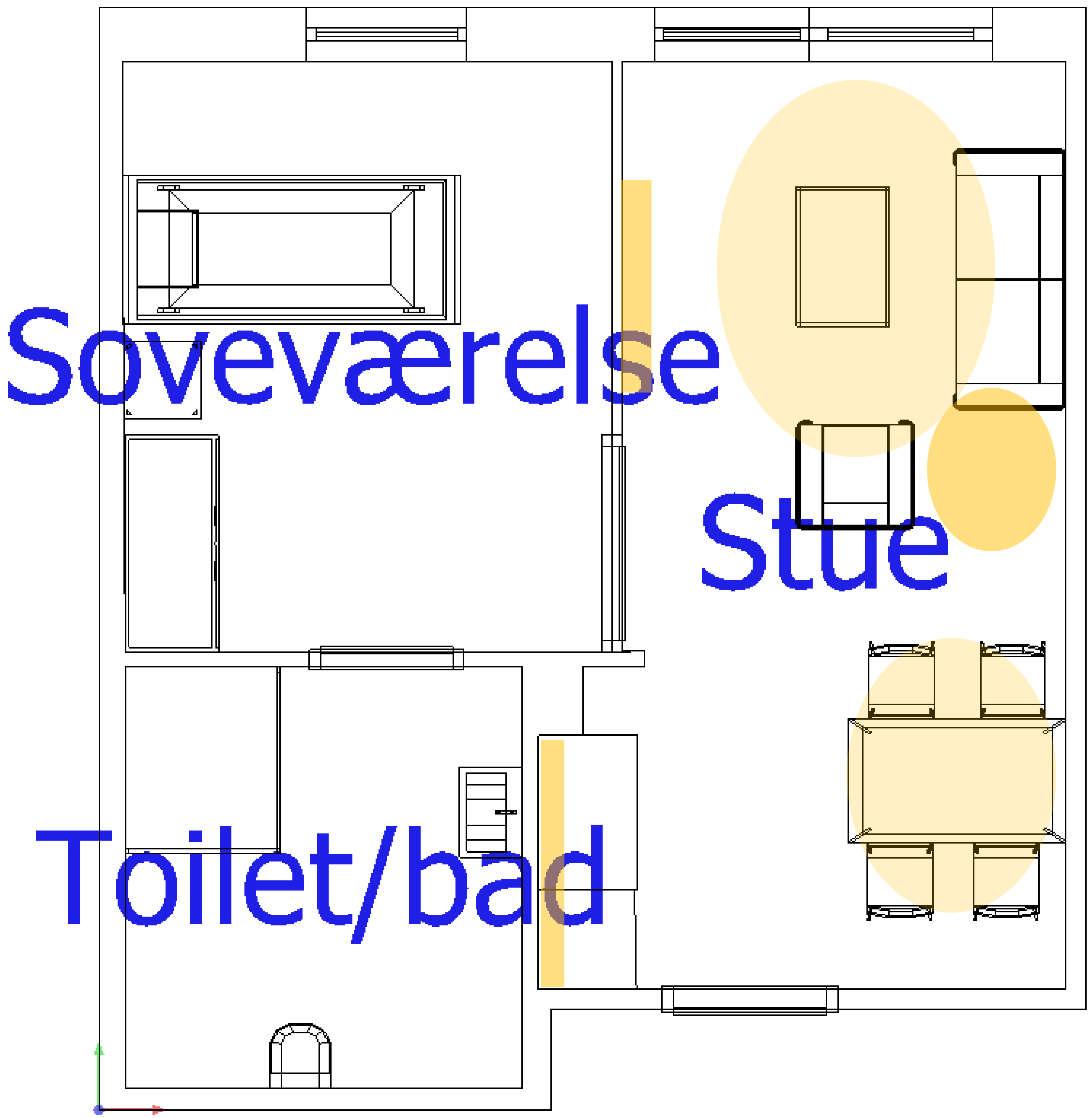


Day: Cleaning. Resident not present.

- Target: 200-300 lux at floor level
- Should not require additional lamps (=setting for cleaning necessary)

