

**A presentation to the Institute for Work and Health, Toronto, ON
November 29, 2010.**

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In addition to being the stimulus for vision, there is increasing evidence that light influences biology and behaviour through other mechanisms. Laboratory studies, clinical evidence, and epidemiological studies are elucidating effects on hormone regulation, neurotransmitter function, and revealing behavioural and health effects not previously recognized. For instance, daytime light exposure influences both immediate social behaviours and night-time sleep quality. The evidence suggests that good health requires a minimum daily dose of light, although we do not yet know what the dose ought to be. The presentation will give an overview of recent research, give an indication of research gaps, and summarize possible implications for practical applications through workplace design, architecture, and individual light hygiene habits.

Biography:

Dr. Veitch is a Senior Research Officer in the National Research Council of Canada Institute for Research in Construction, where she leads research into the effects of the built environment on health and behaviour. Among her leadership roles in professional organizations, she chaired the International Commission on Illumination's TC 6-11 'Systemic Effects of Optical Radiation on Humans' to the first consensus report on the effects of ocular light on human physiology and behaviour, published in 2004. She is a Fellow of the Canadian Psychological Association, the American Psychological Association, and the Illuminating Engineering Society of North America.

NRC-CNRC

National Research Council Canada

- Developing and transferring knowledge to support innovation and commercialization
 - 24 research institutes & programs
 - 1 institute for construction sector
 - ~4000 employees across Canada
- Network of technology advisors to support small business
 - 260 industrial technology advisors in 90 communities
 - over \$125 M in support each year



http://www.nrc-cnrc.gc.ca/main_e.html

http://www.nrc-cnrc.gc.ca/main_f.html

NRC Institute for Research in Construction

NRC-CNRC

- Established 1947
- Guided by industry advisory board & 2 independent commissions
- Facilities in Ottawa, Mississippi Mills, London, Regina
- ~\$30 million annual budget
- ~250 employees
+ ~15-20 visiting workers



http://irc.nrc-cnrc.gc.ca/index_e.html

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NRC-IRC Activities

NRC-IRC

- Research to address industry and government priorities:
 - Sustainability
 - Safety
 - Health and well-being
- Support for building regulatory system
- Evaluation of innovative construction products



Producing:

Technical knowledge - journal and conference papers

Decision tools - software and design guidance

Technology - patents and licenses

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NRC-IRC Research – Well-being

- ~ 90% of our time is spent indoors




- ~ 33% of waking time each week is spent at work



Research into health is centered in the Indoor Environment Research Program, which has three sub-programs. The subprogram staff also work together on multidisciplinary consortium projects.

Ventilation and Indoor Air Quality:

e.g., Managing emissions of VOC's - **Material Emissions Chamber** - used in the creation of Material Emissions Database and Software (IAQuest)

- database provides list of materials with their properties
- software developed to model the IAQ in a specific area (using parameters from the database)

Acoustics:

Anechoic Chamber- used in speech intelligibility tests, part of work on speech security and classroom acoustics

Lighting:

- Lighting quality and individual control over lighting - **lab** and field experiments
- Design tools: Daysim, Daylight 1-2-3, Skyvision

Consortium projects:

e.g., Cost-effective open plan environments (COPE)

IRC studied the impact of various design factors-lighting, acoustics (speech privacy), and ventilation and thermal conditions-on occupant satisfaction in open-plan offices. We used our **Indoor Environment Research Facility** for behavioural and engineering experiments, as well as a large field study of 779 workstations in 9 buildings in 5 cities (and other IRC lab facilities).

Outline

ARC-CARC

- A little biology
 - Photoreceptors beyond vision
 - Circadian rhythm effects
- A little psychology
 - Light dose , well-being, social behaviour
 - Therapeutic lighting
- A little lighting design & application

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Photoreception

- Different retinal receptors process visual and non-visual information.
- For example, some blind people show hormone responses to bright light exposure.
- This system seems to use a small number of widely-distributed retinal ganglion cells.

