Light Beyond Vision: Implications for Human-centric Lighting Design in Tropical Nursing homes

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Abstract. For the elderly people, adequate environment to compensate for increasing frailty and sensory loss are crucial. Normal age-related changes to the eye decrease the amount of light reaching the retina impacting both vision and circadian rhythm. Some attempts have been made recently to conduct tunable white lighting and vary lighting levels and Correlated Colour Temperature (CCT) for health and wellness. However, how to translate such Human-centric Lighting (HCL) concepts proven in laboratory studies into built environments are still in early stage and lack of largely proven practices and strategies on an operational level. This research project aimed to explore HCL design strategies in nursing homes in Singapore. Firstly, state of the art HCL and aging studies were discussed. We then captured the views to illustrate a HCL framework in a tropical context, whereby the quantitative and qualitative approaches were considered. The preliminary design strategies were developed based on this framework and exemplified in a selected nursing home in Singapore. Also, pre-/post implementation user surveys together with quantitative evaluations (involving horizontal and corneal illuminance measurements) were conducted for assessing the performance of the HCL design strategies. These pilot study findings provide initial insight into HCL design-related knowledge and serve as the solid basis towards the HCL best practices in the environment of nursing home in Singapore.

1. Introduction
For the elderly people, adequate environment to compensate for increasing frailty and sensory loss are essential. Normal age-related changes to the eye decrease the amount of light reaching the retina impacting both vision and circadian rhythm. While typical nursing homes provide insufficient lighting, nursing home residents with greater visual impairment perceive far less bright light exposure for circadian rhythm. That leads to the increase of residents falls, hip fractures, daytime behavior and sleep problems, etc. Nonetheless, how to translate the HCL concepts proven in laboratory studies into built environments, including hospitals and nursing homes, are still in early stage and lack of largely proven practices and strategies on an operational level. Specifically, the necessary requirements for the
development and effectiveness of control system for HCL in nursing homes have not been formulated in a rigorous and reliable manner.

To date, the designs of lighting systems in nursing homes are primarily made to support visual acuity for staff and secondly to minimise hazards such as staircases. However, to obtain proper visual sharpness and better contrast people of older age require heightened light levels due to age-related failing vision. Furthermore, the nursing home environments are often purpose-made for hygiene, cleanliness and safety and ignore that light sources produce substantial glare due to shiny floors/surfaces and inappropriate light at night disrupts not only sleep but also the timing of the body clock, with negative consequences for cognition and emotions. Properties of current lighting systems are inflexible and not designed to take non visual effects of light into account for older people's wellbeing in nursing homes. In the last two decade, much has been learned regarding the non-visual effects of light on human circadian entrainment. Light synchronizes physiological and psychological rhythms to the 24-hour rhythm of the environment [1][2]. Light has also acute alerting and activating effects [3], can affect mood [4], and, when applied at night, suppresses melatonin production [5]. These are some examples of the non-visual effects of light in humans. Studies of the bio-logical clock have shown a reduced neuronal activity in the SCN of the elderly, especially after the age of 80 [6], and reduced circadian rhythm amplitude after the age of 50 [7]. This suggests that, at a molecular level, the SCN becomes less responsive to entrainment stimuli such as light-induced neural signals from the retina. Further, it is suggested that some of the neural processes involved in the entrainment process might be dysfunctional or less effective as we age [8]. Thus, the elderly (specifically those with dementia) commonly suffer from mental and behavioural disorders, such as sleep disturbances, agitated behavior, depression, and risk of falls. Studies [9-16] have shown that light therapy supported by professional lighting control system can effectively offset these issues and add to the quality of life (e.g. consolidate rest/activity patterns, improve sleep efficiency, cognition, reduce symptoms of depression and alter the levels of aggressive behaviors) to the elderly with dementia in spatial and temporal dimensions. How to translate the HCL concepts proven in laboratory studies into system implementation in real built environments, including hospitals and nursing homes, are still in early stage and lack largely proven practices and strategies on an operational level [17-18]. There are few past and ongoing pilot research and development efforts that have partially addressed certain aspects of the concerns of this current proposal. Such precedents include Rigshospitalet, Psychiatric Centre Copenhagen: Research project on Ergonomic Circadian Lighting in psychiatry [19], Gateway- evaluating a trial LED Lighting System at the ACC Care Center in Sacramento, CA [20], Elderly Care Home in Solingen Germany [21], and Improved quality of life for resident dementia patients: St. Katharina research project in Vienna [22]. In these projects, companies in lighting industry (e.g. OSRAM, Philips Lighting, Zumtobel) worked closely with the academia and healthcare institutes. In this study, we aim to develop and implement a set of advanced human-centric lighting control strategies to improve the comfort and care of seniors, assist the nursing staff in their nightly rounds, and help residents navigate facility hallways via customizing light exposure scenarios for the residents and staffs.

