Evaluation of the efficiency of a pilot biodynamic lighting installation at the TGM Retirement Home in Beroun

A brief research report on the results of a public tender (Phases 1 and 2)

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1 Motivation

Ageing affects all aspects of human physiology and behaviour, including circadian rhythms. Although the ageing-affecting processes have not yet been fully understood, a growing number of studies suggest that the circadian clock appreciably affects an individual's ageing and longevity. Circadian rhythms play a major role in human health, and long-term disturbance of the circadian clock function is accompanied by unfavourable health effects, as evidenced by a number of studies devoted to the health of workers in shift work (Lunn, Toitou and Boivin, 2014).

The circadian system requires very good synchronisation with the solar cycle in order to work well. This synchronisation is based on the spectral and intensity contrast between the day and night as read by the human visual system, and transmission of this information to the central circadian clock in the hypothalamus. The performance of the circadian system in elderly people is typically endangered by too low a contrast between the day and night. Elderly people are frequently exposed to intense night light, the spectrum of which approaches that of light during the day. Moreover, elderly people reside most of the time inside buildings, and so their circadian clock suffers from a sunlight deficit during the day. Ageing is also associated with a worsening of an individual's vision system, specifically the eye lens, which transmits fewer “blue” sun rays, and so the person requires an improved quality of lighting.

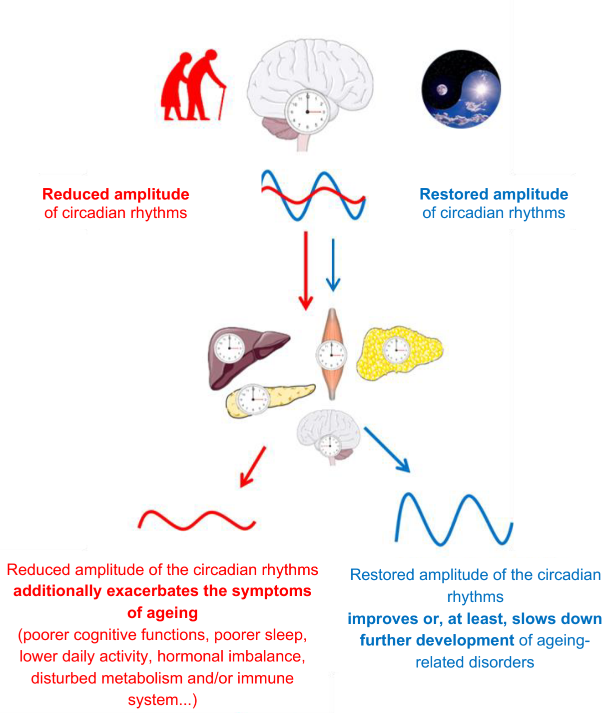


Figure 1 shows that among the typical manifestations of an ageing circadian system is a lower amplitude of the circadian rhythms, bringing about a gradual disturbance of the homoeostatic functions in the whole body and a worsening of their health. This study is based on the assumption that optimisation of the lighting conditions in retirement home buildings can be used to slow down the decreasing circadian rhythm amplitude, or partly improve synchronisation of the circadian rhythms and so suppress the development of the pathophysiological symptoms of ageing. *(Adapted from: Kessler and Pivovarova-Ramich, 2019)*

Signals from the central biological clock during the night induce production of the **melatonin** hormone. This hormone is produced by the pineal gland, also known as the conarium, or epiphysis cerebri. *The melatonin night synthesis process is disturbed by light* and the level of this hormone in the body decreases immediately. Melatonin has a number of functions in the body, e.g.:

a) enters the blood vessel system and acts as an “ambassador” of the central clock, informing all tissues and organs that it is currently night

b) promotes falling asleep and improves the quality of sleep, thereby contributing to the quality of cognitive function

c) acts as an antioxidant and rids the body of dangerous free radicals

d) exerts anti-inflammatory and anti-tumour effects.

Thus it is be clear that rhythmic melatonin production during the day and at night is very important in supporting physical and mental health, and so it is desirable that lighting conditions are modified so they should not disturb melatonin synthesis at night: on the contrary, they should support the natural circadian rhythm of melatonin production, which, regrettably, grows poorer with age.

2 Objectives

The objective of this study was to assess the efficiency of a pilot biodynamic lighting system installation in the building of the TGM (Tomáš Garrigue Masaryk) Retirement Home (TGM RH) in Beroun. This pilot installation was performed by Spectrasol, s.r.o. and comprised replacement of lights in 6 rooms including the entrance halls and bathrooms, in the main living room of the home, in 2 nurses' rooms, in the workshop and in one corridor. The National Institute of Mental Health (NIMH) fulfilled the following tasks: a) to collect biological samples and collect data from questionnaires and cognitive tests (including basic instruction of the retirement home staff and clients); b) to evaluate and interpret the results and provide recommendations; and c), in cooperation with the University Centre of Energy-Efficient Buildings, Czech Technical University (UCEEB), to assess the lighting conditions before and after replacement of the lighting system, assess their effect on the physiological and mental functions and, based on the outcome, provide recommendations for the next steps.

3 Subject of the study

3.1 Lighting in the clients' private areas

The **clients' bedrooms** were initially equipped with common fluorescent tubes providing about 250 lx illuminance on a reference plane, usually emitting a warm colour (3200-3500 K). This lighting was replaced with biodynamic LED lights that enable the light quality and quantity to be varied during the day and night. A central suspended light fixture satisfying the aesthetic requirements of the age group involved was designed for this.