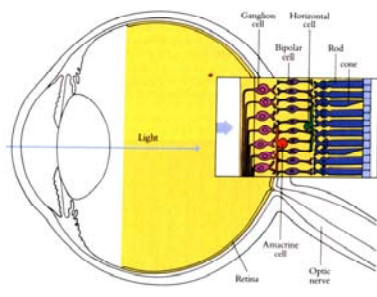


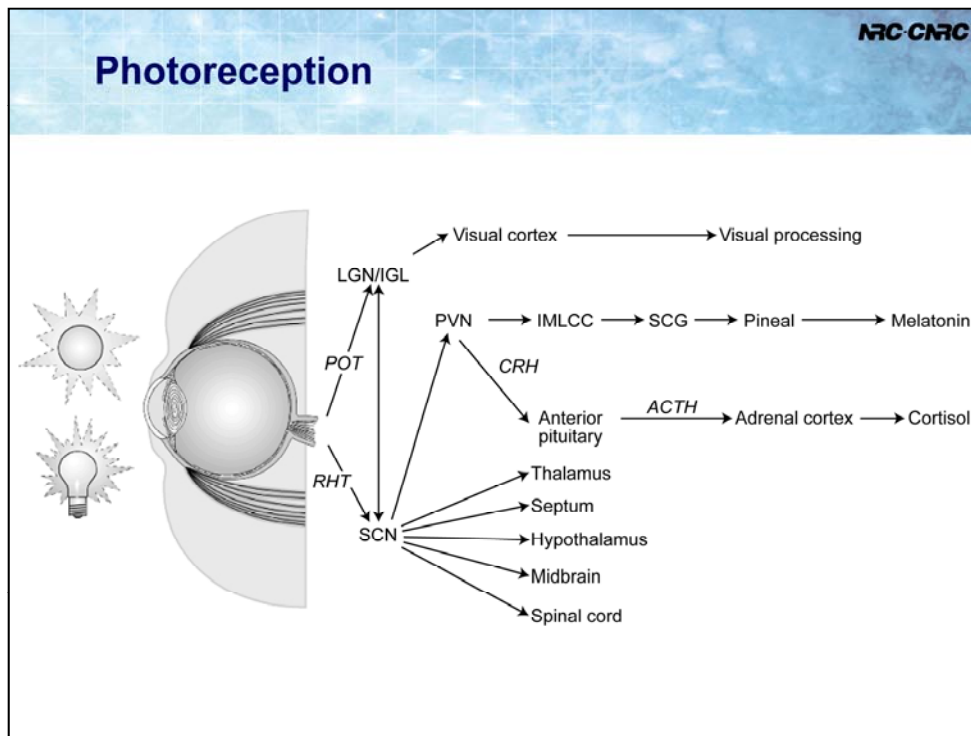
Image © IESNA, 2002

Biologists thought they knew all about light detection when they had identified rods (which operate in black-and-white and at low light levels) and cones (which detect colour and fine details, and operate only at higher light levels). The other cell types shown aggregate and begin to process visual signals before connecting together into the optic nerve.

The discovery of new photoreceptors set the photobiology world on its ear in 2001! We thought we knew everything there is to know about the retina: that rods and cones detect light and send signals to the brain that are decoded to produce visual perception.

However, it was found that some blind people (depending on the type of blindness) showed hormonal responses to bright light exposure. Scientists track the release of the hormone melatonin, which happens at night, in the dark; it can be suppressed by acute light exposure. Certain blind people can't detect the bright light - they can't tell you if they're sitting in light or dark - but yet, their melatonin could reliably be suppressed by light exposure at night, just like in sighted people.

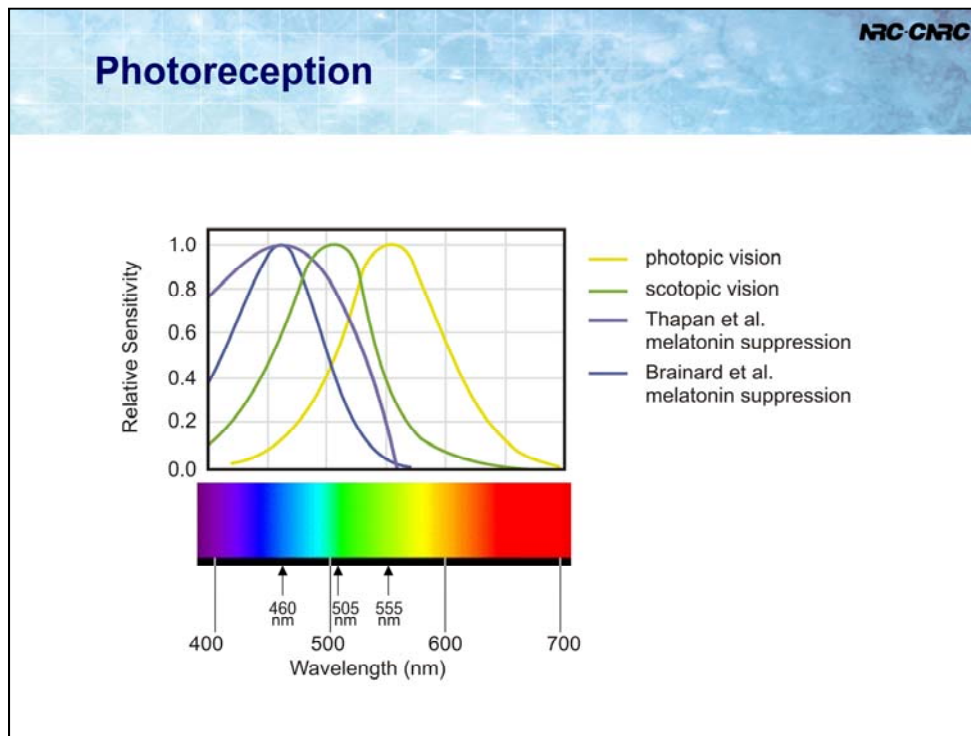
Following anatomical research and other functional studies, we now know that there is a separate set of retinal receptors, a special subset of the ganglion cells (intrinsically photoreceptive retinal ganglion cells, ipRGCs), that detects light and sends signals to the brain. It seems to be a small number of the cells, spread all over the retina.



The signals from these photoreceptors travel a complex route to various brain structures. This figure is from CIE 158:2004, and © CIE, 2009.

Schematic diagram of eye-brain pathways. Light received by the eye is converted to neural signals that pass via the optic nerve to two pathways, one visual and one non-visual. POT = Primary optic tract. RHT = Retino-hypothalamic tract. LGN/IGL = Intergeniculate leaflet of the lateral geniculate nucleus of the hypothalamus. SCN = Suprachiasmatic nucleus of the hypothalamus. PVN = Paraventricular nucleus of the hypothalamus. IMLCC = Intermediolateral cell column. SCG = Superior cervical ganglion. CRH = Corticotropin releasing hormone. ACTH = adrenocorticotropic hormone

Melatonin is the hormone that has received the greatest amount of attention. It's a key molecule in keeping physiological systems on schedule - it seems to start some things up, and slow others down - and it's released in darkness. Because of the dominance of research on this hormone, some people talk about "circadian effects of light", but really there is more to it than this.



What do the new photoreceptors do? They send signals about the presence of light to other brain structures. One of the keys to identifying these cells as being different from rods and cones has been to identify the action spectrum - that is, the response of these cells to different wavelengths of light. The response that has been chosen is the suppression of the hormone melatonin by light exposure at night. Two independent labs, using slightly different techniques, published the first curves at the same time in 2001. It's clear now that the peak response is around 460 nm - in the blue region of the spectrum - and that it's not the same as the response of the visual system (nor of any of its component photoreceptors, not shown). (The range 447 - 477 nm is the key area.)

Two proposed action spectra for melatonin suppression: Results from Brainard et al. (2001) and results from Thapan et al. (2001). Also shown: the scotopic and photopic visual efficiency functions, from Gregory (1977).

