Circadian House: a vision for homes designed to be healthy and human-centric

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ABSTRACT

Based on a series of workshops, a Circadian House is defined as a house that is designed to support a healthy life for its occupants through a human-centric design. The workshops were held in 2012-2013 and defined 3 key principles and ten key factors to consider in the design of homes.

KEYWORDS

Residential buildings, health, indoor climate, circadian rhythm

1 INTRODUCTION

Much focus on sustainable buildings has been on energy aspects. However, health is the most precious resource we have, and energy is only one aspect of sustainability. A primary goal for sustainability should be to sustain good health and a healthy living environment. This was the starting point for a series of workshops with international experts initiated by the VELUX Group, based on a wish to start a discussion on how to create healthier homes.

The result is a vision to realize healthy homes that support the different biological needs of their occupants, in particular including their circadian rhythms, sleep-wake cycles and preferences for temperature and fresh air, as well as the relation to the outdoor environment.

Three key principles were identified: Live in balance with nature, Adaptability and Sensibility. Ten key factors further go a step further: Variation, Stimulation/absence of stimulation, Outdoor/indoor relation, Light/darkness, Electrical lighting, Cool/warm, Silence/sounds, Rest/activity, Control and Flexibility related to seasons.

The principles and guidelines presented here can be used to guide and improve the design of residential buildings of all types, including apartment buildings, and are applicable to both new and existing dwellings (Circadian House, 2013).

2 METHODS

In the context of this paper, a Circadian House is understood as a dwelling that promotes health by synchronising the circadian rhythms of its occupants to the 24h day-night cycle and the seasonal changes of day length.

This paper is based on discussions and findings of 5 workshops; “Light and circadian rhythms”, “Indoor climate”, “The historical perspective”, “What to monitor and how” and “Condensation of the specifications” (WS 5). The workshops were carried out by scientists and consultants specialized in healthy buildings, indoor environment, architecture and planning from November 2012 to August 2013. See the Acknowledgements section.

3 RESULTS

It is not possible to include all results in this short paper. In the following we will highlight selected key results organised around a selection among the ten key factors.

3.1 Contact to nature

Dwellings should have at least one outdoor or semi-outdoor space (e.g. a garden, terrace or balcony) that provides direct contact to nature. Research studies show that improved mood and reduced stress are consistent benefits of living in close contact with nature (Veitch and Galasiu, 2012).

Outdoor spaces must be treated as an extension of the house and designed to inspire the occupants to spend as much time as possible outside, offering a close contact to nature in all seasons of the year. Outdoor spaces should be designed for a variety of activities such as dining, playing, working, relaxing etc. People affected by the seasonal changes in day length will benefit from extra exposure to high levels of daylight in outdoor and semi-outdoor spaces. Also, exposure to daylight and sunlight outside allows our body to produce vitamin D, which people in modern societies often lack due to the large amount of time spent indoors. Balconies and terraces should be shielded from wind and have good connections to relevant rooms of the house in order to maximise their use.

3.2 View to outside

Views to the outdoor surroundings are crucial in order to maintain contact with nature and satisfy our needs for orientation in time and place while indoors. There is clear evidence of the benefits of window views, particularly views offering contact to life and nature. A good view can have restorative benefits (leading to e.g. stress relief) and sometimes even result in quicker recovery time after illness and less post-surgery pain medication.

It is important to analyse view content on-site and make sure that all main living and activity rooms in the house have generous views to the sky and ground, and to natural and/or urban landscapes around the house. Shading systems should be designed so that adequate views to the outside can be maintained in the rooms even at moments when it is necessary to block direct sun penetration. To this effect, it is important to consider proper control of sunlight in summer (Kaplan, 2001; Kellert, 2008).

