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Light conditions for older adults in the nursing home: Assessment of environmental illuminances and colour temperature

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A B S T R A C T

Over 40% of nursing home residents in the Netherlands are estimated to have visual impairments. In this study, light conditions in Dutch nursing homes were assessed in terms of horizontal and vertical illuminances and colour temperature. Results showed that in the seven nursing homes vertical illuminances in common rooms fell significantly below the 750 lx reference value in at least 65% of the measurements. Horizontal illuminance measurements in common rooms showed a similar pattern. At least 55% of the measurements were below the 750 lx threshold. The number of measurements at the window zone was significantly higher than the threshold level of 750 lx. Illuminances in the corridors fell significantly below the 200 lx threshold in at least three quarters of the measurements in six of the seven nursing homes. The colour temperature of light fell significantly below the reference value for daylight of 5000 K with median scores of 3400 to 4500 K. A significant difference in colour temperature was found between recently constructed nursing homes and some older homes. Lighting conditions of the examined nursing homes were poor. With these data, nursing home staff have the means to improve the lighting conditions, for instance, by encouraging residents to be seated next to a window when performing a task or during meals.

1. Introduction

For many people, the loss of a part or all of their vision will become a reality as they grow older. In a recent epidemiological study in the Netherlands, over 40% of nursing home residents were estimated to have visual impairments [1]. Apart from the influence of ageing, there are pathological changes such as cataract, macular degeneration, glaucoma, and diabetic retinopathy that lead to low vision and eventual blindness. These impairments can affect several visual functions as well as daily functions in general [2–5].

Visual impairments stemming from biological ageing are diverse [2,3,6,7]. First, the visual field area declines with age. This means that the portion of space in which objects are simultaneously visible is declining. Second, colour discrimination decreases with age. Blue, green, and violet colours are most affected by the natural yellowing of the lens. Blue objects tend to be observed as darker than they actually are. Third, adapting to the dark can be impaired for older adults when moving from light to dim environments. Fourth, older persons require more light than younger persons for carrying out the same tasks, as the amount of light that reaches the retina is reduced with increasing age [8]. A 60-year old person, therefore, needs three times the amount of light as a 20 year old to complete a visual task comfortably. And fifth, glare or light that is reflected directly back into the eye creates difficulties for older adults to see and should be minimised. The recovery time from the effects of glare is much longer for older than younger adults.

The abovementioned changes in vision do not happen overnight and are the result of the progress of biological ageing. After the age of 50, glare and low levels of light become increasingly problematic. People require more contrast for proper vision and can have difficulty in perceiving patterns. After the age of 70, fine details become harder to see and colour and depth perception may be affected [3].

Although visual impairments can result in the loss of basic visual abilities in over 50% of the cases, treatment of low vision or slowing down of a further decline are possible [1]. Nevertheless, the impact of vision loss in older adults affects daily care. It also influences the way daylight access and light conditions in the nursing home should be designed to meet the needs of older residents of these homes. Achieving adequate care and ambient light levels is a task involving all care and technical professionals in nursing homes. The most important benefits of sufficient light levels inside nursing homes are 'visual', i.e., supporting the ability to see and the

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performance of tasks such as reading and leisure activities. Aarts and Westerlaken [9] assessed light conditions in Dutch care homes and homes for older people. They found that conditions are too poor for proper vision. Similar results have been found and reported in the literature, for instance, in the United States by Hegde and Rhodes [10] and Bakker et al. [11], and in Belgium by De Lepeleire et al. [12]. In these studies, colour temperature of the light and its spectral composition were not considered, and three of the studies [10–12] did not consider vertical illuminances. In addition, adequate lighting can also contribute to the prevention of falls. Especially in nursing home settings, falls are a major problem as there is a higher number of fall incidents among older people in long-term care versus those who live in the community. Falls are among those events in old age that mark the beginning of functional decline [13]. Moreover, light, particularly light with a wavelength of around 480 nm [5,14–22], plays a role in regulating important biochemical processes, immunologic mechanisms, neuroendocrine control, circadian rhythmicity, and behaviour.

In this study, light conditions in Dutch nursing homes are measured, focussing on horizontal and vertical illuminances and colour temperature in frequently used areas for daily functioning and traffic and transfers, including common spaces and corridors. The goal is to know the extent to which older adults are living in proper lighting conditions. With these data, we want to enhance the awareness among care professionals of how light conditions affect the daily lives of nursing home residents. Moreover, care professionals and technical staff could make appropriate improvements to the nursing home environment based on these data. In addition, improved light conditions will, in turn, improve the visual performance of the nursing home residents. This study is part of a larger project on visual impairments and light conditions in the nursing home.

2. Methodology

This study was based on literature research and measurements of illuminance and colour temperature in nursing homes. In the following sections, the studied buildings, the measurement procedure, and the measurement equipment are described.

2.1. Study setting and study period

The nursing homes participating in this study are located in the area around of the city of Utrecht, which is situated in the centre of the Netherlands. The assessments were conducted in seven settings, which are part of four different care organisations (Table 1). These buildings consist of one or two wings. In total, 59 common or living rooms and corridors were assessed in this study. All nursing homes had windows with double glazing. The ratio of window surface and non-transparent wall surface of the outer façade was between 70 and 100%. All rooms were equipped with fluorescent lighting and some incandescent lamps for ambiance. The correlated colour temperatures (CCT) of the fluorescent lamps were 2700 or 3000 K.

In the first nursing home, only two common rooms were assessed. The wards of the second nursing home consisted of two or even four common rooms for a total of ten. The third building had two floors with four wards and two common rooms on each ward. The fourth nursing home was a large-scale building of eight floors with two common rooms on each floor. The fifth nursing home had three floors with wards consisting of two common rooms. The sixth nursing home had three floors with four common rooms on each floor, and the seventh nursing home had five common rooms all on the same floor. In all the included buildings, the residents live in small groups consisting of 8–12 persons spending time in one or more common rooms.

The buildings of the first care organisation were constructed in the mid 1970s, as were the two buildings of the third care organisation. Those of the second care organisation were built in the late 1990s. One of the facilities, however, had been renovated in 2009. Both nursing homes of the fourth care organisation were opened in the city of Utrecht in 2008 (Table 1).

The study was performed between October 2009 and the end of March 2010 during daytime between 10:00 and 15:00 h. The first assessments were conducted in October and November 2009 in nursing home 1 and 3. In January 2010, nursing home 2 was assessed. In February 2010, the assessments in nursing home 3 were completed. In March, assessments were conducted in nursing homes 4 to 7 (Table 1). By measuring in autumn, winter, and early spring, the contribution of daylight to the indoor illuminances was kept at a minimum. Meteorological data on mean cloud cover on the measurement days are provided in Table 1 as well.