These findings are important because:

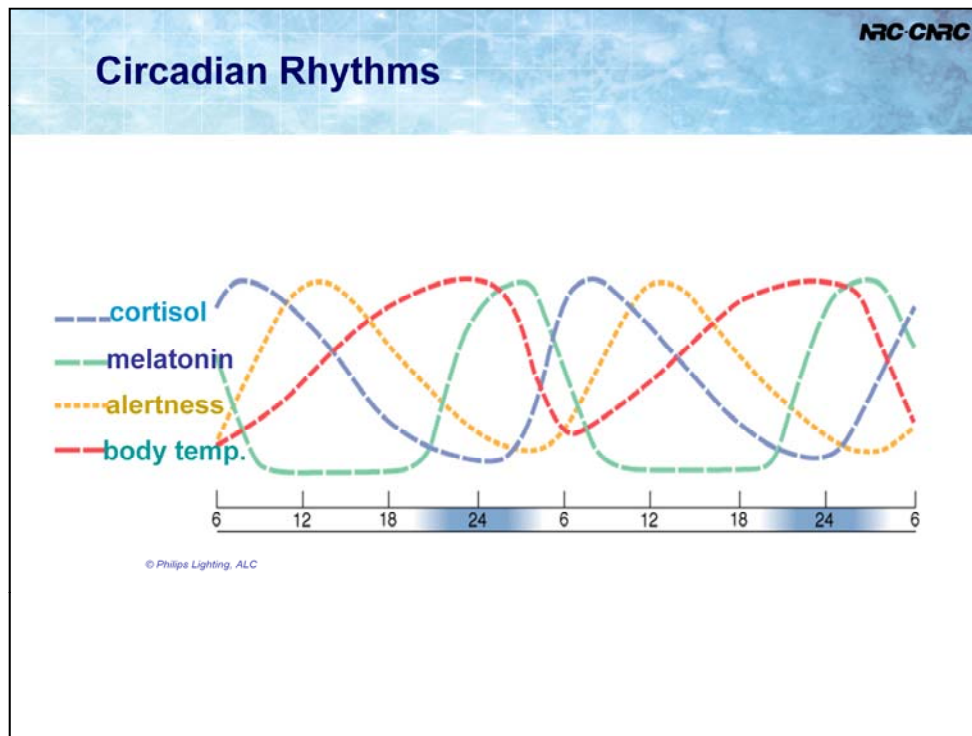
1. It further demonstrates that there's a separate sensory system for nonvisual effects.
2. It tells us that short-wavelength illumination is most potent for influencing the processes to which this signal extends.

References

Brainard, G. C., Hanifin, J. P., Greeson, J. M., Byrne, B., Glickman, G., Gerner, E., et al. (2001). Action spectrum for melatonin regulation in humans Evidence for a novel circadian photoreceptor. *Journal of Neuroscience*, 21(16), 6405-6412.

Gregory, R. L. (1977). *Eye and brain The psychology of seeing* (3rd ed.). Oxford, UK Oxford University Press.

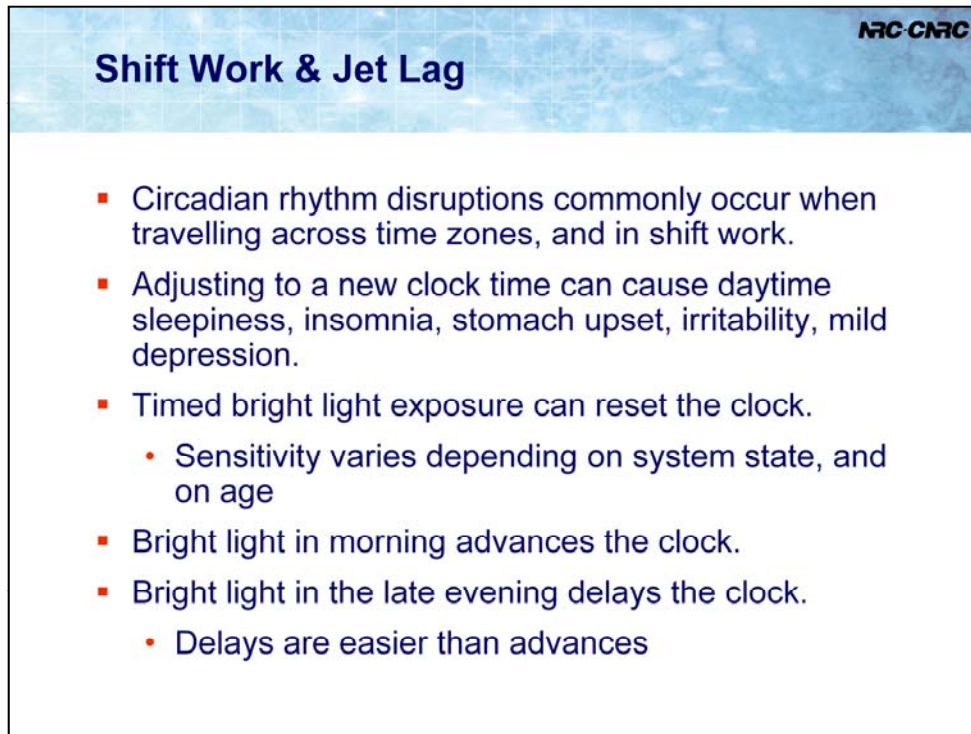
Thapan, K., Arendt, J., & Skene, D. J. (2001). An action spectrum for melatonin suppression Evidence for a novel non-rod, non-cone photoreceptor system in humans. *Journal of Physiology*, 535(Pt 1), 261-267.



This shows in a simplified way how various circadian rhythms vary. Note that the shapes as well as the timing of different events vary. We don't know everything about how these various cycles interact, nor are they the only ones we know of.

One important linkage that is very robust is the pattern of melatonin peak followed shortly by the nadir of core body temperature. This pairing is consistent even when the melatonin peak is shifted (e.g., by bright light exposure).