2. Approach

2.1. Description of the case study area
This pilot study was conducted in a selected residence at level one of the Salvation Army Peacehaven Nursing Home in Singapore. This residence is an entry-controlled area with natural ventilation, including 3 six-bedded rooms, 3 single-bedded rooms, 1 activity room, 8 toilets, and corridor [Figure 1]. There are 21 senior residents with mild dementia resided in this area. In this residence, the lighting system will be retrofitted from conventional 24W CFL lamps with fixed CCT level (i.e. 4700K) to 10W advanced tunable-white LED (2700K to 5000K; UGR<19; beam angle: 40) [Figure 2]. In addition, the smart lighting control system has been installed to allow for individual luminaire control by mobile app via Bluetooth-based mesh network.
2.2. Pre-implementation assessment
The control strategies together with user scenarios was developed. The questionnaires for pre-/post implementations was approved by the IRBs of Singapore Institute of technology and the Salvation Army Peacehaven Nursing Home. We selected 7 locations as reference points for the session of on-site measurement. Also, the illuminance meter (Gossen Mavolux 5032) was used to measure the illuminance in selected reference points.

2.3. Benchmarking of available strategies
This step addresses the benchmarking of available strategies in view of different space categories through the lighting simulation tool- ElumTools, as a plugin of Autodesk Revit. Such considered spaces include corridor, single/6-bedded rooms, and activity room. The preliminary simulations were conducted to compare the visual performances of the scenarios with existing CFL and the ones with selected tunable white luminaires.

2.4. Human-centric lighting implementation and fine-tuning
This step includes the installation of the advanced tunable LED luminaire control system in selected site. This system comprises IoT-based tunable LED luminaires with plug-and-play capability, user-friendly interface (involving embedded multiple control interface in smart devices and re- use of wall switch), and advanced sensing technologies (e.g. human motion, movement direction, motionless occupancy, fallen human detection, high temperature). Also, preliminary human centric lighting strategies were implemented, tested, and commissioned [Figure 3]. The installation and commissioning period was from 1 June to 15 August 2018. After this step, the settings with new control strategies were operated for two months from 15 August to 15 October.
Figure 3. The control scenarios involving luminance output and CCT appearance in the bedded rooms (A), the activity room (B), the corridor (C), and the toilets (D)

2.5. Post-implementation assessment
In this step, we verified and validated the performance of the human centric lighting strategies via post-implementation user surveys. The previous-selected 15 nursing staffs, as participants, conducted the user surveys again to provide their feedbacks and investigate the residents perception variables in view of visual comfort level of the residents and staffs based on the observation during the operation period. The user survey was conducted in from 15 to 31 October, 2017. Also, we measure the illuminance level in selected 7 reference points via the illuminance meter (Gossen Mavolux 5032).

2.6. Data analysis and discussion
In this step, we analysed the collected survey data via Two Tailed T-Test and then discussed the results.

3. Results and Discussion
The data analysis involved: (i) preliminary simulation-based evaluation, (ii) on-site illuminance comparison based on pre-/post retrofitting, and (iii) discussion based on pre-/post installations user questionnaires.

3.1. Preliminary simulation-based evaluation
The BIM model of the selected residence was built in Autodesk Revit for carrying out a set of simulation with its advanced lighting plugin-ElumTools. Specifically, we evaluated the results of selected areas for further assessment, namely one six bedded room, one toilet, the corridor and activity room. Figure 4 and Figure 5 illustrate the an example of the simulation results pertaining to illuminance distributions of existing CFL luminaire and proposed retrofitted LED with four levels (i.e. 100, 50, 30, 10 percent) and CCT value 2700K at the floor and reading levels (0cm and 85cm) in selected six-bedded room and the corridor. The results suggest that the proposed retrofitted tunable white LED has a significant visual performance with higher uniformity compared with pre-installation scenario.
Figure 4. A set of simulation results involving pre-implementation scenario (A) and four sets of post-implementation scenarios with four levels (i.e. 100, 50, 30, 10 percent) and CCT value 2700K at the floor level (0cm), namely (B), (C), (D), (E); unit: lx