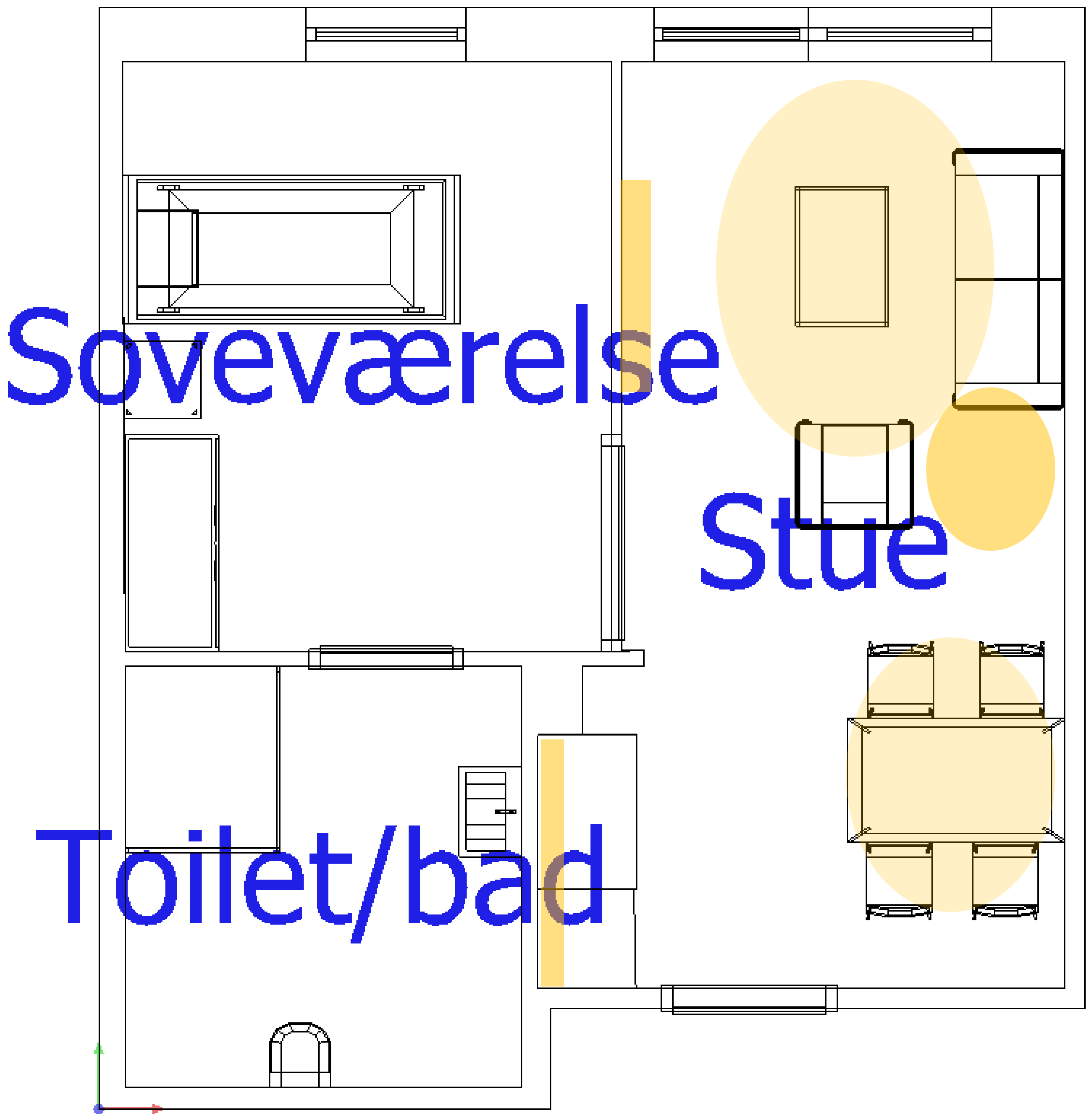
Overview of living room scenarios

Time	Activity
Afternoon, direct sunlight entering room	Watching TV/Reading/Talking
Evening	Watching TV/Reading/Talking …
Morning	Staff preparing medicines. Resident not in room or sitting in couch area.
Day	Cleaning
Afternoon	Resident (and guests?) at dinner table