(This slide was given to me by Gerrit van den Beld of Philips Lighting.)



Shift Work & Jet Lag

- Circadian rhythm disruptions commonly occur when travelling across time zones, and in shift work.
- Adjusting to a new clock time can cause daytime sleepiness, insomnia, stomach upset, irritability, mild depression.
- Timed bright light exposure can reset the clock.
 - Sensitivity varies depending on system state, and on age
- Bright light in morning advances the clock.
- Bright light in the late evening delays the clock.
 - Delays are easier than advances

In this next set of slides, I'll talk about how these mechanisms might affect people who are basically healthy.

Many people experience uncomfortable symptoms such as daytime sleepiness, night-time insomnia, gastro-intestinal distress, irritability, mild depression and confusion, when their circadian rhythms are disrupted by travel, shift work, or sleep disorders.

For people working shifts that rotate rapidly, these can be chronic problems.

Other consequences are an increased error rate, memory disruptions, and cognitive confusion. The accident rate for people driving home from night shifts is higher than for other drivers.



Shift Work & Jet Lag

ARC CRC

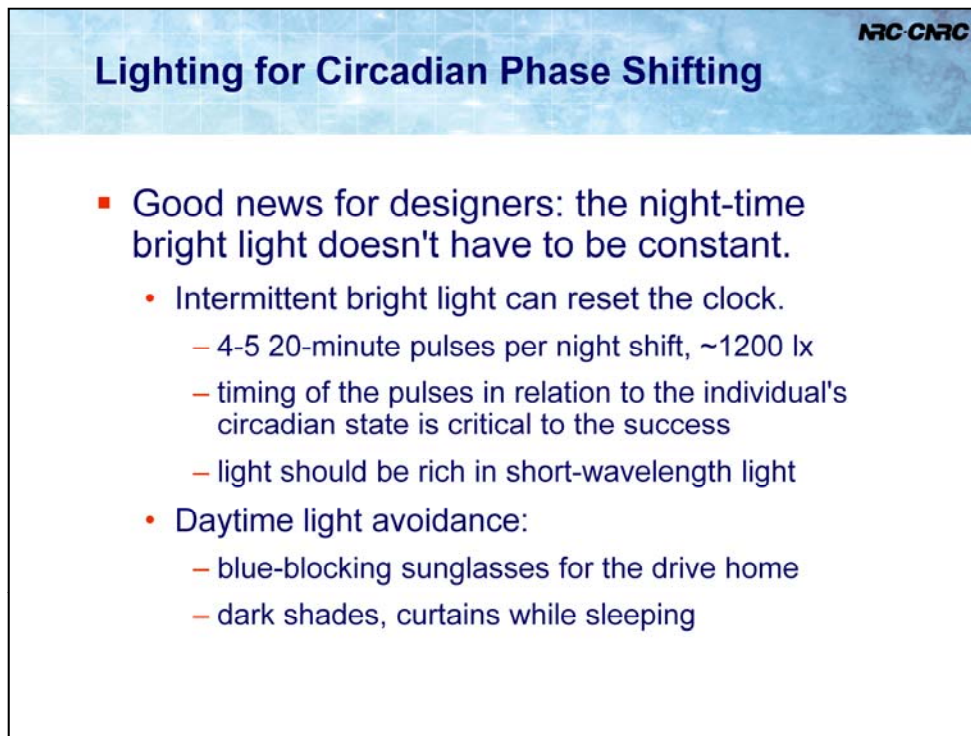
- Key principles to circadian phase shifting:
 - Bright light at night, before minimum core body temperature
 - Keep total daytime light intensity lower than working hours
- Permanent night shift is best - one can reset the clock
 - Rotating shift schedules prevent phase-shifting, leave workers with disrupted rhythms

Charmane Eastman and colleagues have presented a compromise schedule for permanent night shift workers. The bright light at work starts relatively early in the shift at the start of the week, then gradually pushes later and later. Behavioural compliance by the worker is part of the scheme; if they don't avoid light when the shift ends, it won't work.

Eastman, C. I., & Martin, S. K. (1999). How to use light and dark to produce circadian adaptation to night shift work. *Annals of Medicine*, 31, 87-98.

The authors, who are not alone in this recommendation, say that from a phase-shifting perspective, a permanent night shift is best (even more so if you can keep the schedule during days off and vacation, but few do). They are especially critical of rapidly-rotating shifts because the worker is never appropriately phase-shifted. This is especially dangerous for critical positions such as nuclear control rooms, or critical-care nursing, where errors are potentially fatal.

Note: this phenomenon is the same as the experience of jet lag, for which there are also solutions based on timed light exposure and light avoidance.