3.3 Healthy Light

Light is used by individuals for image forming light detection (vision) under a range of varied lighting levels and for a variety of non-image forming light detection (non-vision) tasks including as a daily time cue for sleep timing and as a modulator of levels of alertness. In addition, there is increasing evidence that human biology can be affected by changing light levels across the seasons. Seasonal depression has been linked to reduced light exposure in winter, whilst vitamin D synthesis requires light exposure around 300nm in the UV range and attenuated levels of vitamin D have been linked to increased vulnerability to both developmental and somatic diseases in adults (Wirtz-Justice et al 1996). It should also be noted that UV light also has strong germicidal actions that can prevent the spread of some diseases in buildings. The principles and guidelines for Healthy Light should incorporate all of these divergent biological roles of light. How our biology responds to light intensity, spectrum, timing, duration and its spatial distribution is highly complex and varies greatly between image- and non-image forming light detection tasks (Boyce et al., 2003; Brainard & Veitch, 2007).

Healthy lighting should consider the following factors:

- The total daily light dose, which varies between individuals and as we age;
- Healthy light is linked to healthy darkness at night;
- Light sources with a broad daylight spectrum;
- Light received at eye level;
- Levels of UV-rich light reaching the skin;
- Timing, variation and duration of light exposure over the day and across the seasons

The dynamic variation of light is a critical factor in setting and maintaining our 24h daily rhythms – our circadian rhythms, which in-turn play a key role in the regulation of the sleep/wake cycle. Sleep disruption has been linked to poor cognitive function, stress, depression, poor social interaction, metabolic and cardiovascular disease, and an increased susceptibility to infection and even cancer. As a result an appropriate light signal during the day and darkness at night are critical in maintaining key aspects of our overall health. Outdoor daily light exposure allows us to regulate our sleep/wake timing, levels of alertness and the synthesis of vitamin D. The reality is, however, that we spend most of our time indoors where we are exposed to relatively low light levels of a limited spectral range, and where the patterns of light and darkness occur at irregular intervals. Until recently in the history of our species, the dwelling space was used primarily as a space for sleep with most activities taking place outside. Today, work, entertainment, socializing, eating and sleep all take place in the same or similar physical spaces. Collectively, the consequences of poor light exposure and the subsequent impact upon health are placing a substantial burden on the individual, society and the broader economy.

In order to align our body clock, morning light is the most important signal for entrainment. Light in the morning also increases our levels of alertness, allowing increased performance at the beginning of the day. Whereas reduced light levels in the evening promote sleep at night. For those times when seasonal daylight is not available in the morning, electric lighting can be used to support our non-visual light needs; mimicking the morning, daytime and evening periods in spectrum, intensity and dynamics. Although much is still unknown about the specifics of how light interacts with our non-visual light systems, the data we have already can be used to suggest some important approaches to the nature of daily light exposure:

- The intensity of light should provide opportunities for exposure to high daylight levels at the level of the eye, within the range of more than 1,000 lux up to around 5,000 lux, and should be designed to minimize visual discomfort.
- The light dose per day exposed to >1,000 lux should on average be more than 200 minutes with high intensity boosts, especially, in the morning.
- Good spatial distribution of daylight and sunlight is achieved by distributing windows in multiple external walls and the roof rather than placing them with only one orientation.
- Daylight with minimal spectral filtering should be delivered at those times of day when it is most needed for circadian regulation.

- A dwelling should follow the natural cycle of light and dark exposure - allowing high exposure to daylight in rooms used in the morning and in the main activity rooms used throughout the day, and complete darkness in the bedrooms at night.
- It is important to carefully consider exposure to darkness during the sleeping periods – as circadian and alertness regulation requires both light and dark periods over the day.

3.4 Healthy Indoor Air

Opening windows brings in fresh outdoor air and provides contact to the outside and rapid changes of indoor air quality. It allows you to sense changes in weather during the day and over the year. Contact to the outside is important for the well-being of occupants in residential buildings.

Airings should be a part of the daily cycle. It is executed by many families and associated with wellbeing, comfort and health. Operable windows ideally should be combined with a general system for basic fresh air supply using ventilation grilles in the facades or mechanical ventilation.

Opening windows provides the occupants with an immediate change in the indoor environment, i.e. with a direct effect on air temperature, air velocity and air change rates. Efficient airings can be achieved by having more than one operable window and by locating these windows towards different orientations or at different heights in each main room. There should also be good options for cross and stack ventilation between rooms through the building.