Figure 5. A set of simulation results involving four sets of post-implementation scenarios with four levels (i.e. 100, 50, 30, 10 percent) and CCT value 2700K at the reading level (85cm), namely (A), (B), (C), (D); unit: lx

3.2. On-site illuminance comparison

In this section, we compared the illuminance measurement data measured at 8pm in two selected days (with pre/post-installation scenarios respectively) in this residence. As previously mentioned, we have selected two reference points in one six-bedded room (B1, B2), two points in the corridor (C1, C2), two points in the activity room (A1 and A2), and one point in the selected toilet (T1) [see Figure 6]. The comparison results are arranged in following tables in accordance with the previously described spaces, namely bedded room, toilet, corridor, and activity room [see Table 1].

Figure 6. The locations of the measurements points with height information
Table 1. Measurement results in the bedded Rooms, toilets, corridor, and activity; unit: lx

| Ward/bedded room | Scenarios | Previous | Retrofitted |
|------------------|-----------|----------|-------------|
|                  | Period    |          |             |
|                  | Output    | 100%     | 75%         |
|                  | CCT       | 4700K    | 3500K       |
| B1               | Eh        | 21       | 26          |
|                  | Ev        | 18       | 22          |
| B2               | Eh        | 25.8     | 18.7        |
|                  | Ev        | 16       | 13.6        |
| Corridor         | Scenarios | Previous | Retrofitted |
|                  | Period    | 0-24h    | 08-13h      | 14-18h | 17-5:30h |
|                  | Output    | 100%     | 100%        | 92% | 92%       |
|                  | CCT       | 4700K    | 5000K | 3500K | 2700K     |
| C1               | Eh        | 40       | 380         | 245 | 216       |
|                  | Ev        | 18       | 199         | 122 | 109       |
| C2               | Eh        | 42       | 220         | 135 | 105       |
|                  | Ev        | 56       | 85          | 54  | 46        |
| Toilets          | Scenarios | Previous | Retrofitted |
|                  | Period    | Ad hoc basis |          |
|                  | Output    | 100%     | 91%         |
|                  | CCT       | 4700     | 3500K       |
| T1               | Eh        | 28.4     | 191         |
|                  | Ev        | 56.1     | 107         |
| Dinning/Activity Room | Scenarios | Previous | Retrofitted |
|                  | Period    | 0-24h    | 8-13h | 14-18 | 17-20 | 20-21h | 21-5:30 |
|                  | (Ad hoc basis) |          |          |          |          |          |          |
|                  | Output    | 100%     | 110% | 100% | 100% | 100% | 100% |
|                  | CCT       | 4700     | 5000K | 3500K | 2700K | 3500K | 2700K |
| A1               | Eh        | 75       | 582       | 600 | 515 | 600 | 515 |
|                  | Ev        | 33       | 111       | 115 | 92 | 115 | 92 |
| A2               | Eh        | 92.7     | 170       | 156 | 120 | 156 | 120 |
|                  | Ev        | 28.8     | 73        | 69  | 52 | 69  | 52 |

3.3. Discussion
The results of the above-mentioned sessions (i.e. section 2.2 and 2.5) involving 15 participants were analysed in terms of three categories pertaining to: (i) lighting experiences, (ii) feedbacks and (iii) investigation of the residents perception variables in temporal (i.e. day and night) and spatial (involving bedded room, corridor, toilet, and activity room) approach based on their observation. Thereby, the five-
point qualitative Likert scale of the questionnaire was further converted to numerical values (from 1 to 5). Initial results of the analysis if these sessions are given in the following Figures as mean values. In addition, we conducted two tailed t-test to better evaluate the significant difference between pre and post-retrofitting data. Figure 7 (mean values) compares the evaluation results regarding their lighting experiences in bedded room. As the results shown in Figure 7 imply, HCL solution in our study provides the participants with significantly pleasant lighting experiences in bedded room. HCL solution fairs better than CFL in terms of the categories of natural and bright lighting experiences. Figure 8 shows a comparison of their and residents (via observation) perceptual attitudes in bedded room. As the results shown in Figure 8 imply, the residents are slightly easier to move around during the night. Also, the residents slightly prefer warm white for the colour appearance of the lighting in the bedded room during the night. The nursing staffs are slightly more satisfied with the visual environment at night.