2.2. Measurements of light parameters

Light conditions were measured in places where older adults residing in the participating nursing homes spend most of their day, i.e., common spaces, such as group living rooms and corridors.

The assessment of light conditions consisted of measuring illuminance levels (E [lx]) and colour temperature (T_c [K]) in a given

Table 1
The seven nursing homes of four care organisations included in this study, their year of construction, date of measurements, sunshine duration hours and mean daily cloud cover (Meteorological data for the thirteen measurement days for the Royal Netherlands Meteorological Institute weather station in De Bilt, Region Utrecht, The Netherlands. Source: Royal Netherlands Meteorological Institute (KNMI); http://www.knmi.nl/klimatologie/daggegevens/download.html).

Nursing home	Care organisation	Year of construction	Year of renovation	Orientation of common rooms	Measurement period [ddmmyy]	Sunshine duration [hours[a]]	Mean daily cloud cover [octants[b]]
1	1	1976	1996	North; East	161009	4.8	6
2	1	1974	–	South; South-West	080110;	2.9	6
					150110	0	8
3	2	1997	–	North-East	021109;	2.4	5
					100210;	3.1	7
					170210	3.7	6
4	3	1976	–	West; East	160310;	3.1	7
					170310	8.3	6
5	3	1977	2009	North-East; South-East	090310;	10.3	0
					120310	0.2	8
6	4	2008	–	South; East	230310	9.7	5
7	4	2008	–	South; East	180310;	6.6	6
					190310	0	8

[a] calculated from global radiation.
[b] 9 = sky invisible.

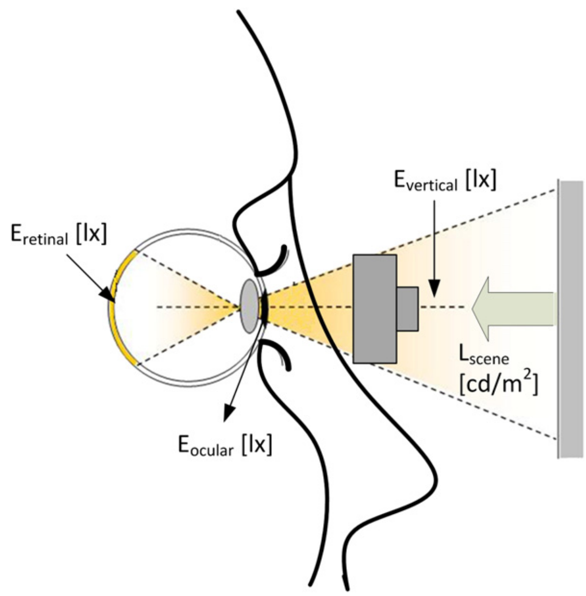

Fig. 1. The difference between ocular and retinal illuminances when measuring vertical illuminances [23].

location in the nursing home. Since the current study is a field study and environmental exposures are relevant to daily practice, all light measurements (illuminance level and colour temperature) were taken in the daytime. These measurements include the contribution of daylight and reflect the light situation as encountered at the moment of observation. Illuminance level and colour temperature were assessed using a Konica Minolta chromameter CL-200 by Konica Minolta Sensing Inc. The measurement range of this instrument is 0.1–99,990 lx, but the measurement thereof may depend on the colour of the measured light. The instrument can display colour temperature values from 2300 to 20,000 K; values below 2300 K may contain a slight bias of unknown size, which has not been corrected for in this study.

The measurements of illuminances and colour temperature were conducted in a vertical direction at the eye (also known as corneal or ocular illuminance), gazing direction, E_v, at a height of 1.6 m (Fig. 1), and in a horizontal direction (at table level at a height of 0.9 m and at chair level at a height of 0.6 m, E_h). These heights represent the older adults standing upright or walking around common rooms and corridors as well as performing a task or holding something in their laps while seated at a table. In the corridors, the measurements were conducted in a vertical direction.

2.2.1. Assessments of illuminance

Since the direction of light at the retina plays an important role in non-visual effects of lighting, the vertical illuminance at the position of the eye was measured taking into account the participant's viewing direction and angle (Fig. 1) as follows from the luminance of a scene (L_{scene}). In theory, there exists a unit of conventional retinal illuminance ($E_{retinal}$), the troland unit [Td] [24,25], which corrects light measurements by scaling outcomes by the effective pupil size. However, as this study does not correct for visual impairments, including the effects on the pupil that are due to biological ageing, the troland has not been used as an outcome