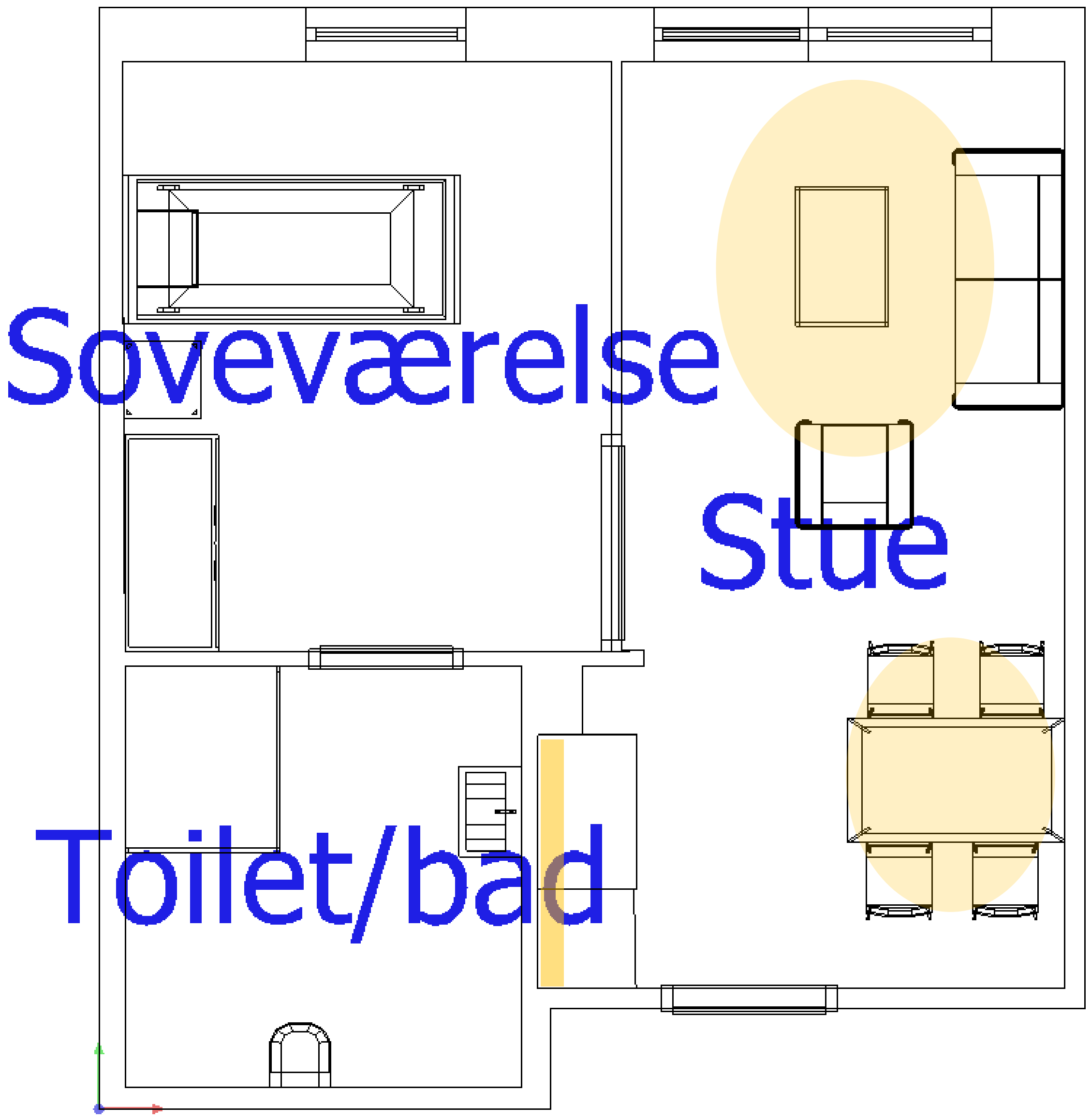
Afternoon: Resident watching TV, reading, talking. Direct sunlight entering room

- Target: 100-150 lux at floor level
  - Colour rendering R_a>90
- Two ceiling lamps (circadian lighting)
  - Pendant at dining table
  - Lamp near sofa/ over sofa table (daylight controlled?)
- Floor lamp easy to move around (from home?)
  - Directional lighting, min. 500 lux for book reading/knitting etc. (Preferable 1000 lux)
- Curtains/ other types of sun shading device may be used
- Avoid glare from TV by wall washing the wall behind.
- Kitchen lighting → min. 500 lux for different tasks + (manual switch)