Lighting for Circadian Phase Shifting

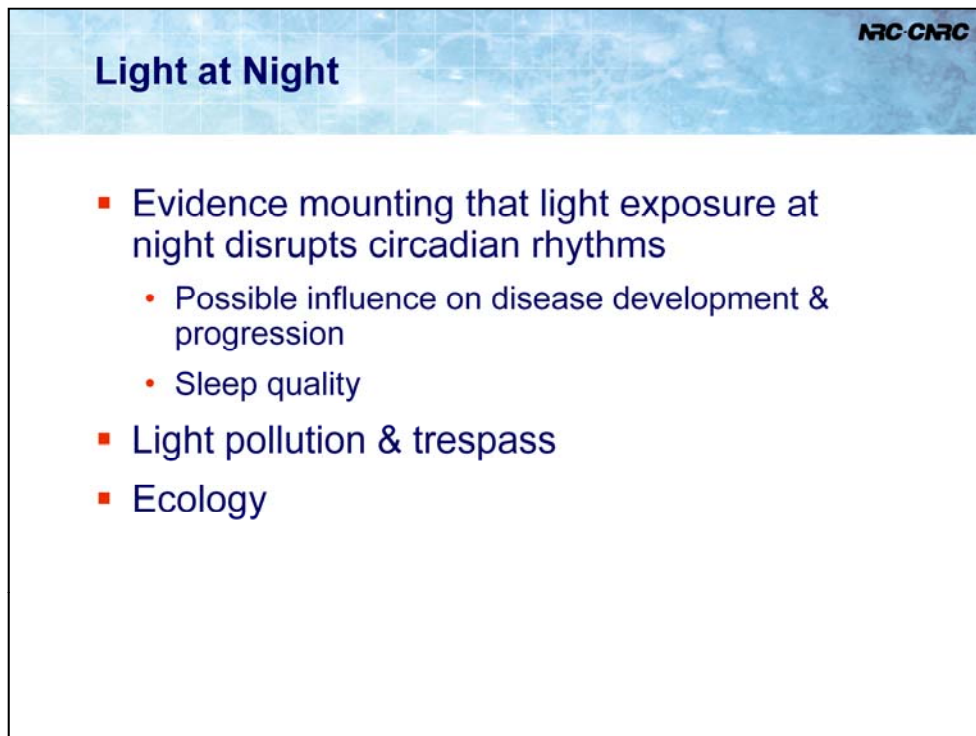
ARC CRC

- Good news for designers: the night-time bright light doesn't have to be constant.
 - Intermittent bright light can reset the clock.
 - 4-5 20-minute pulses per night shift, ~1200 lx
 - timing of the pulses in relation to the individual's circadian state is critical to the success
 - light should be rich in short-wavelength light
 - Daytime light avoidance:
 - blue-blocking sunglasses for the drive home
 - dark shades, curtains while sleeping

Thus, success at phase shifting isn't a matter of technology alone, but of the behaviour of the individual, too.

In designing spaces for night-shift work, it would make sense to build in a way to deliver high-intensity light for short periods. Don't rely on the occupants to use a light box on their breaks; they are unlikely to persist in it. How about a brighter area in the lunchroom?

Remember, that does is **light at the eye**, not on the table.



The slide features a blue header with a grid pattern and the text "Light at Night" in white. The IARC-CARC logo is in the top right corner. The main content is a bulleted list on a white background.

Light at Night

IARC-CARC

- Evidence mounting that light exposure at night disrupts circadian rhythms
 - Possible influence on disease development & progression
 - Sleep quality
- Light pollution & trespass
- Ecology

MRC-CMRC

Daily Light Dose

- Survey: monitored daily light exposure and administered questionnaires
 - Everyone had low overall exposure
 - Evidence that depressive people spent least time in bright light
- Other studies replicated the light exposure measurements:

Daily time > 1000 lx	Summer	Winter
Montreal, QC (45°N)	2 h 36 m	24 m
Rochester, MN (44°N)	2 h 23 m	23 m
San Diego, CA (33°N)	2 h 10 m	1 h 20 m

Sources: Cole et al., 1995; Hébert et al., 1998

I'll turn now to an area that is more controversial: the suggestion that we don't generally have sufficient daily light exposure.

In the industrialized world, total daily light exposure (from all sources) is low. A study of 106 people in San Diego, ages 40-64, found that the median person spent 4% of each 24 hr in illumination greater than 1000 lx, and more than 50% of the time in illuminance levels from 0.1 to 100 lx (an additional 38.6% of the time was below 0.1 lx, consistent with sleeping, driving at night, etc.). The data were collected in August and September, so this isn't a winter effect. This is remarkable given that of all places in North America you would expect southern California to be a place where people spend lots of time outdoors, and have lots of sunlight to experience! San Diego is the 81st percentile in US hours of sunshine. Other places probably show even lower light exposure.

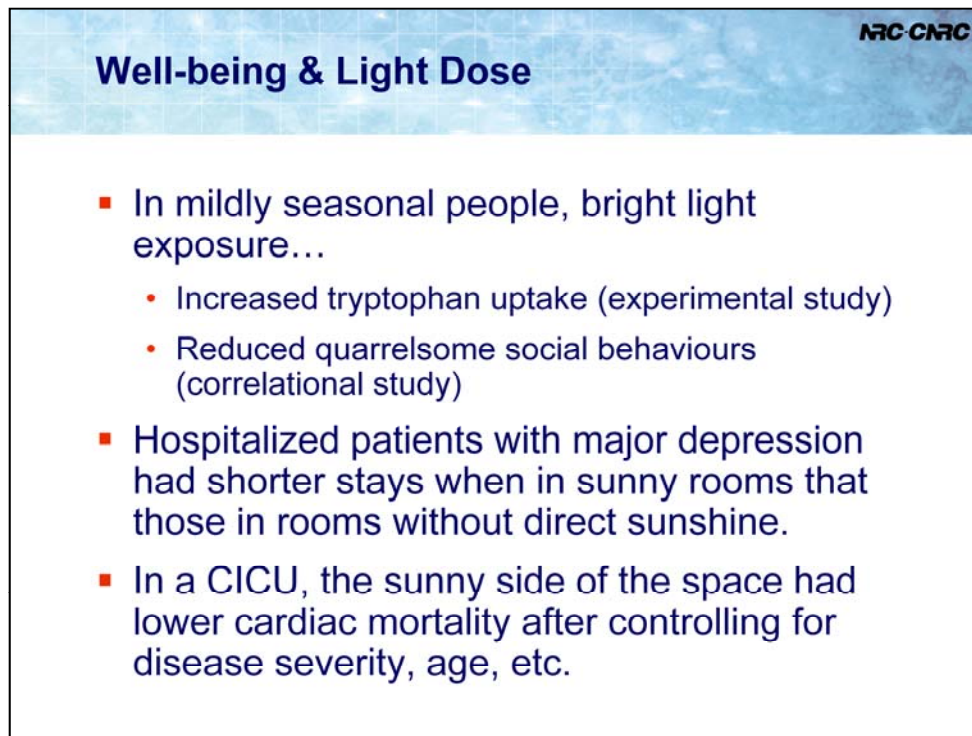
The questionnaire results showed a moderate correlation between atypical SAD mood symptoms and time in bright light ($r = -.27$). This suggests that inadequate light exposure is associated with depressed mood, but doesn't establish a causal link.