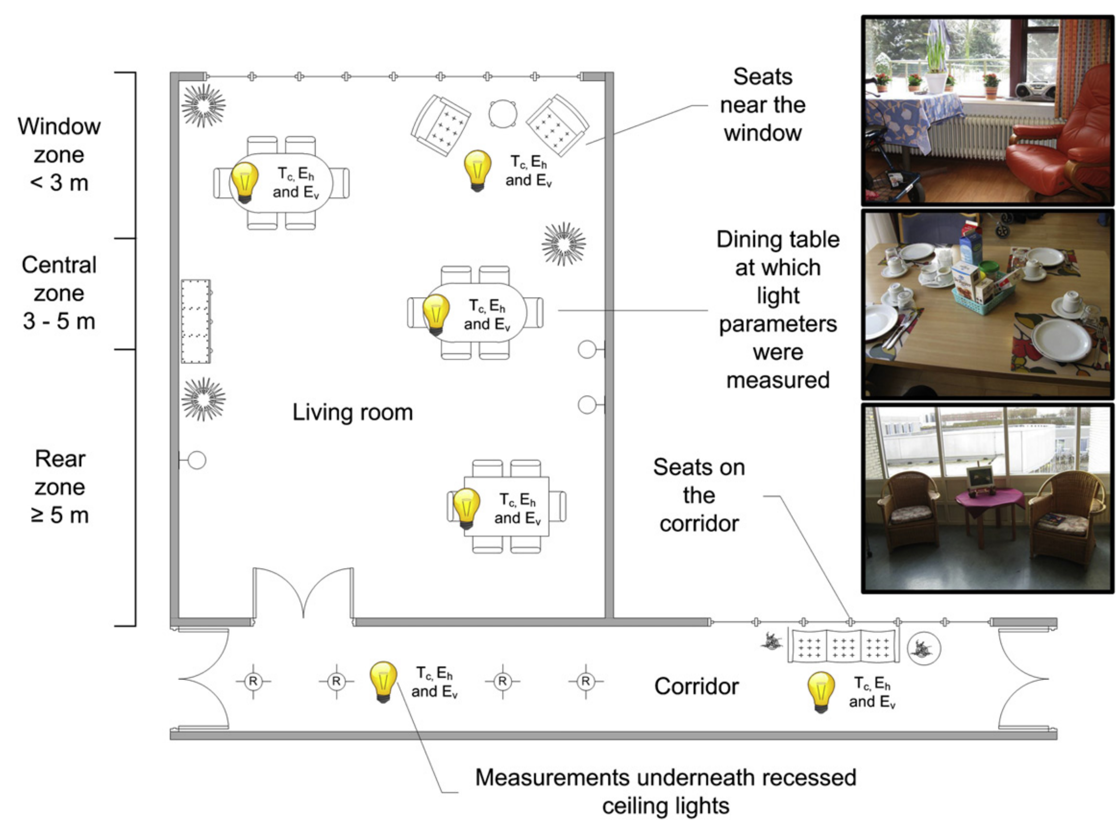

Fig. 2. Schematic overview of measuring locations in the nursing home, showing a common room and a corridor. In the common rooms, three zones were distinguished: the window, central and rear zones. In some corridors, seats were present near windows. In such cases, these corridor seats were treated as part of the corridor measurements. The three inserted figures show seats and a dining table as encountered during the measurements. Three lighting parameters were measured near these seats and at these tables, as is illustrated by the light bulbs in the figure. (T_c = colour temperature, E_v = vertical illuminance, E_h = horizontal illuminance).

Table 2
Recommended horizontal illuminances per room according to van Hoof and Schoutens [27]. Generally, the colour temperature of the light sources should be between 2700 and 3000 K, in accordance with personal preferences. Recommendations by De Lepeleire et al. [12] based on a 55% increase of levels stated in the European Standard Lighting of work places are included in the comments. Taken and adapted from van Hoof et al. [3].

Location	E_h [lx]	Comments
Living room	200–300	
Living room, near seat	1000–2500	At places where a great deal of time is spent, T_c should be between 6500 and 8000 K.
Dining room (table level)	500–1000	
Hobby space	500–1000	De Lepeleire et al. [12] recommend approximately 775 lx
Corridors	100–200	De Lepeleire et al. [12] recommend 200–300 lx during the day and 50–80 lx during the night.

unit. Findings in this study are reported as hypothetical ocular or corneal illuminance levels, not retinal illuminance levels (Fig. 1).

Measurements of vertical and horizontal illuminance levels were separated in zones which are differentiated according to the distance from the windows (Fig. 2). The orientation of the different rooms can be found in Table 1. The 'window zone' is defined as situated within 1–3 m from the windows. The 'central zone' is situated within 3–5 m from the windows. The rear zone is situated at the back of the common room, i.e., more than 5 m from the windows.

In the corridors, measurements of illuminance levels were conducted in a vertical direction at eye gazing level at a height of 1.6 m. Measurements were conducted at several points, under and in between the light sources in corridors. All corridors in nursing homes were situated in the inner part of the building with a window at the end of the corridor. An exception was nursing home 3, in which a corridor was situated at a window side of the building; moreover, there was a sitting area in this corridor.

The observed illumination conditions were compared to the values given in a guideline by the Dutch Society for Illumination (*Nederlandse Stichting Voor Verlichtingskunde, NSVV*) [26], and compared to the values stated by van Hoof and Schoutens [27] and De Lepeleire et al. [12] (Table 2). The available guidelines for light for older people, however, do not distinguish between horizontal and vertical illuminances. In addition, the values stated in the literature mainly concern horizontal illuminances. In practice, the illuminances in the gazing direction are those that are relevant as those illuminances reflect the actual exposure. Therefore, vertical illuminances are included in the current study as well, using the same threshold values as for horizontal illuminances. These two illuminances are not equal and cannot be derived from one another in indoor settings. The illuminances depend on daylight access and the output of lighting systems and dimensions of luminaires.

Nursing homes do not only have a residential function, i.e., providing a home to older adults who require a high level of care, but are also workspaces for nursing staff and other professionals. The European standard EN 12464-1 [28] deals with lighting of indoor work places. The standard specifies illuminances for health care facilities, such as waiting rooms, corridors, examination rooms, and spaces for diagnostics in hospitals. Nursing homes are not included in this standard. The standard specifies a value of 200 lx for corridors during daytime, and this value was also used as a limit in the current study, i.e., as a threshold for light exposure of residents. For common rooms for treatment, values between 300 and 500 lx are advised although for specific eye tasks higher illuminances are provided [28]. The standard does not specifically include colour temperature for health care facilities.

As older adults spend most of their time in the communal living room, enjoying their meals and doing leisure activities, the basic illuminance level for these living areas are recommended to be between 500 lx and 1000 lx [26]. In this study, we set the critical threshold at the mean value of 750 lx and also took the upper level of 1000 lx as a second set-point. Higher illuminances, hypothetically, of at least 2500 lx for older adults (Table 2) are a requirement for certain non-image forming (NIF) effects. These effects include the suppression of melatonin, circadian phase shifts, certain repercussions on human physiology in terms of heart rate, core body temperature, and brain activity, as well as effects on mood and behaviour [17,18,29]. In corridors, the threshold value for vertical illuminance was set at 200 lx, as mentioned previously.

2.2.2. Assessments of colour temperature

Colour temperature of the light to which nursing home residents were exposed is explicitly included in this study, for the importance high colour temperature light may have in relation to non-image forming (NIF) effects.

Exposure to light ($\lambda \sim 480$ nm) is the most important stimulus for synchronising the biological clock [3]. The circadian system, which is orchestrated by the hypothalamic suprachiasmatic nuclei (SCN), influences virtually all tissue in the human body. In older adults, the orchestration by the SCN requires ocular light levels that are significantly higher than those required for proper vision. An additional problem is formed by the ageing of the eye that leads to

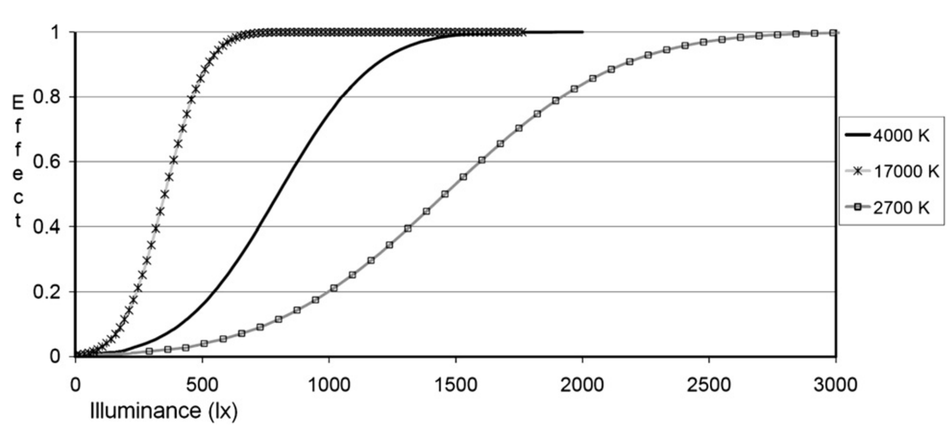

Fig. 3. Hypothesised size of NIF effects of light during daytime for different illuminances at the eye and different colour temperatures. Taken and adapted from Górnicka [30].

opacification and yellowing of the vitreous and the lens, limiting the amount of bluish light reaching the retinal ganglion cells [14].