Figure 2: Lighting in the clients' rooms. The original light (A) was replaced with a biodynamic lighting system with variable spectral composition, light emission characteristics and light intensity matching the day/evening time (B, C). Orientation glow lights were installed in the rooms to facilitate clients' movements during the night (D).

During the day, the light fixtures emit neutral white light (4,600 K) with high colour rendering and reference plane illuminance appreciably exceeding 500 lx. The room is illuminated indirectly by reflection from the ceiling. The light intensity is gradually reduced in the evening and short wavelengths in the spectrum are suppressed. The light flux is directed downwards. When a person moves through the room during the night, the orientation light (amber colour, mean illuminance of units of lx) is automatically activated.

The lighting was also replaced in the **bathrooms and entrance halls**. Normal daylight was strengthened and light distribution was modified so as to achieve a more uniform illumination. The areas were also supplemented with an automatic night mode by using fixtures with indirect lighting and reflection from the room ceiling.

Figure 3: Bathroom lighting. A – The original lighting was strengthened and light distribution was changed (B). The system was completed with a night mode (C, D).

3.1 Lighting in the common areas

The **dining room**, i.e., the main social space, was initially fitted with fluorescent tube fixtures, either ceiling-mounted or installed in lustrous gratings in the false ceiling. Warm and cold lights were eventually mixed in the fixtures during maintenance work. The above fixtures were replaced with flat panels and with opal diffusers controlled through biodynamic regulation. This regulation switches automatically from the high-intensity day mode with a neutral colour to the evening atmosphere, with light appreciably poorer in the short wavelength (i.e. blue) components.

Figure 4: Dining room lighting: A – detail of an original fixture with reflective grates; B – comparison between the original (right) and new (left) lighting in the day mode; C – new lighting in the evening mode.

The existing fluorescent tubes in the **main corridor** of the residential section were also supplemented with the night mode, i.e., amber-tone LEDs providing highly uniform light.

The ceiling-mounted fluorescent tubes in the **workshops** were replaced with a pro-cognitive LED system with indirect illumination directed to the ceiling.

Figure 5: Lighting in the corridor before (A) and after (B) the change; lighting in the workshops before (C) and after (D) the change

4 Methodology

This study was run in 2 phases and included 2 testing waves: in November 2019, before the lighting system replacement, and in February 2020, i.e., 10 weeks after the lighting system replacement. The research subjects included 19 clients of the TGM RH in Beroun (11 clients in the test group – with lighting replaced in their rooms, and 8 clients in the control group – with the lighting system replacement in their rooms only simulated while the light parameters remained unchanged) and 13 volunteers from among the staff. All subjects were familiarised with the study and signed Informed Consent forms. The study had been approved by the Ethics Committee of the National Institute of Mental Health.

4.1 Evaluation of the lighting conditions

As a basis for assessment of the biodynamic lighting effect, the original light environment was measured in the clients' private rooms including the bathrooms and in the common corridors, the workshops and in the social room. Illuminance on a reference plane and the spectral light composition were measured in the two variants: during daylight access and with no daylight present.

All the measurements were repeated after installation of the new lighting. The differences in the nature of the light during the day, in the evening and at night were examined. Brightness analysis was also performed in selected rooms to assess the visual comfort. This concerned, in particular, the glow light for orientation at night.

The data was used to assess the effect of the lighting on the various photoreceptors, based on the CIE method for calculation of the α-opic efficiency. The brightness relations, risk of dazzling and the contrast relations in the field of view were evaluated from the brightness analysis.

4.2 Questionnaires and cognitive testing

The TGM RH clients underwent Addenbrooke's cognitive examination (ACE-R) and completed questionnaires concerning the quality of sleep (Pittsburgh Sleep Quality Index – PSQI), the Morningness–Eveningness Questionnaire (MEQ) and the Geriatric Depression Inventory (GDI) both during the first testing before the lighting replacement and during the second testing after the lighting system replacement. The clients' self-sufficiency status was assessed based on the Disability Assessment for Dementia (DAD) questionnaire. The staff filled out the chronotype questionnaire and the Pittsburgh Sleep Quality Index questionnaire. The same evaluation tools were used during the second (February) testing. Internationally standardised procedures were applied to the evaluation of the questionnaires and cognitive tests.

4.3 Actigraphic measurements and analyses

MotionWatch 8 actigraphs (CamNtech Ltd.) were distributed 4 weeks before the lighting replacement and 8 weeks thereafter. The clients and staff were instructed to wear them continuously for approximately 4 weeks. An actigraph is a watch-like device which is intended to be worn on the non-dominant hand. This device records movement activities, based on which the sleep/wake rhythm can be monitored and certain parameters of the quality of sleep determined. The MotionWatch 8 devices also record the lighting conditions in the area. In order to complete the data from the actigraphs with additional information, the participants were asked to fill out sleep diaries. The data was analysed using MotionWare software (CamNtech Ltd.) with respect to the sleep and circadian rhythmicity (total time of sleep, sleep efficiency, variability, stability, etc.) applying a 30-sec sampling interval.

4.4 Saliva sampling and melatonin level determination

Saliva samples for melatonin level determination were collected from the participants in 3-hour intervals over 24 hours, both before and after the lighting system replacement. Volunteering employees provided saliva samples taken at home and some of them also samples taken during the night shift. The melatonin level in the biological samples was determined by radioimmunological analysis (RIA). The results obtained before and after replacing the lighting were interpreted in relation to the light intensity and light spectrum in the TGM RH building.