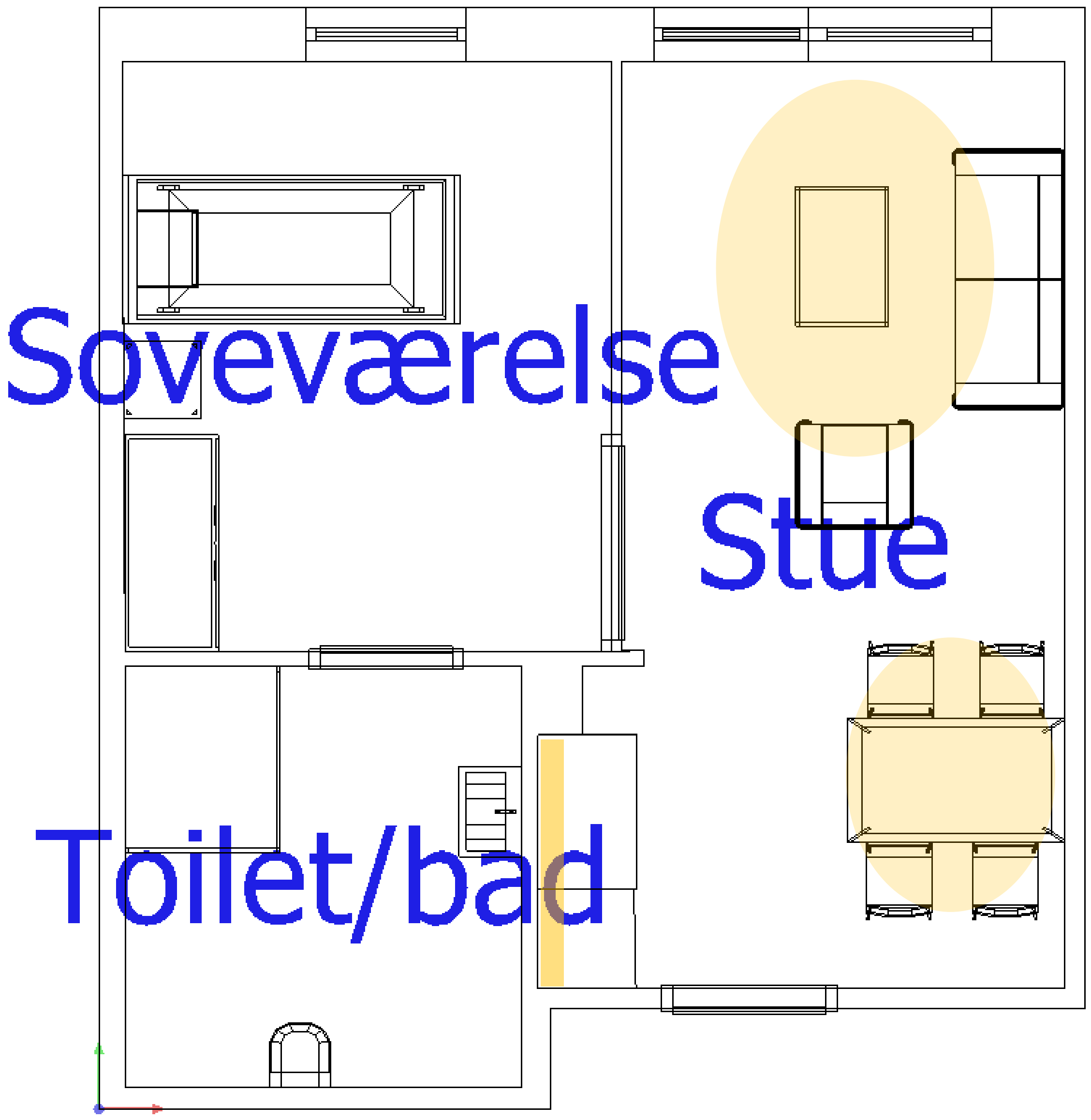
Evening: Resident watching TV, reading, talking.

- **Same as previous slide.**
- Target: 100-150 lux at floor level
  - Colour rendering R_a>90
- Two ceiling lamps (circadian lighting) →
  - Pendant at table
  - Lamp near sofa
- Floor lamp easy to move around (from home?)
  - Directional lighting, min. 500 lux at book/knitting etc.
- Avoid glare at TV by wall washing (circadian)
- Kitchen lighting (manual switch)



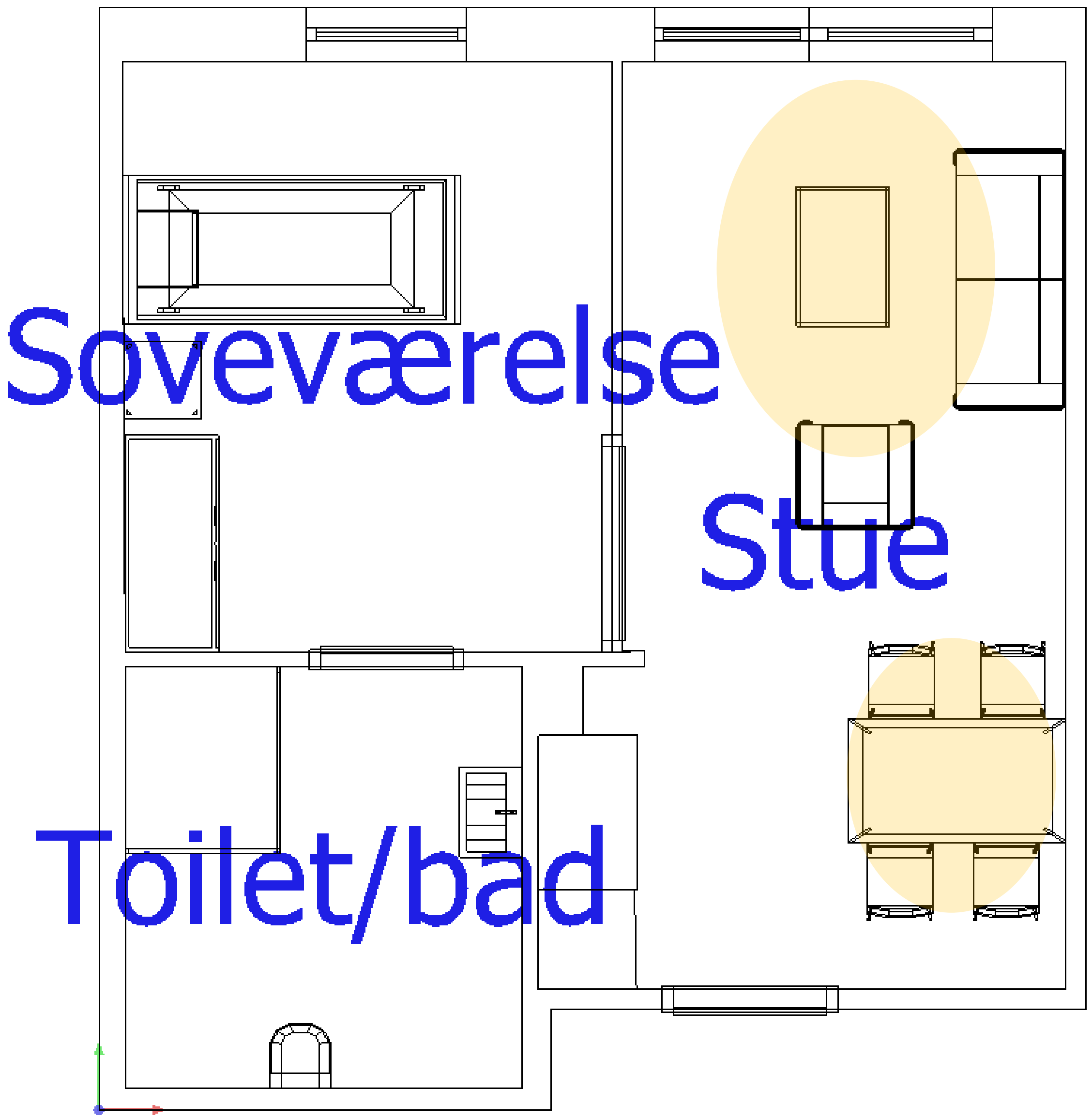
Morning: Staff preparing medicines. Resident not present or in sofa area.