Górnicka [30] calculated the NIF effects of lamps for office situations. She found that the higher colour temperature of light, the more NIF output the light yields (Fig. 3). The colour temperature provides a first indication of the spectral distribution or composition of the light, but the colour temperature is of course not the same as the spectral composition. Due to the aforementioned opacification and yellowing of the vitreous and the lens, and thus increased filtering of the short wavelength light, this ratio may differ in older people. The outcomes of the colour temperature assessments are compared to a reference value for daylight of 5000 K. Moreover, the NSVV guideline [26] and van Hoof and Schoutens [27] (Table 2) mention a colour temperature of 6500 K as a lower threshold for lighting in practice to allow for NIF effects to take place. Therefore, the light conditions found in the nursing homes were compared to this value, too.

2.2.3. Combined assessments of illuminance and colour temperature in relation to the perceived ambiance

The Kruithof curve [31] relates the illuminance and colour temperature of visually-pleasing light sources. This curve depicts the connection between colour temperature and illuminance in relation to the perceived ambiance. The colour sensation of a given light mixture may vary with absolute luminosity. This is because both rods and cones are active at once in the eye, with each having different colour curves, and rods taking over gradually from cones as the brightness of the scene is reduced. The data found in this study is superimposed over the Kruithof curve in order to assess the ambiance of the light conditions found in the seven nursing homes.

Boyce [32] has already stated that the work underlying the Kruithof curve has not been extensively reported, and the validity of Kruithof's boundary conditions is open to discussion. As the original boundary conditions have not been described in Kruithof's original work [31], the boundary conditions taken for this study are a reconstruction of the original curve. To our knowledge, this is the first study to use the Kruithof curve for the assessment of light conditions in nursing homes. In practice, when there is sufficient time for chromatic adaptation to occur, the recommendations based on the Kruithof curve are unnecessarily restrictive [32]. Moreover, the correlated colour temperature (CCT) of fluorescent lamps is a minor factor in determining satisfaction with the lighting of an office; illuminances are more important [32].

2.3. Statistical analyses

Data analyses were carried out using SPSS 17.0 for Windows. The critical *p*-value was set at 0.05 for comparisons between the seven nursing homes, and the Bonferroni correction was applied setting the critical *p*-value at 0.008. Non-parametric statistics (two-tailed Kruskal–Wallis *H*-test and Mann–Whitney *U*-test) for independent samples were employed to test differences in colour temperature levels in the seven nursing homes. A two-tailed non-parametric sign test was employed to explore the differences in measured illuminances and colour temperatures in the nursing homes compared to their reference value. The critical *p*-value again was set at 0.05.

2.4. Ethics

Managers of the participating organisations agreed on the light measurements from the start of the project and were involved in the planning of the project. Professional and family carers were invited for an information meeting at the start of the project after the management of the care organisations had agreed to

Table 3
Light conditions in the seven nursing homes: illuminances in common spaces (minimum and maximum levels) compared to a threshold level of 750 and 1000 lx (frequency of measurements below threshold in relation to the total number of measurements); illuminances in corridors compared to a threshold level of 200 lx; and minimum, median and maximum colour temperatures, and comparisons to 5000 and 6500 K. Number of measurements are given as part of the total number of measurement points per nursing home.

Nursing home	Number of common rooms measured ($N = 59$)	E_v at the eye gazing direction in common rooms				E_h at the eye gazing direction in common rooms				E_v in corridors			T_c [K]				
		E_{min} [lx]	E_{max} [lx]	$N < 750$ lx	$N < 1$ klx	E_{min} [lx]	E_{max} [lx]	$N < 750$ lx	$N < 1$ klx	E_{min} [lx]	E_{max} [lx]	$N < 200$ lx	Min	Median	Max	$N > 5000$ K	$N > 6500$ K
1	2	110	850	13/14 92%	14/14 100%	290	460	5/5 100%	5/5 100%	20	250	9/12[a] 75%	2308	3400	5233	2/31 7%	0/3 0%
2	10	30	2750	88/94 94%	89/94 95%	60	2500	28/32 88%	28/32 88%	6	240	13/14 93%	2580	3800	7480	39/141 28%	2/141 1%
3	8	90	3060	59/90 66%	68/90 76%	200	1880	28/41 68%	32/41 78%	9	260	16/21 76%	2013	4500	9459	50/151 33%	14/151 9%
4	16	20	1590	170/179 96%	176/179 98%	20	3670	40/50 80%	45/50 90%	13	250	87/89 98%	2087	3800	5749	16/286 6%	0/286 0%
5	6	40	1230	77/81 95%	78/81 96%	50	3330	40/43 93%	40/43 93%	38	2450	47/61 77%	2686	3300	6044	10/187 5%	0/187 0%
6	12	150	3700	78/120 65%	82/120 68%	170	3200	21/38[a] 55%	27/38 71%	14	1120	15/45[a] 33%	2030	4300	6161	43/204 21%	0/204 0%
7	5	70	1770	41/54 76%	46/54 85%	100	3660	19/26 73%	20/26 77%	18	740	19/21 90%	2738	4300	6295	18/101 18%	2/101 2%
Total	59																

[a] Nursing homes with a number of measurements significantly higher than the threshold. Two-tailed sign test, $p < 0.05$.

participate. Two out of the seven nursing homes (nursing homes 4 and 5) asked for additional informed consent from the family board, which was given on request. During data collection, the professional and family carers who were present, along with the residents, were informed about the assessment protocol. Daily activities were not disturbed nor hindered by the measurement procedure. Results of the light conditions of each nursing home were discussed with the staff of that nursing home.

3. Results

In 59 common rooms, data were collected measuring illuminances (vertically as well as horizontally) and colour temperature as mentioned before. The data as collected for illuminance in the nursing homes have been included in Tables 3 and 4, as well as in Figs. 4 and 5. Table 4 shows colour temperature measurements.

3.1. Illuminances

Results show that 55% or more measured vertical and horizontal illuminances in the common rooms of the nursing homes fell below the 750 lx threshold derived from the NSVV guideline [2], as will be illustrated in the following sections.