4.5 Statistical processing

The statistical methods were selected so as to match the type of analysis and nature of the data. Both paired and non-paired statistical t- tests, Pearson's correlation analysis and cosinor analysis for rhythm determination were employed.

5 Major study outcomes

The effects of the new lighting system were comprehensively evaluated by the interdisciplinary team from many objective and subjective aspects. The conclusions derived from the observations were in mutual agreement, supporting each other nicely.

5.1 Light environment

Lighting in a retirement home must be selected taking into account the specifics of the clients. The specifics included, in particular, the need for a higher illuminance for visual activities, slower adaptation to a lighting intensity change, a higher risk of dazzling because of poor tolerance of high contrasts in the field of view, as well as poorer ability to discern between low-contrast areas. Eye ageing is associated with a lower sensitivity to short-wavelength light, the field of view frequently grows narrower, etc. The clients' limited ability to move, slow reactions, etc., must also be taken into account.

Visual comfort

The measurements gave evidence of a higher illuminance in the residential rooms. While the illuminance in many rooms originally failed to attain the levels required by applicable standards, now it was more than twice as high.

The measurements also proved that distribution in the space reduces unwanted contrasts and sharp shadows. The clients' bedrooms are illuminated indirectly via reflection from the ceiling, providing outstanding light uniformity and limiting the risk of dazzling despite the relatively high illuminance. The indirect illumination also prevents light rays from directly hitting the eye of a lying person.

The night orientation lights in the bedrooms, corridors and bathrooms are dimmed lights emitting an amber light. The light is directed towards the floor to illuminate any obstacles and enable safe movement across the room. Illuminance is adequate (units of lx) thanks to the uniform distribution. The indirect night illumination in the bathrooms uses light dispersed via the ceiling surface. It enables adequate orientation in the area and, at the same time, enables the eye to adapt to the low illuminance, so one can move safely when returning to the room without having to turn on the main lighting system.

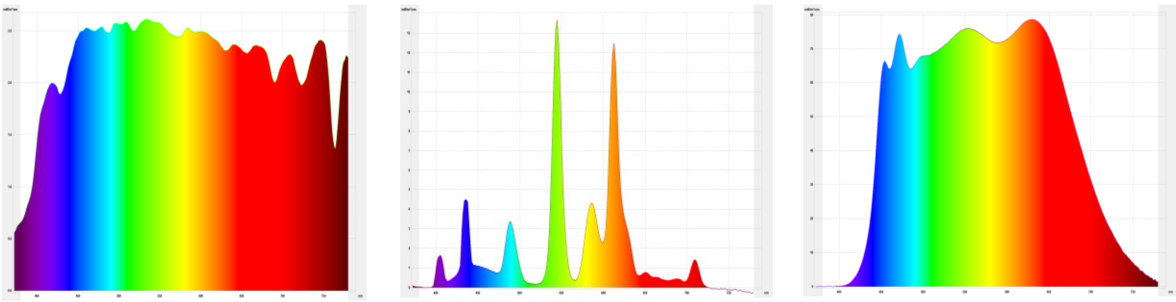
Spectral composition

Spectral analysis of the source used for the day lighting showed that the spectrum approaches that of natural daylight. The chromaticity temperature of 4,700 K is in accordance with that of daylight (6,500-5,000 K) reduced based on the Krujthof diagram for lower interior illuminance, due to which the recommended chromaticity temperature for residential rooms is 4,500-5,000 K.

Furthermore, all the wavelengths across the central range of 450-650 nm are uniformly present in the spectrum, with a deviation not exceeding ±13%. Thus, the colour rendering is much better than that provided by conventional light sources (the colour rendering index is >91) and the spectral composition approaches that of natural daylight. Hence, the spectral characteristics of the LED system used for lighting during the day satisfy the requirement for a full-spectrum light source. All photoreceptors in the eye are uniformly stimulated, as is normal in a natural environment. Being in a room illuminated with full-spectral sources is less tiring for the body than when using conventional electrical lighting systems, which typically lack a part of the spectrum and as such can be more strenuous for the brain to process visual information.

Compared to conventional LED sources, the spectrum is also richer in the range of the biologically activating blue and azure wavelengths (450-500 nm). Such a source can be referred to as a pro-cognitive light source, i.e., a light source supporting cognitive performance. Pro-cognitive LED lighting, similar to natural daylight, is capable of promoting a number of mental activities, such as the ability to concentrate and memory. A quality lighting system for the day also demonstrably stabilises the body's biorhythm and favourably affects sleep during the following night. This more efficient body recovery process can bring about (in the long run) a higher physical performance, subjective satisfaction and better health and vitality. Beneficial in this respect is the high efficiency of the full-spectrum source with respect to the stimulation of the internal biological clock. The pro-cognitive light technology was created based on the knowledge of human biorhythms.

The spectrum contains a high proportion of long wavelengths (the red part of the spectrum) which contribute to a high colour rendering and high-quality colour perception.