Figure 9 and Figure 10 compare the results involving lighting experiences perceptual attitudes in the corridor while Figure 11 and Figure 13 do the same for the activity room. As the results shown in Figure 9 imply, HCL solution in our study provides the participants with significantly natural and strong lighting experiences in the corridor. HCL solution in our study provides more pleasant and bright lighting experiences in the corridor. The results show that staffs and residents are with AGREE ratings regarding the sufficient and uniformed brightness of the lighting during the day and night. As the results shown in Figure 10 indicate, the residents and staffs significantly prefer cool white in the corridor during the day. Also, residents slightly prefer warm white during the night while the staffs significantly prefer warm white during the night. As the results shown in Figure 11 imply, HCL solution provides the participants with significantly more monotonous lighting experiences in activity/dining room. HCL solution fairs better than CFL in terms of the categories of natural lighting experiences. As the results shown in Figure 12 imply, the staffs significantly prefer warm white for the colour appearance of the lighting in the activity room during the night while the residents remain neutral. The residents are slightly more comfortable with light conditions in activity room thru the whole day. The residents slightly prefer cooler white during the day. No significant difference for task performance of residents during the day and caregivers during the night. Figure 13 related to the comparison of their and residents (via observation) perceptual attitudes in the toilet. The participants left AGREE ratings in terms of the clear path to the toilet due to the sufficient brightness of the HCL lamps through the whole day. The participants are with neutral rating in terms of warm white for the colour appearance of the lighting in the toilet during the night. As the results shown in Figure 13 portray, the residents significantly prefer cool white for the colour appearance of the lighting in the toilet during the day. Also, the glare has been slightly restrained.

Figure 7. Light experience in the bedded rooms (Mean values, N=15);*p<0.05

Figure 8. Evaluation results related to the perceptual attitudes in the bedded Rooms (Mean values, N=15)
3.4. Limitation
In our research efforts, computational lighting simulations and empirical measurements were successfully applied for the comparative studies. However, the results could be further compared for all the spaces instead of selected rooms and reference points. Also, in order to better evaluate the impacts of HCL lighting, the supplementary data (involving the body health) of the senior with mild dementia collected via FDA-approved wearable devices could be included in future studies.

4. Concluding Remarks
As the regular circadian rhythm is timely required for those senior with mild dementia and nursing staffs with long-term working hours, it is necessary to specify the circadian practices in the nursing homes based on our findings in previous sections, whereby two primary focus strategies are discussed as follows. Firstly, the effective methods to maintain the circadian rhythm should be further explored. Such example includes the optimization of natural light levels with the replacement and/or supplement of electric lighting to artificially stimulate the human circadian system. Thus, the natural light and dark cycles are enhanced to facilitate sleep while natural light spectrum shift with the supplement of artificial...
lighting over the 24 hours are conducted. Potential applicable spaces in the nursing homes include ward bedded rooms, non-work related windowless environments, common areas, communal environments where relaxation is emphasized. In addition, for such gloomy space with poor daylight penetration, advanced dynamic lighting control systems could be applied to artificially emulate a cycle of dynamic light with natural color shifts timed for circadian support. Also, it may be applied to provide tunable wavelengths of enhanced blue or white light for the purpose of enhancing performance and eliciting specific behavioral outcomes. Potential applicable spaces in nursing homes comprise nursing stations, dispensing pharmacy point, windowless office environments, night shift work areas, and residential settings for better sleep quality management.

This research efforts contributed to above-mentioned two focus strategies. The presented paper demonstrated the preliminary study of a design strategy for HCL systems in nursing homes. Firstly, state of the art HCL and aging studies were discussed. We then captured the views to illustrate the preliminary HCL design strategies in a tropical nursing home, whereby the quantitative and qualitative approaches were considered. The preliminary design strategies were developed and exemplified in a selected nursing home in Singapore. Also, pre-/post implementation user surveys together with quantitative evaluations (involving horizontal and corneal illuminance measurements) were conducted for assessing the performance of the HCL design strategies. These pilot study findings provide initial insight into HCL design-related knowledge and serve as the solid basis towards the HCL best practices in the environment of nursing home in Singapore. For future phases of this research, we will make an attempt to further articulate current effort toward the implementation of HCL for a diversity of space and building types in the Tropics.

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