- Light in kitchen (500 lux on kitchen table)
- Two ceiling lamps as mentioned before
  - Control for these lamps: Manually controlled by switch(es) at hallway/bedroom door
- Remember: Some residents may prefer not turning on light at sofa area (slow adaption)



Day: Cleaning. Resident not present.

- Target: 200-300 lux at floor level
- Should not require additional lamps (=setting for cleaning necessary)

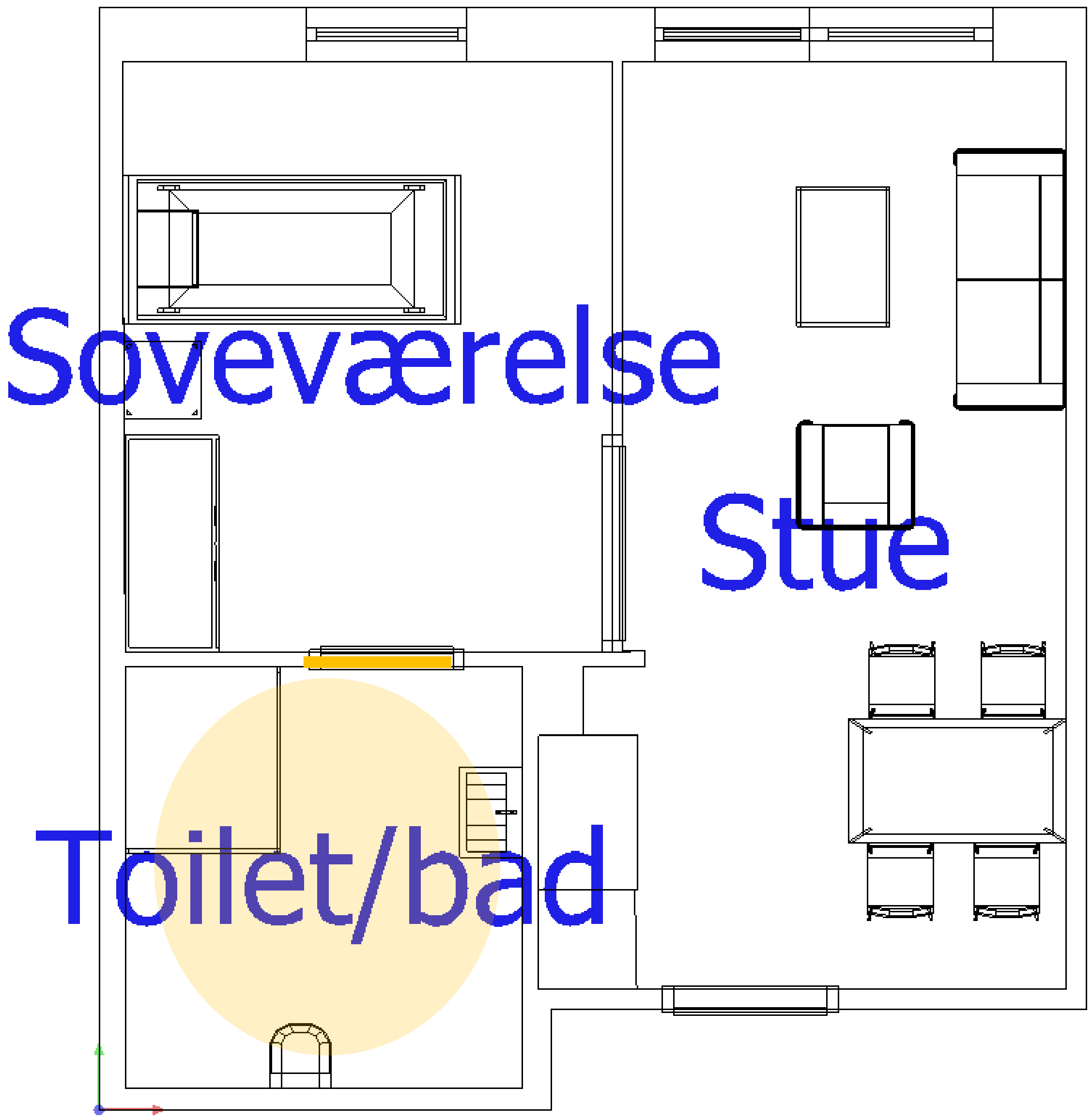


Afternoon: Residents (and guests) at dinner table

- Light at dining table:
  - Approx. 100-200 lux (maybe more?)
  - R_a>90 (reduced appetite)
  - Lighting direction downwards (avoid glare) → lamp shade from residents previous home?
- Ceiling lamp at sofa area → maybe guests over here?