Daylight (noon, a sunny day) CT ~ 5,500 K

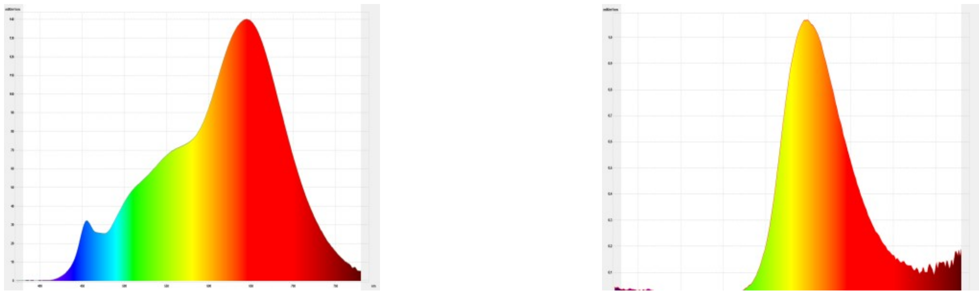
Original lighting system – fluorescent tube, mix of neutral and warm white colours, CCT 3,371 K; Ra 82

LED, full-spectrum, pro-cognitive light, CCT 4,755 K; Ra >92

Figure 6: Spectral composition of the light sources for use during the day

Spectral analysis of the sources installed for the evening mode showed a lower fraction of short wavelengths, an associated lower chromaticity temperature (2,636 K) and a very high colour rendering quality Ra > 92 compared to the conventional sources. This parameter is important, particularly with respect to the specific needs of the elderly users.

The night orientation lighting completely lacks short wavelengths, so it cannot be considered white light. Its amber colour tone is suitable for use at night, the calculated colour rendering index Ra = 50 is sufficient for the purpose (spatial orientation) even in older age groups, especially if a high uniformity of light distribution in the space is maintained.



LED, warm white;
CCT 2,636 K; Ra > 92

LED, amber;
CCT 1,832 K; Ra 50

Figure 7: Spectral composition of the light sources for evening and night use

System management/control

The main lighting elements in the bedrooms and the lighting in the dining room are automatically controlled according to the time of the day so as to simulate the natural day/night rhythm. The changes in the spectrum, the light output and spatial distribution take place slowly and naturally. The users have no access to the lighting quality or quantity control: they can only turn it on/off. The target lighting conditions are derived from the natural conditions during the equinox, so they are not variable during the year. The main lighting system is complemented with local lighting at the beds and on the table.

The night orientation lighting in the bedrooms is controlled by a motion sensor located at the floor so as to detect any movement around the bed or nursing staff entering the room.

Physiological light efficiency

A comprehensive assessment of the effectiveness of light falling on the human eye must include evaluation of its effect on the entire complex system of light perception for visual and non-visual perception. The light source efficiency assessment showed significant differences between the sensitivities of the individual photoreceptors for the individual sources, see Table 1 and Figure 8.

The various light sources possess different melanopic efficiencies: the strongest light (day LED) stimulates the body >250 times more than the weakest (night) light. Although still not achieving the variability in a natural environment (see the last column of the table, efficiency comparison with daylight), this ratio is much closer to it than in the environment before the lighting system replacement where no variability was possible, but it is also significantly larger than as enabled by the common lighting systems designed and implemented according to the applicable standards.

Table 1: Calculated efficiencies for the various photoreceptors

	CCT K	Ra -	Photopic lux	Cyanopic s-cone	Melanopic ipRGCs	Rhodopic rod	Chloropic m-cone	Erythropic l-cone	Melanopic efficiency, comparison with daylight [%]
Full-spectral, pro-cognitive LED for the day	4,755	92	561	299	**500**	525	564	583	50%
Warm white LED for the evening, full power (max)	2,636	94	331	67.6	**160**	196	266	333	16%
Warm white LED for the late evening, reduced power (min)	2,600	92	43	8.0	**21.2**	25.5	34.3	43.1	2.1%
Amber LED for orientation at night	1,832	50	10	1.9	**2.1**	3.2	7.2	10.6	0.2%
Fluorescent tube, neutral white for the day (original lighting)	3,371	82	248	113.9	**128.5**	161	211	240	13%
Natural daylight; 5,500 K	5,500	99	1,000	880	**996**	1,005	1,004	989	100%

Owing to the big difference between the potentials of the light sources, the new lighting system can be referred to as a **biodynamic system**, i.e., a system simulating the natural light environment. In view of the high lighting quality needed to satisfy the visual functions – uniformity and good stimulation of all the traditional photoreceptors (rods and cones), this lighting system meets all the requirements for visual and non-visual light perception, hence, it is **integrative lighting** (according to CIE).