References

Cole, R. J., Kripke, D. F., Wisbey, J., Mason, W. J., Gruen, W., Hauri, P. J., et al. (1995). Seasonal variation in human illumination exposure at two different latitudes. *Journal of Biological Rhythms*, 10(4), 324-334.

Espiritu, R. C., Kripke, D. F., Ancoli-Israel, S., Mowen, M. A., Mason, W. J., Fell, R. L., Klauber, M. R., & Kaplan, O. J. (1994). Low illumination experienced by San Diego adults: Association with atypical depressive symptoms. *Biological Psychiatry*, 35(6), 403-407.

Hébert, M., Dumont, M., & Paquet, J. (1998). Seasonal and diurnal patterns of human illumination under natural conditions. *Chronobiology International*, 15(1), 59-70.



Well-being & Light Dose

NRC-CNRC

- In mildly seasonal people, bright light exposure...
 - Increased tryptophan uptake (experimental study)
 - Reduced quarrelsome social behaviours (correlational study)
- Hospitalized patients with major depression had shorter stays when in sunny rooms than those in rooms without direct sunshine.
- In a CICU, the sunny side of the space had lower cardiac mortality after controlling for disease severity, age, etc.

aan het Rot, M., Benkelfat, C., Boivin, D. B., & Young, S. N. (2007). Bright light exposure during acute tryptophan depletion prevents a lowering of mood in mildly seasonal women. *European Neuropsychopharmacology*, 18(1), 14-23.

aan het Rot, M., Moskowitz, D. S., & Young, S. N. (2008). Exposure to bright light is associated with positive social interaction and good mood over short time periods: A naturalistic study in mildly seasonal people. *Journal of Psychiatric Research*, 42(4), 311-319.

Beauchemin, K. M., & Hays, P. (1996). Sunny hospital rooms expedite recovery from severe and refractory depressions. *Journal of Affective Disorders*, 40(1-2), 49-51.

Beauchemin, K. M., & Hays, P. (1998). Dying in the dark: sunshine, gender and outcomes in myocardial infarction. *Journal of the Royal Society of Medicine*, 91(7), 352-354.

Well-being & Light Dose

ARC-CARC

- ~ 90% of time indoors
- Correlational studies associate low daily light exposure with more depressed mood
 - Do more depressed people stay indoors more, or does bright light improve mood?
- Finnish experiments improved mood with higher light doses for healthy adults



Windows - View & Light Dose

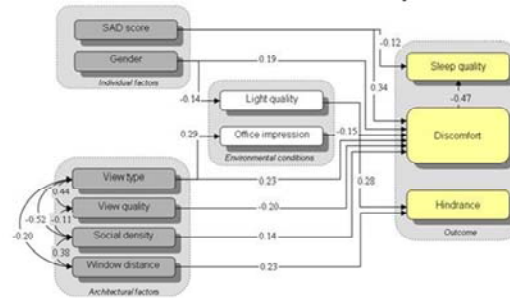
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- People want access to windows & daylight
 - "Natural daylight indoors improves my mood." - 80% agree (Veitch & Gifford, 1996)
- People with larger sun patches on office floor reported lower strain

Windows - View & Light Dose

ARC-CARC


- Access to nature (images, through view, and in contact) improves well-being by promoting recovery from stress
- More attractive views from offices were linked with reduced discomfort and better sleep quality

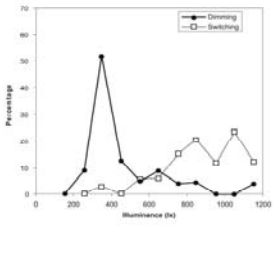


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Preferences for Office Lighting

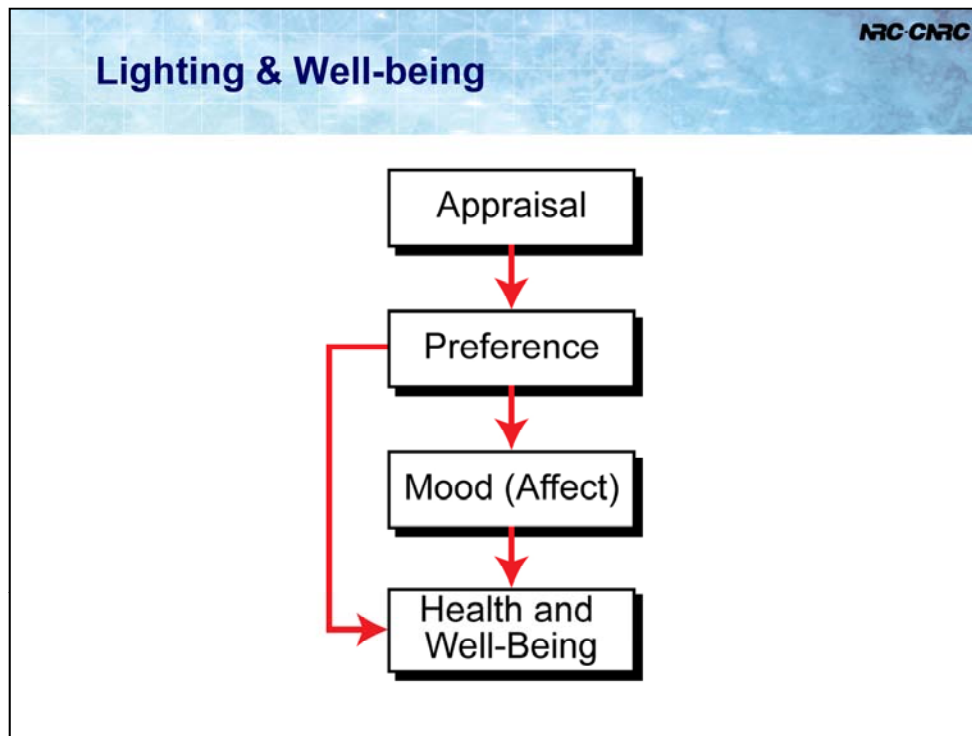
- Wide individual differences in preferred lighting levels, but a consistent preference for direct-indirect systems
- SAD patients have higher preferred levels all year





Percentage of participants choosing a mean desktop illuminance in 100 lx bins for the Switching Control and the Dimming Control conditions. .

