Review of Low-E Window Information for Discussion

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The team building the two new high schools for the Halifax Regional School Board has asked for

1. information that caused low-E window glazing not to be used in N.S. schools since the building of Halifax West High School, and

2. if there is new research that would influence the decision regarding use of low-E windows in schools now.

Part 1: Background

Between 2000 and 2002 the Healthy School Construction Committee (HSCC) sought information on low-E window use in schools as it relates to potential health of occupants over the short term or long term. The HSCC was a committee struck by the N.S. Department of Education to guide the healthy school aspects of the province's benchmark "Healthy" school, Halifax West High School. The committee and design team looked at low-E glazing as a part of the process. Depending on the coatings selected, low-emissivity (low-E) window glazing has several benefits including heat and energy savings, prevention of overheating in rooms in direct sunlight, and providing a more even room temperature by avoidance of "cold spots" near windows. Because anecdotal evidence and preliminary research indicated some need for caution, some building environment experts were recommending that glazing such as tinted windows and low-E glazes not be used in schools until research clarifies whether or not their use may have negative impacts on health, behaviour, development or performance of building occupants, particularly on children's developing bodies.

Section 3:15 of the Appendix of *the HSCC's Healthy Schools Design and Construction*, July, 2003 reads: "The current trend is to look at energy efficiency above health impacts, however CMHC did a study of twenty-five homes where low-E were either installed in a new home or used to replace old glazing. Some occupants developed SAD within a year or so. An avid orchid grower who always had blooming orchids failed to get any blooms after he put low-E windows in his home. Even ivy, which thrives in low light died. In addition, when a solar blanket was stuck onto the window in an apartment, a ten-year-old jade plant withered over the next few weeks. Plants that had survived many moves and been with owners for a long time withered or died.

Also, A Swedish study looked at ninety volunteers in a blind study of responses to the use of glazed rooms. One room had low-e and another clear glazing. The condition responses in the low-E room were midway between responses reported on the room with clear glass and a windowless room below grade.

Low-E technology is still focussed on energy efficiency. Research and development is producing different kinds of low-E glazing. It narrows the spectrum and cuts down the amount of transmitted light, so both the amount of light and the quality of that light is changed, depending on the low-E coating used. For example, a coating designed for Florida will allow in only a fraction of the light as compared to clear glass.
Research shows light has subtle but important effects on how the body functions modulated by light received through the eye. It nurtures metabolism, affects hormones, circadian rhythm, mood, and well-being.

RECOMMENDATIONS: Use clear glazing and shades if necessary to control glare and overheating. Alternatives for increased energy efficiency of windows:
(1) use good quality sealers
(2) use good quality spacers
(3) use argon (or other) gas between panes
(4) fit the windows well in the opening
(5) conserve heat by closing blinds at night (Salares, CMHC)

Oetzel (of Environmental Education and Health Services Ltd.) recommended triple glazing. Small (of Envirodesic) said "Rather than choosing which rooms should risk being over heated by sun in the wrong seasons, it may make sense to arrange for proper shading of windows." Lee (Of U of Calgary) added that "Fixed awnings outside can serve several purposes in a well-designed building."

Chapter 10 of The Healthy Schools Handbook (Miller, NEA, USA, 1995) and Rousseau's Your Home Your Health Your Well-being advise that "natural light without glare is best. Artificial light which approximates natural light and does not flicker or glare and is neither too little nor too much, is desirable. The kind of light does more than let students see the page. It can influence mood, behaviour, and well-being." (3:17 Lighting, *Healthy Schools Design and Construction*)

The decision not to use low-E glazing came from a review of the above information in detail and the following: Of the seven professionals working in the healthy building field who were reviewers/contributors to the document *Healthy Schools Design and Construction*, none advised use of low-E windows. Those who specialize in energy issues did support use of low-E until discussions around potential health impacts were had. There was some discussion of holes in the ozone layer necessitating use of filtering UV light but CMHC researchers confirmed that regular clear glazing removes harmful UV. "Ordinary glass windows have little effect on wavelengths in the visible spectrum or the infrared range, while they exclude wavelengths below 380 nm rather sharply." (*Lighting and Human Health: A review of the literature. Salares et al, CMHC, 1996.*)

At the meeting between the C-2000 team from Ottawa and the building team over Halifax West High School's energy saving potential, pros and cons of low-E window use were discussed. The cost of replacement of broken windows was a concern of the school board. A Department of Education participant recounted learning from a local window instalment company (Lockharts, Beaver lumber) that they frequently are called back to remove low-E windows and replace them with clear glass. It was acknowledged by those at the meeting that there is minimal research available either indicating health impacts or indicating lack of health impacts. A calculation by the C-2000 team of energy savings for the Halifax West project resulted in a low potential for savings. As a result, the decision was made not to use low-E or tinted windows, to use methods such as shading, good window design and construction, placement of classrooms to avoid south and south west exposure, and until research shows no harmful affects, to use clear glazing. The Design Requirements manual DC350 calls for clear glazing (Part 2, Section 2, Division 8, Section 08500, item 2)

A note on tinted glazing:
The literature indicates that tinted glazing alters the quality and quality of light noticeably. "Tinting glass alters its spectral characteristics, but also reduces the intensity of light passing through the window: the latter change may encourage additional use of artificial light." (Robertson et al, 1989) As with low-E glazing, the DC350 DRM also limits the use of tinted glazing.

Part 2: Current Information

Has anything changed? Healthy building specialists who had originally given input to *the Healthy School Design and Construction* document replied that there is no new research or evidence regarding health and low-E window use in schools.