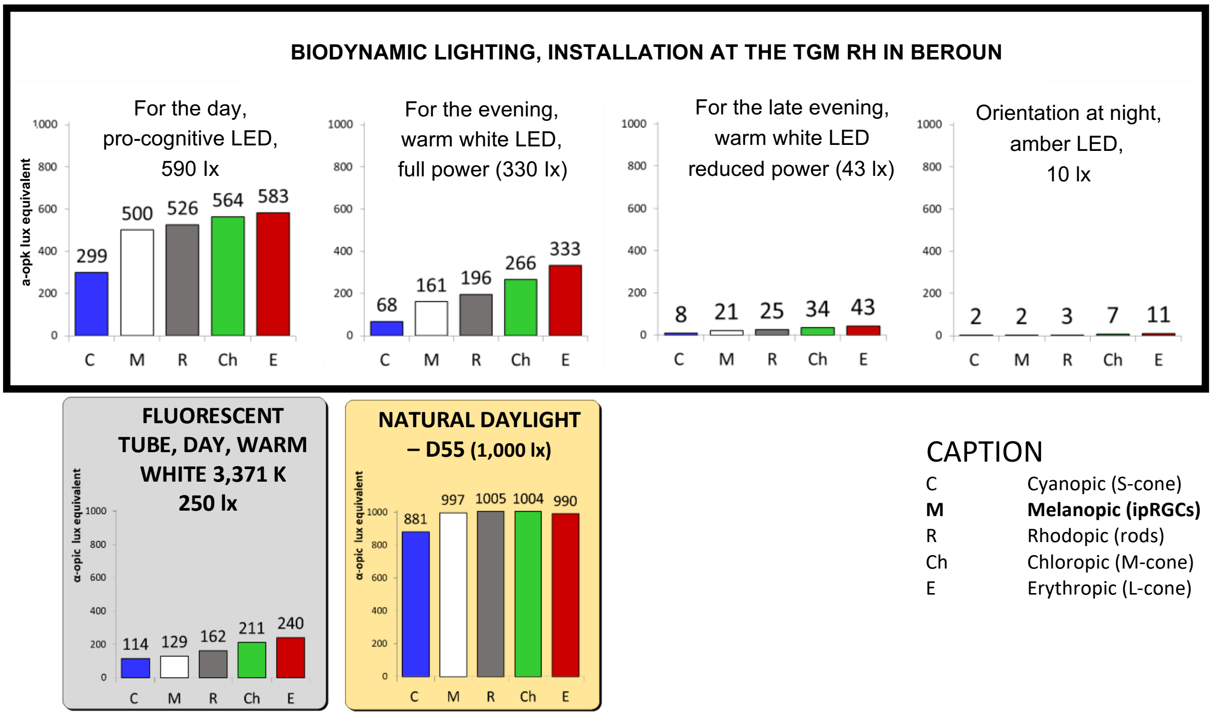


Figure 8: Efficiencies of the light modes of the biodynamic lighting system acting on the various photoreceptors in the human eye (top) compared to natural daylight and the original fluorescent sources (bottom). Measured on a horizontal plane at bed height, night light measured on a vertical plane 150 cm above the floor.

5.2 Subjective assessment of the biodynamic lighting efficiency

From the interim evaluation (January 2020) of the subjective feelings of the individuals from the test group (n=11) concerning the lighting system change, it follows that the installation of this new system was well received and had a favourable effect on the subjective perception of the retirement home clients. The majority was satisfied with the change (82%), of whom 36% were significantly satisfied. None of the subjects regarded the new lighting installation as an undesirable change (Figure 9). In particular, the clients appreciated the easier movement through the areas after installation of the new automatic night lighting. 60% of the clients felt safer when walking than before (Figure 10). Sleep improvement was reported by over one-third (36%) of clients (Figure 11) and marked mood improvement was reported by 9% of clients (Figure 12). The most frequent assessments one month after the use of the new lighting were “I feel much safer now when going to the bathroom during the night” and “I take a nap during the day much less now than before”.

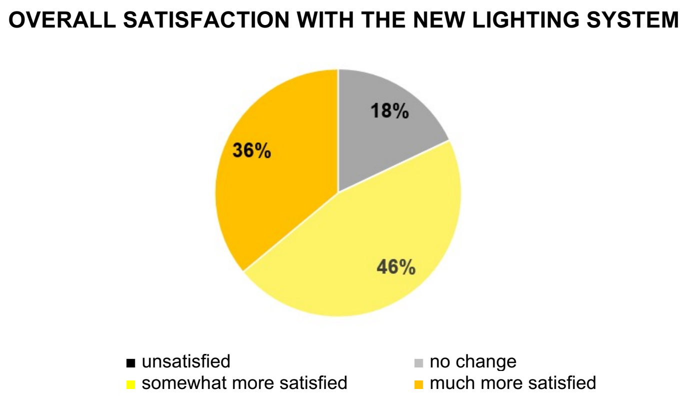


Figure 9: Overall satisfaction with the new lighting system in the test group (n=11). This comprehensive assessment of the new lighting system encompasses any mood change, sleep quality change and easy moving through the (bed)room and in the corridor.

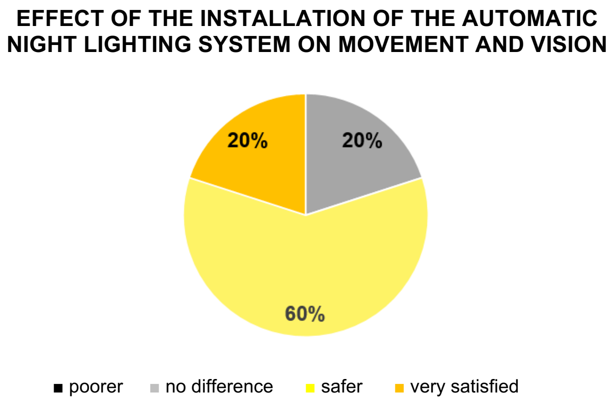


Figure 10: Subjective assessment of change in movement and vision after replacement of the lighting system (n = 10). Answer to the question: "Would you say that it is easier for you to walk through the room and corridor now that the new automatic night lighting system has been installed? (Specifically, do you think you can see better at night without disturbing your roommate by using the ceiling lighting?)" Improved mobility in the space after installation of the new automatic night lighting system was reported by the majority of subjects (80%): 60% felt safer than before when walking, 20% were very satisfied with the new lighting system. No change was reported by one-fifth of the subjects.

SLEEP AFTER THE LIGHTING SYSTEM REPLACEMENT

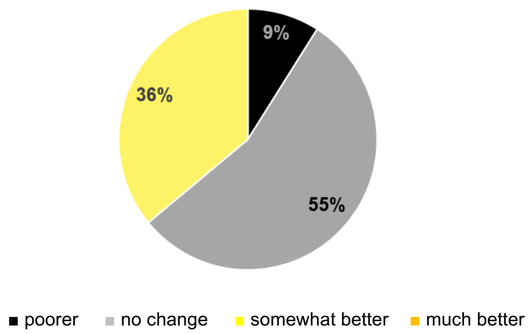


Figure 11: Subjective assessment of sleep after replacement of the lighting system (n=11).