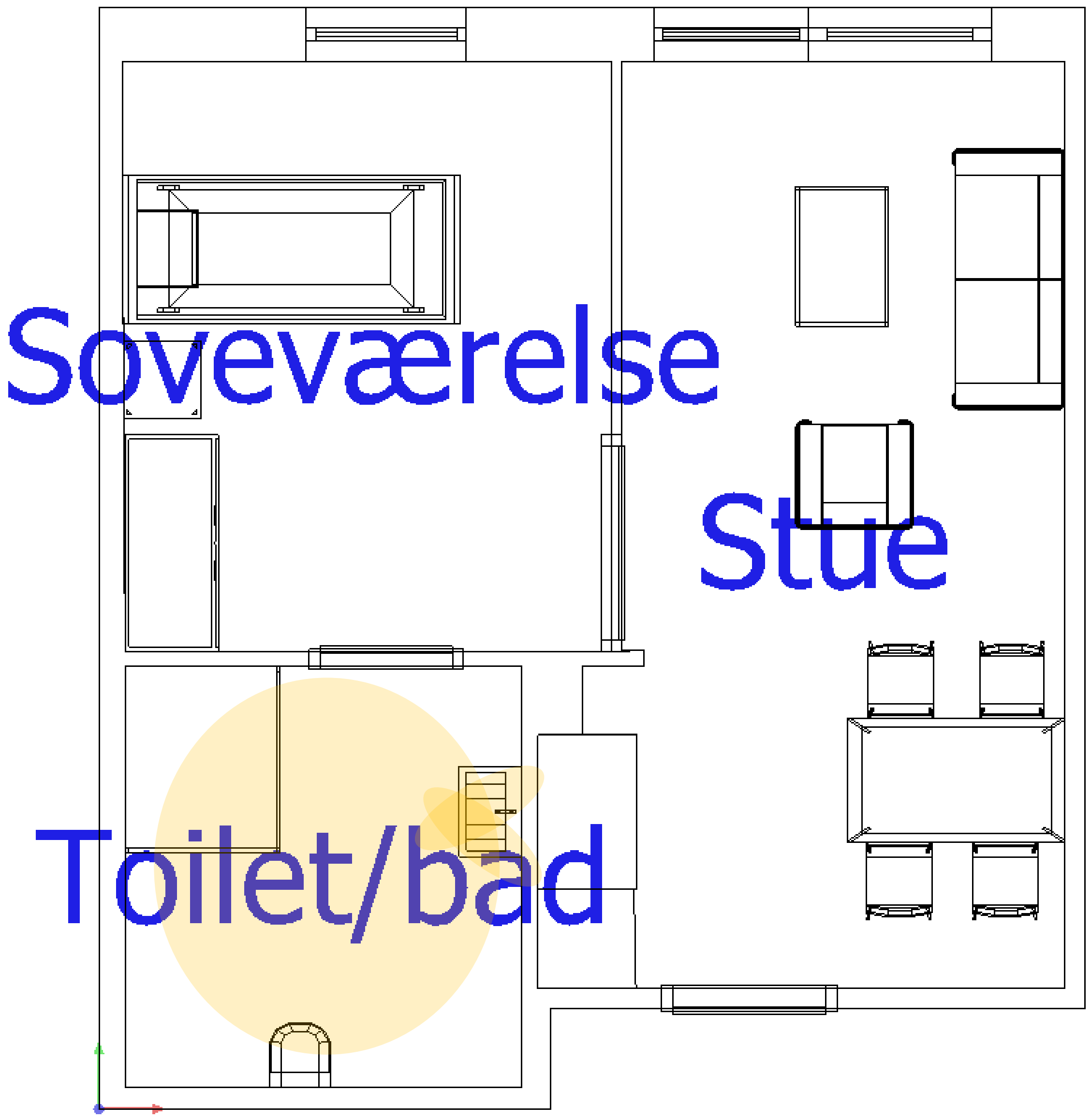
Overview of bathroom scenarios

Time	Activity
Night	Resident just woke up, using toilet
Day	Staff and resident present (assist with bathing, diaper change)
Day	Resident or guest using toilet/mirror
Day	Cleaning



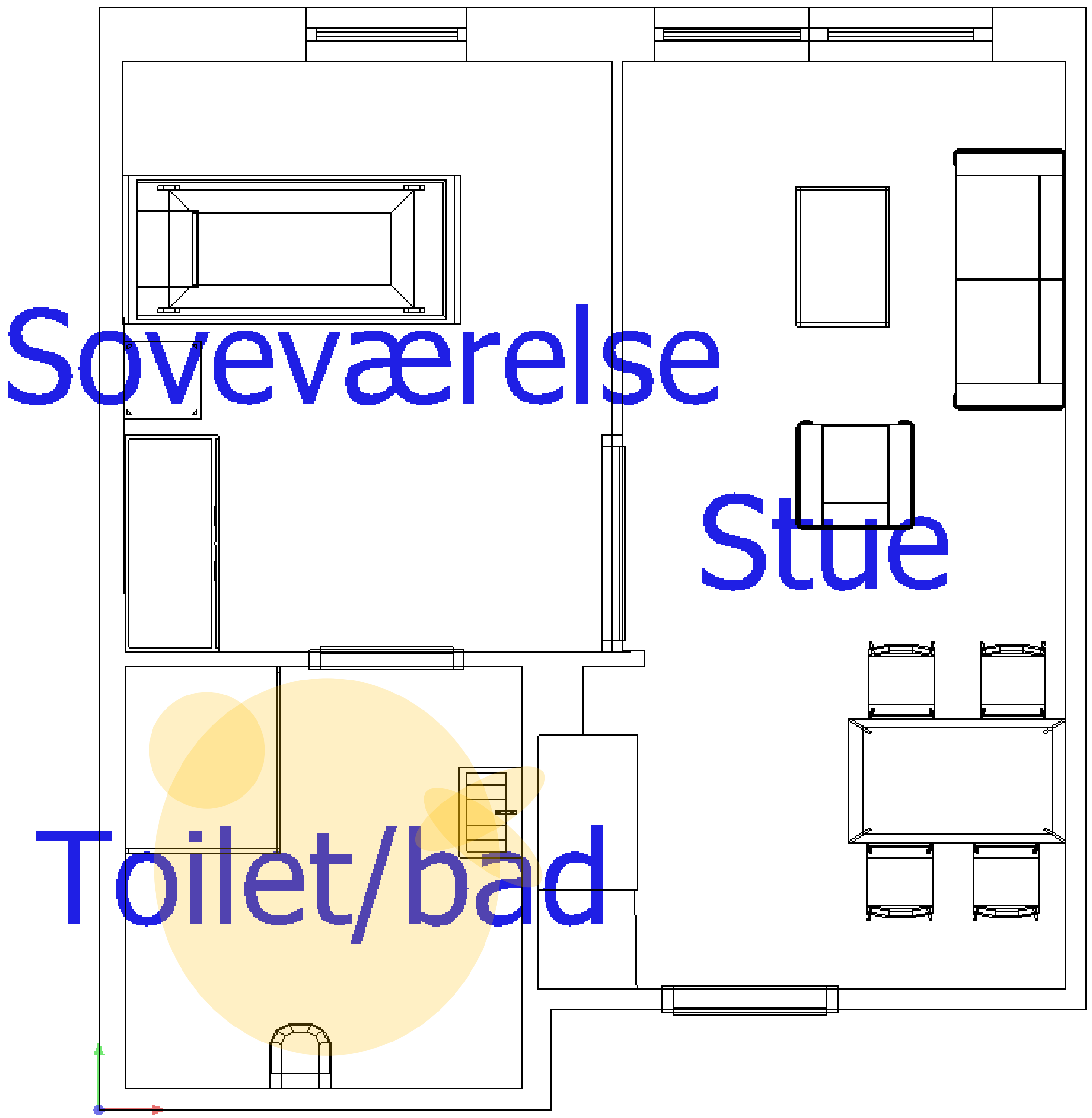
Night: Resident just woke up, using toilet

- For light guide resident back to the bed: LED- strips with Warm light (2000-3000 K) around bathroom door
- Ceiling light:
  - Low lux-level on the floor→ the resident feels safe and do not wake completely up.
  - Sensor under the bed turns the light on in the bathroom
  - Warm light → the resident feels safe and do not wake completely up.