Table 3 shows that nursing home 3 and 6 had the fewest measurements, which fell below the threshold of 750 lx (min-max 20–3700 lx), of all seven nursing homes; i.e., 59 out of 90 (66%) and 78 out of 120 (65%) measurements, respectively. All the other nursing homes showed a higher number of measured vertical illuminances that fell below the 750 lx threshold (>75%). In nursing home 1 almost all measurements (13 out of 14) were lower than 750 lx. Even a higher percentage of the vertical measurements were below 1000 lx, and, accordingly, every nursing home shows a higher percentage of measurements below 1000 lx as compared to the measurements below the threshold of 750 lx. All nursing homes showed a significantly high number of measurements below 750 lx.

Horizontal measurements at table level or on the lap at chair level showed the same results, and again nursing homes 3 and 6 tended to score best in relation to the threshold level of 750 or 1000 lx. Only 21 out of a total of 38 measurements (55%) for nursing home 6; and 28 out of 41 measurements (68%) for nursing home 3 were lower than 750 lx (min-max 20–3670 lx). However, only nursing home 6 did not show a significantly high number of measurements that fell below the threshold of 750 lx. As the threshold was set on 1000 lx, even a higher percentage of the measurements at the horizontal level fell below this point, and, accordingly, every nursing home shows a significantly high number of measurements below 1000 lx.

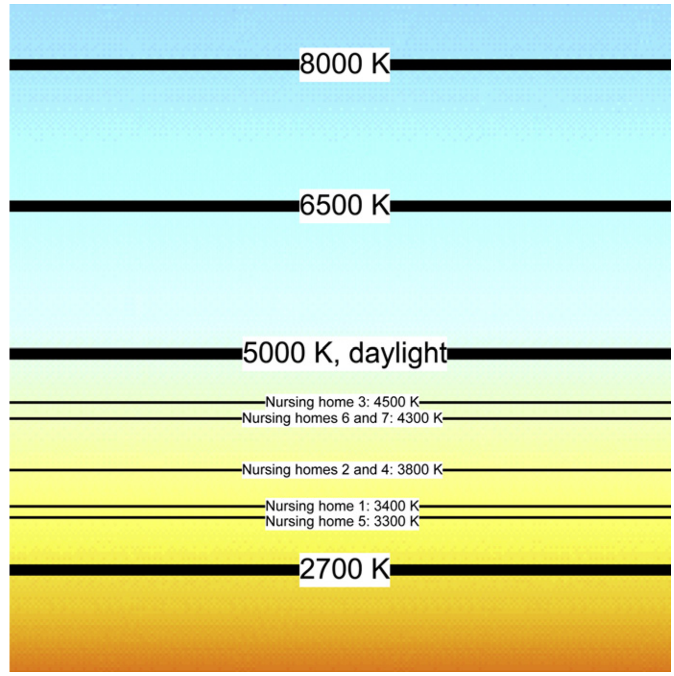

Fig. 4. Medians of measured colour temperature in the seven nursing homes compared to the threshold limits of 5000 (daylight); 6500 and 8000 K [26,27] and the common CCT of 2700 K of fluorescent lamps.

In the corridors of the nursing homes, 75% or more of the measurements fell below the threshold level for corridors, which was set on 200 lx. Nursing home 6 is the exception; in this nursing home, 'only' 15 out of 45 of the measured illuminances were lower than 200 lx, which makes this the nursing home with the most illuminated corridors. In nursing home 2 only 12 measurements were taken in the corridors. A significantly high number (9 out of 12) of measurements was above 200 lx. In all the other homes, light conditions were less favourable as 75% of the measurements or more fell below the threshold of 200 lx.

The measured illuminances (E_v and E_h) in the various nursing homes can also be differentiated by the zone in which the measurements took place (Table 4). Again, a high percentage of 70% or higher (157 of a total of 223 measurements at the window zone) of measurements showed vertical illuminances that were below the threshold of 750 lx. Horizontal measurement at the window zones was an exception. The number of measurements significantly higher than the threshold at the window zones was higher as compared to the central and rear zone. In these zones, 90% or more of the number of measurements fell below the threshold level of 750 lx.

A higher percentage of illuminances that were measured at horizontal level in the window zones exceeds the threshold level of 750 lx, namely 41% (or 41 out of 101 measurements in total). Horizontal measurements were assessed at table level or lap level in a seated position in a chair. This means that a higher percentage of measurements that were taken at the tables that were placed in the brighter zones of the common room exceed the threshold of 750 lx. Placing tables in the direct window zone provides the residents with the most favourable light conditions. In the central and rear zones of the nursing homes, almost all measured horizontal illuminances fell below the threshold limit of 750 lx (79 out of 88 for the central zone; and 29 out of 32 for the rear zone).

Table 4
Vertical illuminances at the eye gazing direction in all nursing homes. For the common rooms, the threshold limit for illuminance was set at 750 lx. For corridors, the threshold limit for illuminance was set at 200 lx. Horizontal illuminances at table level or on the lap when seated for three zones are given for a threshold level of 750 lx. Absolute frequencies and percentages of vertical and horizontal measurements of illuminances in the window, central and rear zones in relation to the threshold limit of 750 lx for common rooms and 200 lx for corridors.

E_v [lx]	Zone in the nursing home			E_h [lx]	Zone in the nursing home		
	Window zone	Central zone	Rear zone		Window zone	Central zone	Rear zone
<750	157 (70%)	293 (88%)	76 (100%)	<750	60 (59%)	79 (90%)	29 (91%)
>750	66 (30%)	40 (12%)	0 (0%)	>750	41[a] (41%)	9 (10%)	3 (9%)
<200							
>200							
Total	223	333	76	Total	101	88	32

[a] Zones with a number of measurements significantly higher than the threshold. Two-tailed sign test, $p < 0.05$.