MOOD CHANGE IN RECENT DAYS

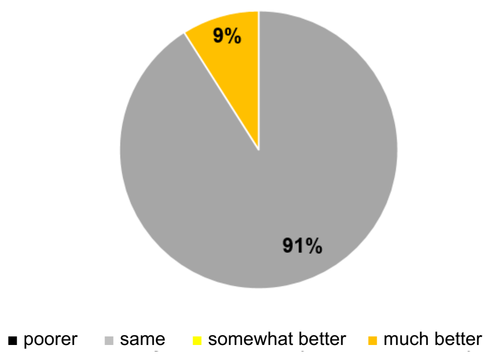


Figure 12: Subjective assessment of mood change after replacement of the lighting system (n=11).

5.3 Objective evaluation of the biodynamic lighting efficiency

This objective evaluation of the biodynamic lighting efficiency is based on the outcome of the cognitive testing, analyses of actigraphic records and measured melatonin levels. In summary, the results showed that the lighting system replacement brought about better synchronisation of the circadian rhythms, a higher rhythm amplitude and better cognitive performance. The more clear-cut amplitude of the circadian rhythms is apparent both from the actigraphy data and from the observed day and night melatonin levels.

An important parameter in the actigraphy data is the interdaily stability, expressing the extent of synchronisation of the circadian rhythmicity (the timing of sleep and wake in particular) based on a comparison of the circadian rhythm parameters (period, amplitude and phase) between the days of measurement. The data show that circadian rhythm synchronisation improved significantly in the subject group after replacement of the lighting system (Figure 13).

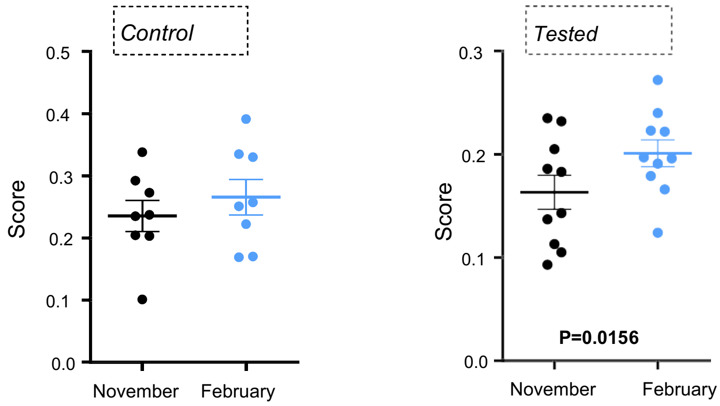


Figure 13. IS (interdaily stability) factor obtained by actigraphic measurement. The diagram shows a significant improvement in synchronisation between the November measurement and the February measurement.

Similarly, the observed melatonin levels point to an improvement in synchronisation and more clear-cut amplitude of the circadian rhythms in the study subjects after replacing the conventional lighting with the biodynamic lighting system. The figures below document that the melatonin rhythm amplitude became more apparent (Figures 14 and 15) and melatonin synthesis started earlier in the evening hours (Figure 14) in the TGM RH clients in whose rooms the lighting system had been replaced.

Also, the day melatonin levels decreased in those subjects (Figure 16). A significant correlation was found in the group between the melatonin level and sleep (nap) during the day: the lower the melatonin level, the less the subjects slept during the day (Figure 16).

The cognitive performance measured by Addenbrooke's cognitive examination also improved in the subject group after the lighting system replacement. The performance in the test correlated positively with the melatonin rhythm amplitude (Figure 17).

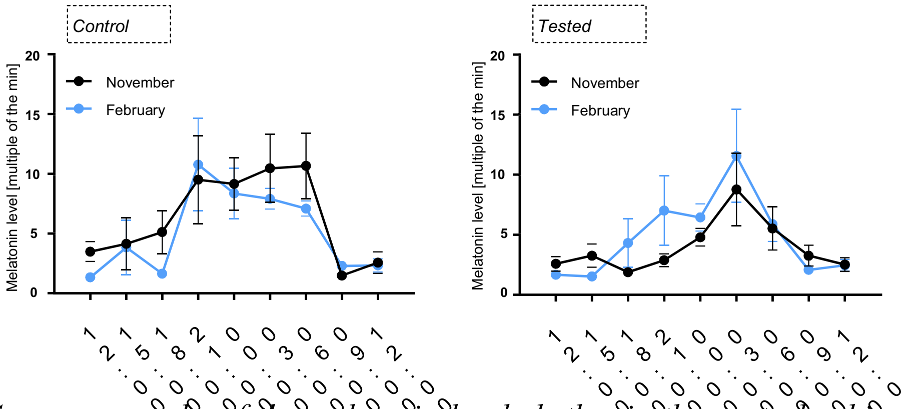


Figure 14. Summary graphs of the melatonin level rhythm in the control subjects (n=8) in whose rooms the original lighting was retained, and in the test subjects (n=11) with the new lighting system in their rooms. The graph for the control subjects shows that the melatonin level rhythm was similar in November and in February, while the graph on the right shows improvements in the amplitude and earlier onset of melatonin synthesis towards the evening.