Ventilation devices should be designed in such a way that occupants can prioritize privacy and silent operation when they prefer minimum sensory stimulation, e.g. during night time, but without compromising the basic requirements for ventilation. Control of the systems (and the momentary fresh air supply) is important. For more information about control of ventilation, see also under ‘building controls’.

Many indoor air pollutants often present in dwellings cannot be sensed by humans and the house should, therefore, offer protection from these ‘stealth pollutants’. To minimize adverse health effects from indoor air pollution, the primary strategy should be source control.

The kitchen can be the most affected room due to the pollutants (particles, NOx, etc.) emitted from the stove and oven when cooking. The negative health effect is increased if the kitchen is in open connection with the dining area, as exposure to cooking-related particles are not limited to the kitchen area in that case. The most effective means of reducing pollutant exposure from cooking is by using an efficient cooking hood and ensuring that it will be turned on and in use whenever the kitchen is used for cooking. The cooking hood should be sufficiently quiet so that it does not annoy the occupants, but should be audible so that it is not forgotten.

In kitchens and bathrooms, exposure to (excess peak levels of) moisture is also an issue. Well-functioning ventilation systems and adequate cooking hoods also take care of that.

Note that periodical exposure to pollutants in small and non-harmful doses, particularly as a child, will decrease the risk of developing allergies at a later stage in life. The effect is referred to as the hygiene hypothesis and is related to the functioning of the immune system.

3.5 Healthy Thermal Environment

Preferably indoor temperature varies over the course of the day, in parallel with the outdoor temperature, which typically increases during the day and drops during the night. The indoor temperature should also follow the seasons (with limitations, of course), with minimum levels during the winter and maximum levels in summer (Brager and de Dear, 1998).

Solar gains through windows have a large impact on the indoor temperature and should primarily be controlled with shading. Solar gains provide spatial variation of temperature in the rooms with local warm and cool spots. During winter with little solar gains, a local 'hot spot' should be provided for in e.g. the living room, typically with a high temperature (vertical) radiant heat source. This 'hot spot' allows the occupants to seek a warm or cool position in the room that suits them and may thermally differ from the position of others in the same room. This 'hot spot' can look like a fireplace or gas stove in older houses, but then in a modern form without the air pollution side effects, e.g. hot water based local heating systems.

Architectural spaces should ideally promote people to have an active and healthy lifestyle, as opposed to being more passive. A thermally comfortable environment is not necessarily one that favours physical health. An example is a study (Lichtenbelt & Kingma, 2013), which showed that for persons exposed to an indoor temperature at the low end or even just below the comfort range, non-shivering thermogenesis is activated which leads to increased metabolism. It is thus a quality of the indoor environment if there is some temperature variation and temperatures in winter are a bit on the cold side (and in summer on the warm side).

In summer the main issue is to keep the dwelling cool and avoid too high temperatures from excess solar gains. Overheating can normally be avoided by the use of solar shading and natural ventilation through window openings. Additional summer ventilation can be achieved by cross ventilation or stack ventilation (e.g. with windows and/or skylights in adjacent walls/roofs). Bedrooms are particularly important and must be designed and located to minimise overheating, e.g. by choosing a north/east location.

3.6 Building controls

It is important that the functioning of control systems is transparent and comprehensible for the occupants and they can easily adjust the interior daylight levels, electric lighting, temperature, fresh air supply etc. according to their personal needs. Automatic systems are often of advantage, but always see to it that easy-to-use options to override the systems are available. Feedback indicators on e.g. indoor air quality and temperatures (telling you that the systems have understood that you want some kind of change and giving you information about the current status of e.g. temperature, CO_2-levels, etc.) are a plus as they help occupants to use the building service systems 'as intended'.

It is important that many indoor climate parameters can be controlled at the individual room level, not just at building level. Automated control strategies that work in one kind of room may not work in other room types.

Control strategies, where possible, should support the circadian rhythms of residents. For example, the control strategy for electric lighting could include light sources with varying spectrum and intensity enabling programming according to time of day and type of room. Also, e.g. heating systems could be programmed to anticipate daily temperature changes.