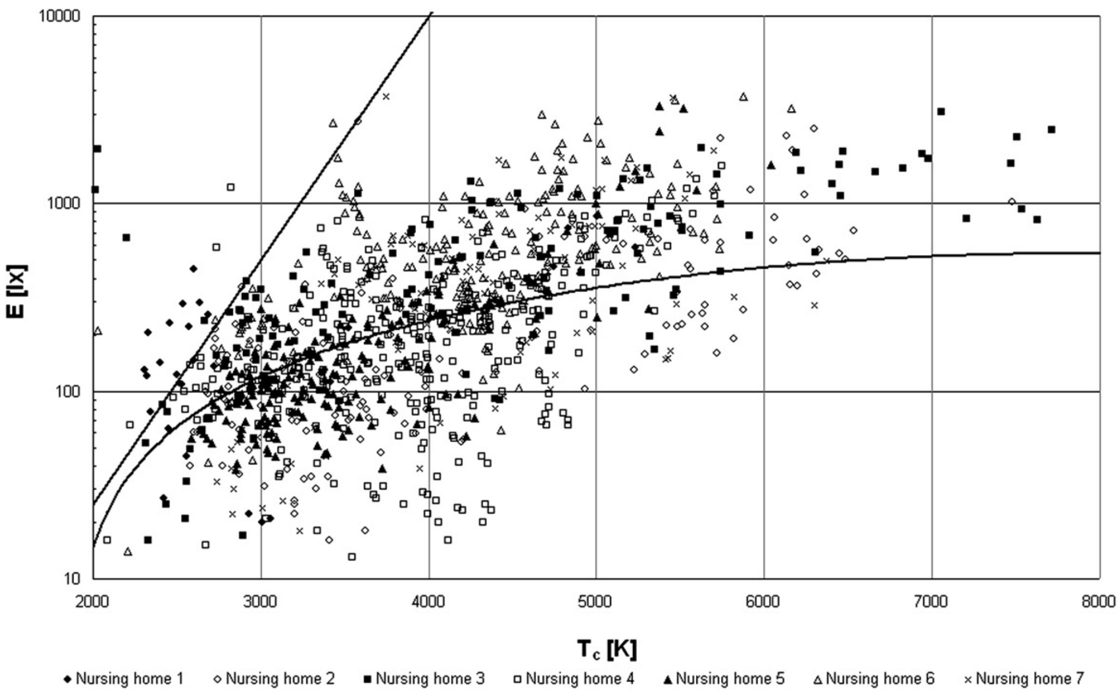

Fig. 5. The data points, combining illuminance (Y) and colour temperature (X) of the light inside the seven nursing homes, depicted in the reconstructed Kruithof curve [31], showing the lower and upper boundaries for acceptable ambiance.

3.2. Colour temperature

The median colour temperature scores of the seven nursing homes have been determined (Table 3), along with the minimum and maximum colour temperatures. In all nursing homes, the median colour temperature of the light is lower than the reference value for daylight, which was set on 5000 K. The colour temperatures ranged roughly between 2000 and 9500 K. In terms of matching daylight conditions, nursing homes 3, 6 and 7 come closest to this reference value of 5000 K, but still fall about 500–700 K short (Fig. 4). In terms of the recommendations by van Hoof and Schoutens [27] (Table 2) that the colour temperature should be between 6500 and 8000 K, it becomes clear that the colour temperatures inside the nursing homes fall even farther below these values. At the same time, conditions between the seven nursing homes are not similar. A Kruskal–Wallis *H*-test for independent samples showed that there is a significant difference in colour temperatures between the seven nursing homes ($p < 0.05$).

The differences in measured colour temperatures in the seven nursing homes are explored by using a Mann–Whitney *U*-test for two independent samples (Table 5). Nursing home 1 appears to have a significantly lower colour temperature as compared to all the other facilities. Nursing homes 6, 7 and 3, which came closest to the 5000 K reference value for daylight, show no significant differences when compared to each other. Although in nursing homes 2 and 4 the median value for colour temperature was 3800 K, nursing home 4 differs significantly from nursing homes 5, 6 and 7, whereas nursing home 2 is not statistically different. These differences may be caused by the larger range of scores of nursing home 2 as compared to nursing home 4.

The sign test was used to explore the differences in measured colour temperatures in the nursing homes from the 5000 K reference value for daylight. All nursing homes had a significant number of measurements that fell below 5000 K.

3.3. Combined assessments of illuminance and colour temperature in relation to the perceived ambiance

The illuminances and colour temperatures measured inside the seven nursing homes also contribute to the ambiance or atmosphere inside these facilities. When plotting all the data of this study in the Kruithof curve (Fig. 5), about 40% of the data points fall below the lower boundary. This means that these conditions are too dim and cold. The majority of data are within the boundaries of pleasant light conditions. The maximum values for every nursing home are within the limits of being perceived as a cold ambiance. The few data points in the upper left corner are said to reflect an overly colourful environment. Apart from the lighting conditions being too dim for NIF effects to take place, the light conditions are too dim for visual comfort and not pleasing according to the Kruithof curve.

4. Discussion

In the following sections, the design of lighting for nursing homes in relation to higher illuminances, the impact of colour temperature of ambient light and its relation to interior design and NIF effects, and the benefits of lighting and ethics are discussed.

Table 5
Exploration of differences in colour temperatures between the different nursing homes; $p < 0.008$ (according to the Bonferroni adjustment).

Nursing home	1	2	3	4	5	6	7
1	–						
2	*	–					
3	*	ns	–				
4	*	ns	ns	–			
5	*	*	*	*	–		
6	*	ns	ns	*	*	–	
7	*	ns	ns	*	*	ns	–

* = significant; ns = not significant.

Earlier studies, for instance, Charness and Dijkstra [33], have already shown that living and public areas for older adults often have poor lighting and thus poor light conditions. This study makes clear that lighting conditions in the living areas for older adults are poor due to both low illuminances and low colour temperature of the light.

4.1. Methodological issues

Illuminance and colour temperature thresholds are not specified for nursing homes in official international documents. The choice for a certain colour temperature of light(ing) is not prescribed in much detail in the available literature. If white light is required for reasons of user acceptability, then either daylight or one of the very high colour temperature discharge light sources would be most effective [34]. The ageing of society may correlate with an increase in the number of co-morbidities (the presence of one or more disorders/diseases in addition to a primary disorder/disease) meaning that more people may need nursing home services. Therefore, it is relevant that future studies should examine threshold levels in nursing homes both for residents as well as nursing home staff. In this study, measurement points (locations) were chosen in relation to the positioning of furniture, such as chairs and tables. No corrections were made for orientation of the building or for the presence of trees in front of the windows as the actual light conditions the residents were exposed to mattered in this study.

4.2. Illuminances for older adults

The basic strategies for creating a healthy living environment for older adults with low vision include: (i) increasing illuminance levels, (ii) controlling brightness, glare and luminance ratios, (iii) using clear and contrasting colours, (iv) arranging a convenient layout of spaces and (v) realising 'clear acoustics' [2,23,35]. As to clear acoustics, Heylighen et al. [[36], p.283] state that *"[…] good conditions for auditory communication require attention to the acoustic qualities of a space […]. It is especially important for people with a hearing or visual impairment, but also for the growing group of [older] people or when an extra language effort is needed."* In practice, however, Aarts and Westerlaken [9] have shown that light levels (vertical illuminances) inside care homes and homes for older people in the Netherlands, even during daytime, are too low to allow for proper vision and NIF effects. Paradoxically, the subjects in their study were satisfied with their lighting conditions that fell below standard. This discrepancy, however, can be explained by inherent biases in satisfaction research among older adults [10]. Similar results have been found and reported in the literature, for instance, in the United States by Bakker et al. [11], and in Belgium by De Lepeleire et al. [12]. In these previous studies, colour temperature of the light and its spectral composition were not considered either, and the majority of studies did not consider vertical illuminances. Lindner et al. [37] studied the subjective lighting needs of people with cataract and glaucoma. The study showed that eye diseases can have an impact on the preferred illuminance levels, which can be hundreds of lux-units lower than those preferred by healthy subjects. As to colour temperature, the so-called warm white light was preferred by all groups.