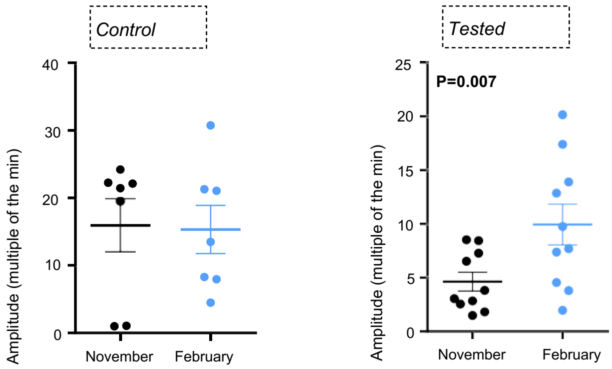


Figure 15. Differences in the melatonin rhythm amplitude between November and February in the control subjects (with the lighting unchanged) and in the test subjects (with the new lighting). The graph demonstrates statistically significant rhythm amplitude increase in the test group after lighting replacement and no amplitude change in the control group.

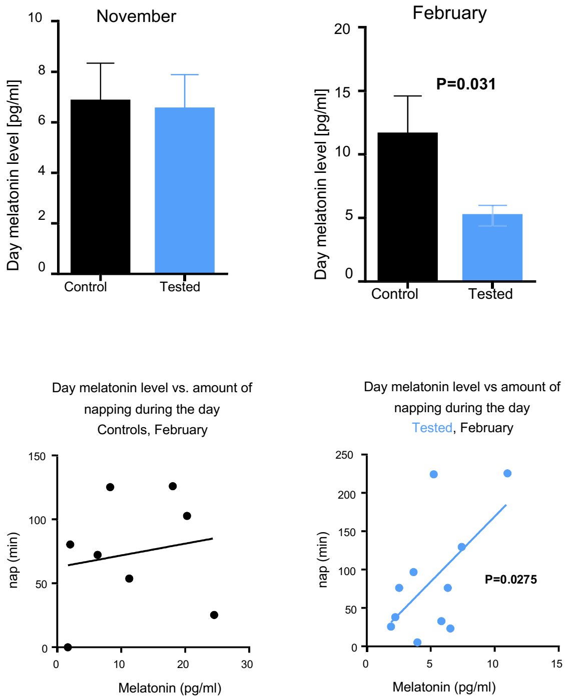


Figure 16. A correct melatonin rhythm consists of a high night level and a very low to zero day level. A high day melatonin level indicates poor synchronisation of the circadian clock by light or a lower sensitivity to light, and may bring about disturbed sleep cycles and increased daily napping. Our results indicate a significant day melatonin level decrease in the test subjects in February compared to the control subjects (top right), correlating significantly with the amount of napping observed through the actigraphic measurements (bottom right). The day melatonin levels before the lighting system replacement (in November) were identical in the two groups (top left) and the correlation with the amount of napping in the control subjects in February was insignificant.

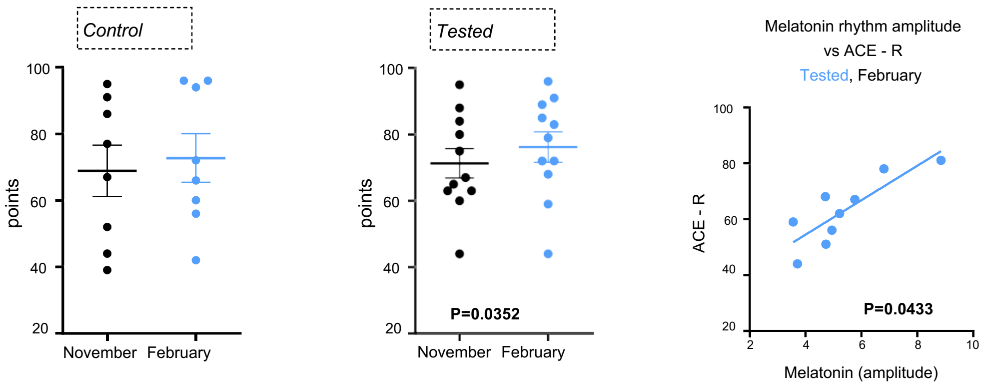


Figure 17. The graphs show the summary results of Addenbrooke's cognitive examination. While the results for the control group were nearly identical in November and in February, a significant improvement was found in the test subject group from November to February. This better performance correlates significantly with the increased melatonin level rhythm amplitude (right).

By way of example, Figure 18 below shows the daily melatonin level rhythms in one subject (RH client) in the test group, one subject (RH client) in the control group and in the caregiver staff during the first and second measurements (i.e. before and after the lighting replacement, respectively).