A building control system needs to be robust toward different kinds of occupant use, toward failures/problems of parts of the systems, toward incorrect design assumptions (e.g. number of persons per room) and against occupant misuse.

At least, the following systems require some central control in combination with manual override options and an interface:

- Mechanical ventilation systems;
- Heating systems;
- Window opening systems;
- Solar shading systems;
- Electric lighting systems.

4 DISCUSSION

During the workshops, several fundamental questions were asked about the link between housing quality, indoor environment, circadian rhythms and health. Questions like: Can a house really support circadian rhythms? Not by just providing for the adequate amount of daylight given the time of day, but also, e.g. by allowing indoor temperatures to follow (to a certain extent) the variation in outside temperatures. Can a building's design really support a healthy and active lifestyle? And how can the indoor environment in our homes promote comfort and wellbeing, rather than just maintain acceptable indoor conditions? In the 1860s, Florence Nightingale identified five essential points in securing health in dwellings: pure air; pure water; efficient drainage; cleanliness; and light, especially sunlight. "Do not build good hospitals, build good homes" is her famous quote (still very true).

5 CONCLUSION

Based on the discussions, the core elements of a Circadian House have been identified under 3 key principles and 10 key factors.

5.1 Key principles

- Live in balance with nature - A house in balance with nature allows the occupants to live with and follow the daily and seasonal cycles of the outdoor environment.

- Adaptability - A house whose space and occupants can adapt to changing conditions (daily, seasonal) and needs.

- Sensibility - A house that provides protection against harmful substances, which humans cannot sense, and allows freedom to control parameters that can be sensed.

5.2 Key factors

- Variation: the focus on nature's cycles implies that the indoor environment should vary in time and space rather than target uniformity or non-variability.

- Stimulation/absence of stimulation: The level of stimulation from environmental factors (light, sound, air, temperature) should be higher during day than night.

- Outdoor/indoor relation: Outdoor and semi-outdoor areas are designed to be inspiring and easily accessible; and occupants are able to follow (changes in) outdoor conditions in all main living areas of the house.

- Light/darkness: Exposure to high levels of daylight are needed in the main living areas of the house during daytime, with special attention to the rooms that are mainly used in the morning, whereas the bedrooms need to provide complete darkness at night time.

- Electrical lighting should follow, support and supplement change and variation in the light spectrum and intensity through the course of the day and distribution in space.

- Cool/warm: The house should provide temporal and spatial variation in the thermal environment that are logical (and e.g. follow – to a certain extent) outside temperature variations.

- Silence/sounds: The presence of sound and contact to sounds from outdoors are desired during daytime, whereas quiet spaces are needed at night time.

- Rest/activity: The house design should inspire the occupants to be active, but also have areas for rest and restitution.

- Flexibility related to the seasons: the use of outdoor and semi-outdoor spaces should be stimulated outside the heating season.

- The occupants should be able to control the systems that influence parameters that can be sensed, e.g. like lighting level, air quality and indoor temperature.

6 ACKNOWLEDGEMENTS

The work is based on workshop discussions and correspondence with the following, without whom there would have been no Circadian House specification. Anna Wirz-Justice, University of Basel, Switzerland; Anne Helene Garde, National Research Center for the Working Environment, Denmark; Atze Boerstra, BBA Binnenmilieu, The Netherlands; Dean Hawkes, University of Cambridge, UK, Francis Allard, University of La Rochelle, France, Hal Levin, Building Ecology, US, Jelle Laverge, University of Gent, Belgium, Koen Steemers, University of Cambridge, UK, Luc Schlangen, Phillips Lighting, The Netherlands, Mariëlle Aarts, Eindhoven University of Technology, The Netherlands, Nick Baker, University of Cambridge, UK; Ole Bouman, Biennale Shenzhen; Pawel Wargocki, Technical University of Denmark; Per Olaf Fjeld, University of Oslo, Norway; Richard Hobday, Independent researcher, UK; Russell Foster, University of Oxford, UK; Staffan Hygge, University of Gävle, Sweden; Thomas Witterseh, Danish Technological Institute, Denmark; Truus de Bruin, Delft University of Technology, The Netherlands. The VELUX Group provided financial support for the workshops.

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