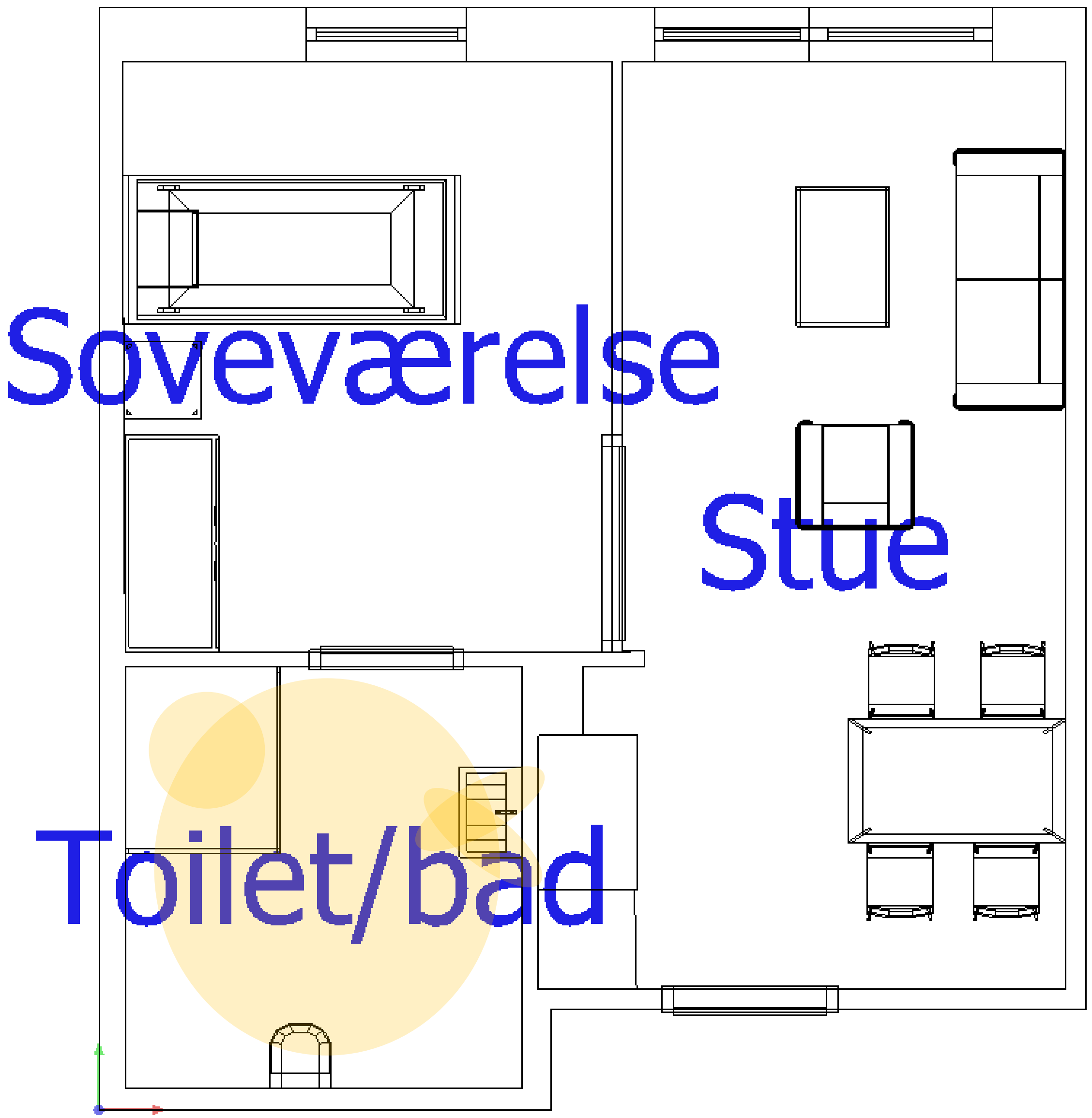
Day: Resident/guest using toilet/mirror

- Light around the mirror → lamps placed vertically
- Ceiling light:
    - Higher lux-level on the floor. Around 200 lux
    - Colour rending: R_a>90
    - Colour temperature: The light should resemble daylight → 4000-5000 K



Day: Staff and resident present (bathing, diaper change)

- Light around the mirror → lamps placed vertically
- Maybe more light in the shower?
  - Higher lux level 200-300 lux
  - What should the lamp's light distribution and placement be?
- Ceiling light:
  - Same as the previous slide.
  - Higher lux-level
  - R_a>90



Day: Cleaning. Resident not present.

- Target: 200-300 lux at floor level
- Should not require additional lamps (=setting for cleaning necessary)