As mentioned earlier, older people may suffer from low vision due to both the effects of biological ageing and several pathologies, for instance, a decreased crystalline lens transmittance and pupil area. This is one of the reasons why lighting levels in nursing homes should be much higher than they are today. This is illustrated by Turner et al. [22], who stated that illuminance levels of 128–320 lx; 184–460 lx; 256–640 lx; 400–1000 lx; 536–1340 lx; and 656–1640 lx would be insufficient in 45, 55, 65, 75, 85 and 95 year old adults, respectively. These illuminance levels are much higher than average residential light levels and the levels found in this study. These lower levels point to the need for light levels in nursing homes to be substantially higher than they are today. The aforementioned illuminances [18] were not considered for the measurements in this study as the specific age of potential residents was not included, and existing standards and guidelines were used for setting threshold levels.

In addition to vision problems, Turner et al. [22] stated that insomnia in older people may be aggravated by poor light levels. Threshold intensities of at least 2500 to 3000 lx have been shown to reduce or alleviate insomnia; increase sleep efficiency, total sleep time, and restorative slow-wave sleep; and improve daytime vigilance and sleepiness [22]. Such high levels were hardly encountered in the seven nursing homes included in this study, apart from values measured in the direct window zone. This might imply that the residents suffering from insomnia may do so (partly) because of low ambient light levels. At the same time, their condition may be aggravated because of their lack of exposure to bright light brought about, for instance, by not going outdoors.

4.3. Including colour temperature in lighting schemes

Apart from the abovementioned solutions and their apparent short-comings, Turner et al. [22] wrote that residential lighting could be optimised by time-structured illuminances designed for circadian demands during daytime hours and limited to lower thresholds required for vision during the night. Architectural solutions that can supplement such illuminances and such solutions include the use of skylights, large windows, and passive light pipe illuminators [22]. In addition, Figueiro [34] has proposed a 24-h lighting scheme for older people. Figueiro's daytime lighting system would provide higher ambient light levels (400 lx at the cornea) and use light sources with more short wavelength content, i.e., 6500 K or higher. Her evening lighting system would use fewer luminaires to provide lower ambient light levels (<100 lx at the cornea) and use light sources with less short wavelength content (such as 2700 K) [34]. In the bedrooms, ceiling luminaires can be used as the daytime system (>6500 K) and turned off during the evening. Table and floor lamps using 2700 K compact fluorescent lamps can be used to provide evening ambient illumination [34]. According to Boyce [19], p.16], the aims of this "*scheme are to provide high circadian stimulation during the day and low circadian stimulation during the night, good visual conditions during waking hours and nightlights that are safe for movement but that minimise sleep disruption*". In addition, nightlight should provide no more than 5 lx at the cornea and provide residents with perceptual information that enables them to orient themselves around the space [19]. Assuming that specific tasks are to be performed in common rooms, additional illumination is needed to perform (instrumental) activities of daily living as well as for leisure activities.

The implementation of adequate lighting calls for carefully chosen lighting solutions, as was illustrated by Figueiro's [34] lighting scheme. Circadian efficacies of lighting solutions are among the factors that need to be considered. Table 6 shows that particularly fluorescent light sources with a high correlated colour temperature yield the highest circadian efficacies, i.e., influence day and night rhythm and possibly behaviour. In the seven nursing homes, lights were mainly 2700 and 3000 K fluorescent light sources, whereas a minimum at 6500 would be advisable from the perspective of health and well-being (Table 6), as the circadian/visual ratio of such light is twice that of 2700 K light.

Table 6
The calculated ratio of circadian to visual efficacies of commercially available light sources; scaled such that the incandescent lamp has a circadian efficacy of 12 CS/W and a luminous efficacy of 12 lm/W. Taken and adapted from Figueiro [34] and Boyce [19].

>(Correlated) colour temperature [K]	Type of light source	Circadian/visual ratio
4100	Fluorescent	0.72
2700	Fluorescent	0.73
n.a.	Incandescent	1.00
3000	Fluorescent	1.08
6500	Daylight	2.07
8000	Fluorescent	2.11
7900	Metal halide	2.22
17,000	Fluorescent	3.84
n.a.	Blue LED	17.6

n.a. = not available.

In this study, the measured colour temperature differed from one nursing home to the other. The year of construction of the nursing homes, and hence the architecture and choice of building materials, can explain the measured differences in colour temperature. In the newer buildings, common rooms are constructed with a larger window surface area. This results in exposure of residents to higher colour temperatures as they are frequently seated in the window zones. Windows of the common rooms were situated at the 'broad' side of the rooms, i.e., the longest wall of a room is equipped with windows, resulting in more daylight access. In these common rooms, all residents could be seated near the windows. In the older buildings, windows were placed at the 'narrow' side of the room resulting in low illumination levels.

However, some of the nursing homes showed significant differences in colour temperature and measurements were significantly lower as compared to the threshold of 5000 K. This can negatively affect NIF effects in the residents. Furthermore, extra attention is needed for light conditions in corridors and halls in five of the seven nursing homes. Step changes in the light conditions, particularly illuminance levels, between common rooms and corridors may contribute to an increased risk of falls and will be a topic of future research. As high colour temperature light is found in the window zones of the nursing homes in this study, the use of the window zone spaces by residents should be encouraged by nursing home staff and family carers.

In this study, the Kruithof curve [31] has been used to assess lighting conditions in nursing homes. The exact implications of the use of this curve for the nursing home environment, which, of course, differs from an office setting in terms of population and function, are not clear and could be an area for future study. The effects may be more pronounced in older adults as they require higher illuminances for proper vision and in terms of NIF effects. As to older people with dementia, unnatural lighting conditions may even lead to certain visuoperceptual errors and problem behaviours [7]. At the same time, high correlated colour temperature lighting, which has been recommended in the aforementioned studies, could negatively influence the atmosphere inside some nursing homes as, within the Dutch context, people prefer lower colour temperature light for reasons of cosiness and ambiance. These cultural differences in preferred ambiance have also been suggested by Boyce [32]. Viénot et al. [38] only partly validated Kruithof's rule that the combination of high colour temperature and low illuminance is perceived as unpleasant. No indication was found that high colour temperature is judged more pleasant than low colour temperature. Low colour temperature conditions were judged the most pleasant at any tested illuminance (150, 300 and 600 lx). This again might support the notions of preferred ambiance as stated by Boyce [32].