Boyce, P. R., Veitch, J. A., Newsham, G. R., Jones, C. C., Heerwagen, J., Myer, M., & Hunter, C. (2006). Occupant use of switching and dimming controls in offices. *Lighting Research and Technology*, 38(4), 358-378.



Veitch, J. A., Newsham, G. R., Boyce, P. R., & Jones, C. C. (2008). Lighting appraisal, well-being, and performance in open-plan offices: A linked mechanisms approach. *Lighting Research and Technology*, 40(2), 133-151.



Therapeutic Lighting - SAD

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- Seasonal affective disorder is a **recurring seasonal pattern** of clinical symptoms
 - Emotional depression, a desire to withdraw socially, and a drop in physical energy, **and**:
 - Atypical symptoms of nonseasonal depression: an increased need for sleep, increased appetite, unacceptable weight gain, and cravings for carbohydrates and sweets
- Population estimates are that ~2.6% of Ontarians might have winter SAD; this is 10% of all depression cases.

We hear a lot about SAD and light treatment. I want to emphasize that this is not a very frequently occurring disease.

When I say we might need more light exposure, I don't mean we all should use the light treatment I'm going to discuss here.

N.B. The evidence for increasing incidence with latitude is very weak. Going up north is not a sure-fire way to get this disorder.

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Therapeutic Lighting - SAD

- Light therapy for SAD uses bright white light (10,000 lx for 30 min), delivered to the eye, in the morning
- Benefit stops when treatment stops
- ~66 % of patients respond to light therapy

- Few side effects
 - except with photosensitizing medication (including St. John's Wort)




Photo: <http://www.day-lights.com/>

Michalak, Lam, & Levitt, 2002: "Light therapy has been shown to produce relatively limited or mild side effects, with the most common being headache, eye strain, nausea or agitation. Rare reports of hypomania or mania as a result of light therapy have occurred. Consequently, patients with bipolar disorder should be monitored closely during treatment. There are no absolute contraindications to light therapy, and no evidence exists that it associates with ocular or retinal damage. Nevertheless, patients with ocular risk factors (for example, retinal disease, diabetes, macular degeneration, photosensitizing medications, such as lithium, St. John's Wort, and phenothiazine antipsychotics) should have a baseline ophthalmological consultation prior to starting light therapy and should undergo periodic monitoring."

The cause of SAD is **not known**. It's not necessarily a lack of light. After all, pneumonia is cured by penicillin, but the cause of pneumonia is not a lack of penicillin!

Therapeutic Lighting - Alzheimer Patients

ARC-CARC

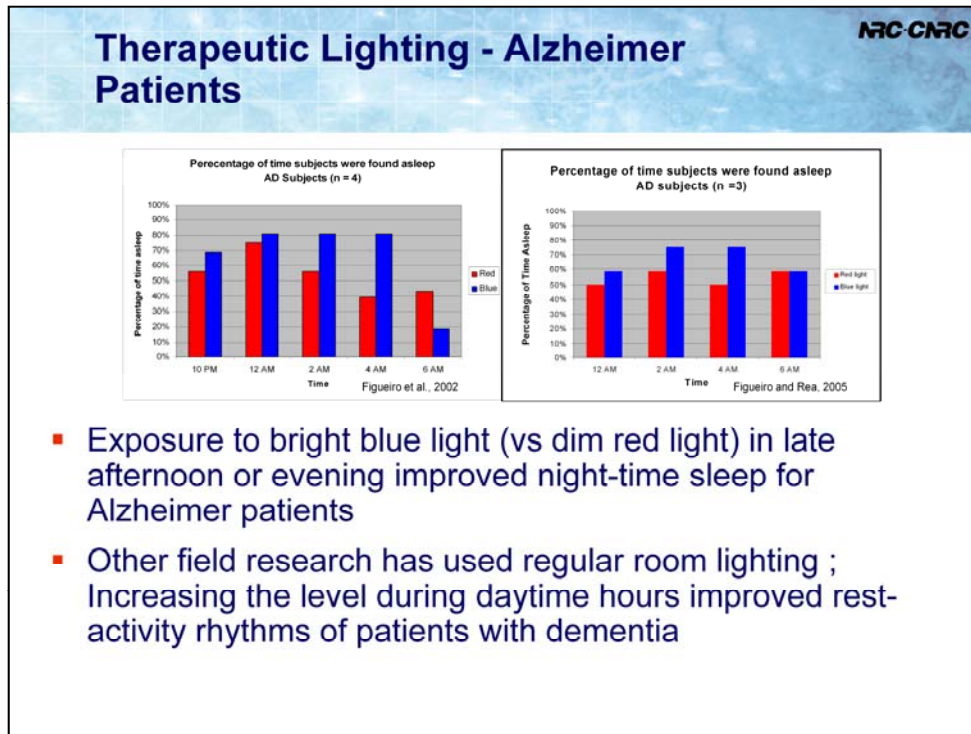


Photos courtesy Lighting Research Center


- Two studies by the Lighting Research Center tested use of blue LEDs to increase light dose of Alzheimer patients in a nursing home.
- Compared bright blue to dim red LEDs, both with afternoon/evening exposure

Alzheimer patients often suffer from disrupted sleep and night-time restlessness. This is a big problem for caregivers.

It's likely the case that institutionalized AD patients have very very low light exposure - so the problem may not entirely be the disease.




In both cases, night-time waking was lower for the blue-light condition than the red. The sample size is small, but that makes the demonstration more convincing as it's hard to get statistical significance for a small sample.