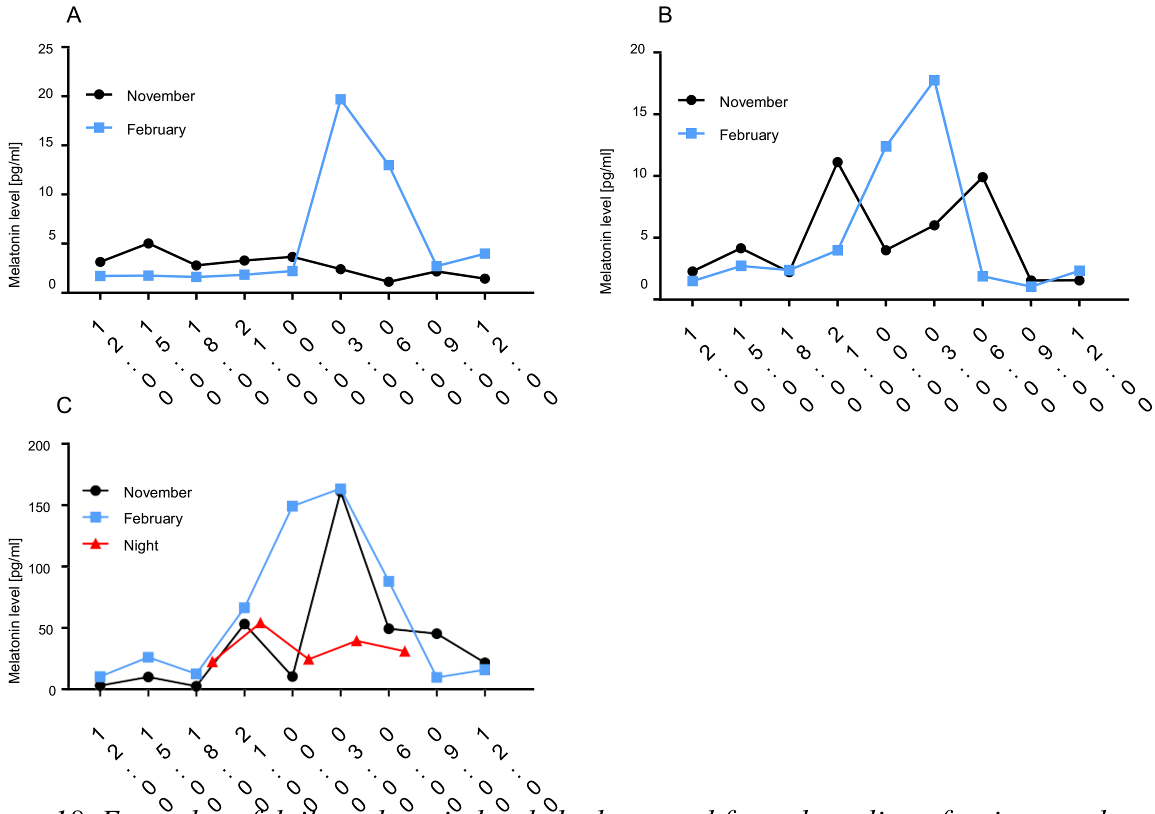


Figure 18. Examples of daily melatonin level rhythms read from the saliva of retirement home clients (A, B) and a representative of the caregiver staff (C) before (November) and after (February) installation of the new lighting system. Figure A shows a daily melatonin profile with a zero amplitude observed in November and its appreciable improvement in February owing to the optimised lighting conditions. Figure B shows the November rhythm, with 2 peaks at the beginning and at the end of night. This decrease between the two peaks is believed to be due to unsuitable lighting during the night checks of the clients by the nursing staff. The melatonin rhythm consolidated and the night valley on the curve disappeared once the new lighting system had been installed. Figure C shows the difference between the November and February melatonin rhythms. In particular, the high melatonin level persisted through the night in February and did not show any decrease at about midnight like in November. The red curve shows the melatonin level during a night shift. The melatonin synthesis suppression by the night light is typical.

6 Summary and recommendations

Both the objective light parameter measurements in the areas and the subjective assessments obtained via questionnaires show that the installation of the new lighting system led to better visual comfort for the retirement home clients. In particular, the orientation night lighting was welcomed because the users feel safer when moving through the area during the night. Analysis of the α-opic illuminances and their changes throughout the 24 hours of the automatic light cycle showed the appreciable contrast between the day and night illuminances, as can be assured by the system. The physiological parameter testing results proved that the installation of the biodynamic lighting system significantly improved the melatonin production rhythm amplitude, which correlated with the enhanced performance in the cognitive tests of the study subjects and also was associated with a lower day melatonin level, which had the favourable effect of shortening the nap period during the day. Actigraphic measurements showed the better synchronisation of rhythms in physical activity and sleep as a marker of overall consolidation of the circadian system. The improvement in the melatonin production rhythm amplitude can be seen as an outcome that **unambiguously indicates the significant contribution of the new biodynamic lighting system to improvements in the symptoms of ageing in retired persons**. The retirement home clients also described the better sleep and mood brought about by the lighting system replacement, which is proof of the favourable **effect of the biodynamic lighting on the quality of their lives**. It is noteworthy that the test group included persons inhabiting rooms on the ground floor (where the lighting system had been installed). In other words, medication or disease diagnosis was not taken into account when selecting subjects for the testing. It appeared during the study that the subjects tested had been in an overall poorer health and physical state and required more night interventions that the subjects in the control group. Even so, the favourable effect of the biodynamic lighting on them, compared to the control group, was proven. This was in spite of the fact that the new lights had also been installed in the common areas and hence, the control group was also partly exposed to them. This fact indicates that any **installation of a biodynamic lighting system must constitute a complex project** and must include modification of the day and light lighting in all areas. It is advisable to augment the regulation according to the time of the day with **seasonal regulation**, taking into account the different lengths of the day during the various seasons of the year. Furthermore, the fact should be stressed that a 3-month adaptation period is rather short with respect to changes in the circadian system. It is reasonable to assume that the differences will be even more pronounced after longer use of the new lighting system. It would be worthwhile examining whether the long-time effect of biodynamic lighting is so pronounced that it brings about significant differences in the overall performance, health and cognition of elderly persons. Based on scientific literature and the data measured, we believe that this is quite likely. We therefore recommend that **a third stage of testing to the full extent as described above should be carried out for roughly 1 year utilisation of the new biodynamic lighting system**.

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