4.4. Colour temperature: interior design and NIF effects

The colour content of a room, including the furniture, may impact the colour properties of the light, both in terms of measurements and perception. The findings in this study suggest that the orange-coloured solar blinds found to be a part of the majority of nursing homes' façades impact the ambiance inside by lowering the colour temperature of the light indoors, i.e., creating a warm ambiance. A related effect has been reported in the literature by Mizokami et al. [39], who found that when the colour inside a miniature test space was orange, people in their study perceived the room as being illuminated by incandescent light sources, even though fluorescent lights with a higher CCT were used in the experiment. The colour of an object is thus not only perceived by its luminance and chromaticity but, more specifically, in relation to the environment in which it is placed [39].

The lower colour temperatures found inside the nursing homes in this study, however, also negatively influence the size of the NIF effects, as is illustrated by Fig. 3 by Górnicka [30]. According to this figure, low colour temperatures seen inside the nursing homes' common spaces would negatively affect NIF effects in the residents. When comparing the ranges of the colour temperature as measured in the seven nursing homes (minimum 2000 to 2700 K; median 3400 to 4500 K; and maximum 5200 to 9500 K) and given the dim conditions indoors, the NIF effect sizes are rather small or negligible. In contrast, the light conditions found in window zones can contribute to maximum NIF effect sizes if persons spend sufficient amounts of time in these zones, which, in turn, depends on the illuminance and colour temperature of the light (Fig. 3).

4.5. Benefits of lighting and ethics

Improved lighting conditions may lead to a number of benefits for nursing home residents, relatives, and staff. These benefits include more support in daily life from the environment and a decreased burden of care. Moreover, care professionals may benefit from the lighting equipment themselves because of visual and non-visual effects the systems have on persons with normal vision (Fig. 3).

As mentioned before [17,18], an improved lighting condition undoubtedly has benefits in terms of visual capacities. At the same time, special artificial lighting can never be a substitute for taking older adults outside or for care capacity problems. "*Every human being has the right to go outside – not merely for sensory activation – even though there are few (in)formal carers to take residents out for a short walk just to catch some fresh air*" [[17], p.154]. Turner et al. [22] state that the exposure to sunlight is usually minimal and declines with ageing. Young adults in industrialised countries typically receive only 20–120 min of daily light exceeding 1000 lx, whereas older adults receive only one third or up to two thirds as much daily bright light exposures. In older women, these levels are a mere quarter or half of the light exposures of age-matched men [22]. This illustrates the need for both the installation of adequate lighting systems in nursing homes as well as the construction of accessible outdoor areas or the stimulation for older people to spend some time outdoors.

In practice, we see programmes aiming at improving the energy efficiency of lighting systems in Dutch health care facilities. This may not only mean the substitution of incandescent lighting by fluorescent lighting but also a lessening of indoor illuminances, particularly as the main emphasis is on energy consumption, not the well-being of older people and other users of health care facilities. Given the obvious benefits of improved lighting conditions, energy conservation measures need to be monitored closely to see if such measures do not lead to a worsening of lighting conditions.

Figueiro [34] recognises the challenges when implementing special lighting solutions due to the initial costs and energy codes and regulations. In her view, these challenges should not stop designers from building public awareness of how lighting can make an important contribution to the lives of older people. "*It is this public awareness that will ultimately promote the changes we need to facilitate the implementation of these lighting solutions in senior facilities. Finally, to be truly successful, it will be necessary to go beyond good intentions and begin to formulate thoughtful, quantitative lighting solutions rather than qualitative solutions (i.e. bright or dim or cool or warm). These quantitative solutions should be based upon basic principles of circadian regulation while at the same time maintaining good vision and safety when the residents are awake and minimising sleep disruption and risk of falls at night* [[34] pp. 159–160]".

5. Conclusions and recommendations

In all nursing homes that were assessed, illuminances and colour temperature were both below the threshold levels of 750 lx and 5000 K, respectively, except for the horizontal illuminances in nursing home 6 and the corridors in nursing home 1. This means that residents are living in rather 'dark' environments. These environments, when considering lighting conditions, might limit their daily activities and social participation. Therefore, care professionals working in nursing homes should pay attention to the light necessary for conducting certain leisure activities and eating and reading tasks. When needed, facility workers should replace the lighting for one with the proper output in terms of illuminance and colour temperature. Long-term changes in older buildings can be planned in future renovations. In new building projects, proper arrangements for effective daylight and illuminance can be taken into account.

Measurements in different zones showed that the best place to put a table or seats for older adults is, as expected, near the window. However, in many cases tables were situated in the central or rear zone of the common room. This led to table level illuminances that in the majority of measurements in the seven nursing homes fell below the threshold of 750 lx. It is, therefore, recommended to put tables as close to the windows as possible, approximately 1–3 m from the window. The same should be done with chairs in which people sit whilst reading a book. Chairs in the window zone should be placed in such a way that the light falls on the book or magazine that is being read. Care professionals should make sure that residents alternate between lighter and darker corners without taking people out of their preferred seats. This can be done, for instance, by organising leisure activities close to the window. The 'dark corners' of the common room can be designed as a television area during the evening hours. In the daytime, older adults should stay as close (1–3 m) to the windows as possible, as long as illumination equipment is not sufficient.

High colour temperature (>5000 K, which can be achieved by a combination of daylight and 6500 K lighting) of ambient light, in combination with higher illuminances (>2500 lx for older adults), may positively affect the biological clock, resulting in better sleep quantity and quality. Care professionals should be aware of the benefits of light and change the seating arrangements of residents during the day in order to expose all of them to sufficient amounts of (day)light. In the end, additional lighting systems may be installed to improve the light conditions inside nursing homes as architectural and organisational solutions may not be sufficient.

When leaving the common room to the entry of the corridors, the measured illumination level fell below the standard of 200 lx resulting in dissimilar lighting conditions (i.e., too large step changes). As adaptation to dark is affected by biological ageing, this can increase the risk of falls. Care professionals should be alert to such step changes in illuminance levels between common rooms and corridors and try to equalise these levels as much as possible by adding light sources. Corridors were all located in the inner part of the buildings, which automatically results in low illuminance levels if electrical lighting systems are not sufficient. Professional carers should be aware of badly illuminated environments where their residents spend the larger part of the day. Moreover, facility workers should receive alerts from professional carers and install appropriate and sufficient illumination in corridors. Energy saving actions, such as switching off lights, should be done with great caution as the additional light(ing) may, in fact, be needed by occasional passers-by.

Awareness, of improving the indoor environment of nursing homes among technical professionals, including building services engineers, is as important as having awareness among care professionals. On the one hand, lighting technology and controls must be functional and easy to be used. On the other hand, care professionals should be aware of how to implement and use technology as well as to ask for assistance from professionals from the domain of technology. Furthermore, technical professionals should be aware that current lighting guidelines are not specifically developed for older adults even though standards are applied for nursing home settings. In these settings, special attention should be paid to the fact that older adults need more light than younger persons to perform the same tasks and that adaptation to darker conditions is limited in old age.

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