Principles of Healthy Lighting

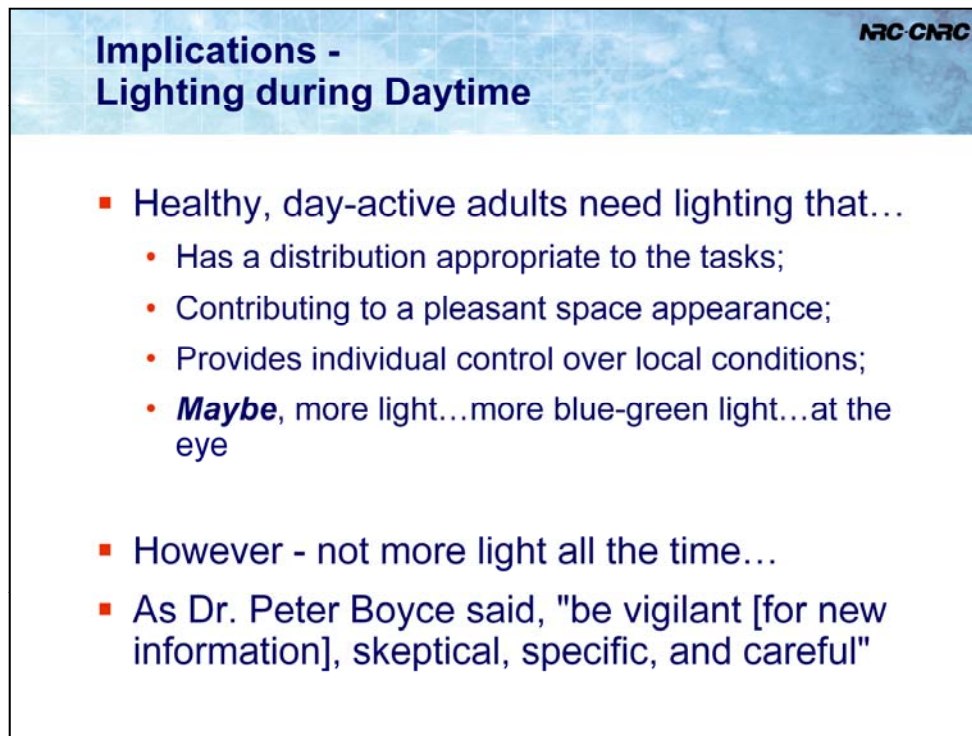
1. The daily light dose received by people in Western countries might be too low.
2. Healthy light is inextricably linked to healthy darkness.
3. Light for biological action should be rich in the regions of the spectrum to which the non-visual system is most sensitive.
4. The important consideration in determining light dose is the light received at the eye, both directly from the light source and reflected off surrounding surfaces.
5. The timing of light exposure influences the effects of the dose.



Although we can't say what the necessary daily dose for light might be, there's evidence that

- a. Most people get very little light exposure on a daily basis, even if they live in climates where it would be possible.
- b. Lower light exposure is associated with poorer mood.

These are not causally related in the literature, but there is an evidentiary path that could lead us to recommend that people get more light exposure during waking hours than they currently receive.



Implications - Lighting during Daytime

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- Healthy, day-active adults need lighting that...
 - Has a distribution appropriate to the tasks;
 - Contributing to a pleasant space appearance;
 - Provides individual control over local conditions;
 - **Maybe**, more light...more blue-green light...at the eye
- However - not more light all the time...
- As Dr. Peter Boyce said, "be vigilant [for new information], skeptical, specific, and careful"

What does all this mean for lighting practice?

The implications are not at all clear for daytime lighting, because we don't know the necessary light dose. Remember all those brain structures the light signals go to - we don't know much about most of them.

Light Hygiene

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www.glasbergen.com



**"You've been working awfully hard lately.
If you need a little fresh air and sunshine,
you can go to www.fresh-air-and-sunshine.com"**

- **Maybe your teacher was right: Go play outside at recess!**



**Implications -
Lighting at Night** **NRC-CNRC**

- **Healthy, night shift workers**
 - Need to shift circadian phase
 - Need light exposure at night
 - Need light avoidance by day

- **Sleeping rooms for all**
 - Get some darkness as well as light each day
 - Light avoidance - direct outdoor lights away from windows, etc.
 - Red/amber, not blue/green, nightlights

We do have some clear guidance for night-shift workers. Happily, we know we don't need to increase their light exposure hugely, all the time.

For all of us, at night we should try to avoid light for at least part of the time.

Design Choices – Lighting

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- People tend to appraise the following conditions more favourably...
 - Installations with a combination of direct and indirect lighting
 - Individual control over illuminance levels (as a means to achieve individual preferences)
 - Light sources they believe to include a high proportion of daylight

Design Choices – Nature & Light

ARC-CARC

- Maximize the number of people with window access
- Provide glare controls, but encourage bright light exposure
- Encourage time spent outdoors, on breaks & lunch

Conclusion

The logo for ARC CRC, consisting of the letters 'ARC' and 'CRC' in a bold, sans-serif font, positioned in the top right corner of the slide's header area.

- Researchers in my area have lots of work to do
 - What is this "necessary light dose"? What spectrum, how intense, when...?
 - Does everyone need the same thing? (If not, how can we design for that?)
 - What are the contributions of individual behaviour vs. design & technology in providing good light hygiene?
 - How can we ensure that we achieve good lighting, while being energy-efficient about it?



The slide features a blue header with a grid pattern and the text "Information Sources" in white. In the top right corner of the header, the "NRC-CNRC" logo is displayed. The main content area is white and contains a bulleted list of information sources.

Information Sources

- International Commission on Illumination (CIE) (www.cie.co.at)
 - Division 3 Interior Environment and Lighting Design (TC 3-46)
 - Division 6 Photobiology & Photochemistry
- Illuminating Engineering Society of North America (www.ies.org)

Credits

ARC CRC

- Colleagues: Myriam Ariës, Peter Boyce, George Brainard, Mariana Figueiro, Robert Gifford, Guy Newsham, Gerrit van den Beld