CMHC researcher Dr. Virginia Salares replied that "research is still focussed on energy efficiency and there is little interest in the industry on examining health questions. Absence of research does not mean there is no effect." The Research and Development section of the CMHC website article *Energy Efficient Windows, Lighting, and Human Health* gives an overview of current knowledge. Dr. Salares restated that many factors make windows energy efficient: the number of panes, argon fill, type of spacer, sealing of thermal unit, insulation value of frame and how the windows are installed. "Have all of these been optimized before specifying low-e glazing? How much energy is saved by the low-E alone?" She stated that light levels need to be optimized in the rooms, so a high transmitting low-E coating would have to be selected. There is Daylighting research that is well done and indicates impacts on learning, behaviour and health. Dr. Salares suggested looking at the light transmittance of the selected low-E coating throughout the spectrum and comparing these at increments throughout the spectrum of panes of clear glass and "look for proof that any alteration from that of clear glass has no effect on health at all". (personal communication, December 14, 2004)

What we know about lighting and health:

Lighting and Human Health: A Review of the Literature, CMHC, 1996 offers research up to 1996 on characteristics and measurement of light and light sources, the human visual system, including eye and brain physiology, hormone production, effects on the body through eye and skin exposure, effects of light on physiology, light and mental health including SAD, full spectrum lighting, sick building syndrome, windowless classrooms, effects of aging and has an extensive bibliography. "Sunlight and artificial light have been found to have different effects on people in a work environment. "In one study, illumination of a desk surface with >1000 lux was regarded as excessive, but the same intensity provided by daylight was not (Boyce, 1981) Similarly, in another study, exposure to bright, artificial light (3,500 lux) over a long period of time triggered increased levels of cortisol secretion, presumably reflecting a stress response. By contrast, natural sunlight of similar or brighter intensity was not reported to have similar effects (Hollwich, 1979)" p.72. The Executive Summary is included in the appendix of this paper. Some of the conclusions are that light levels for visual function may not be adequate for maintenance of normal daily rhythms, mood and arousal, the potency of these photic effects and the degree of variability among people in their sensitivities to them need more study, tinted and coated windows can screen some wavelengths and reduce general illumination, certain populations are at higher risk for inadequate lighting, light therapy is effective in treating SAD, and that more research is sorely needed. The overall recommendation is for more research into all aspects of lighting and human health. This book is available from CMHC at (613) 748-2367.

Professor Tang Lee of the University of Calgary, Building Science Department, indicated the following lighting research:

Figure 1. Electromagnetic Spectrum, "The human eye sees less than 1% of the total electromagnetic spectrum. Little is known about the mysterious light sources at either end of the visible spectrum - the ultraviolet, infrared, and so-called background radiation - but evidence now seems to indicate that they exert a profound influence on the physical and mental health of animals, plants and man."

Study into the Effects of Light on Children of Elementary School Age: A Case of Daylight Robbery. Policy and Planning Branch of Alberta Education, 1992.
"The conclusions in support of Daylit schools:
Fewer sick days (3.2 to 3.8 fewer days per person per year.)
Lower noise (and less hyperactivity)
More positive moods in students
Less tooth decay by 9 times
Higher growth by 2.1 cm more (over two years)"

Analysis of the Performance of Students in Daylit Schools, Nicklas and Bailey, Proc. of the 1997 Annual Conference, ASES.
"1. Students attending daylit schools outperformed the students who were attending non-daylit schools by 5 - 14%."
2. The impact for multiple years is even greater.
3. "New" does not necessarily translate into better performance. The new non-daylit North Johnston Middle School actually showed a negative impact on performance.
4. It is quite clear that placing students in temporary, mobile classrooms had a very significant and negative impact on the performance of students... a 17% decrease in student performance."

John Ott's book *Health and Light* (Figure 2) reports a study of tumour growth in rodents living under various light conditions showed that the mice lived an average of 15.6 months under sunlight and under full spectrum lighting, twice as long as under fluorescent lighting. Subtle changes in the amount/quality of light from various sources produced changes in the death rate. We can not conclude, however, that research on mice applies directly to humans. (*Health and Light: The effects of natural and artificial light on man and other living things*, Ott, J.N., The Devin-Adair Company, Old Greenwich, Connecticut. 1973.)

The *Daylighting in Schools* research found that "Controlling for all other influences, we found that students with the most daylighting in their classrooms progressed 20% faster on math tests and 26% faster on reading tests in one year than those with the least. Similarly, students in classrooms with the largest window areas were found to progress 15% faster in math and 23% faster in reading than those with the least. And students that had a well-designed skylight in their room, one that diffused the daylight throughout the room and which allowed teachers to control the amount of daylight entering the room, also improved 19-20% faster than those students without a skylight. We also identified another window-related effect, in that students in classrooms where windows could be opened were found to progress 7 to 8% faster than those in rooms with fixed windows. This occurred regardless of whether the classroom also had air conditioning. These effects were all observed with 99% statistical certainty." (*Daylighting in Schools: An Investigation into the Relationship Between Daylighting and Human Performance.* Heschong Mahone Co. for California Board for Energy Efficiency Third Party Program, Pacific Gas and Electric Co.1999.)

CMHC's factsheet entitled *Research & Development Highlights. Energy efficient windows, lighting & human health* includes a report called *the Spectral Transmittance of glazing used in Canadian Houses*. It "examines a variety of glazing types used in Canada. Clear, tinted, and low-E glass were tested for their spectral transmittance, based on glazing thickness and number of panes used in the window assembly. Samples of clear glazing gave visible transmittances in the visible around 90%, while lower transmittances (as low as 50%) were seen for tinted glass and glass with increased glazing thickness. The low-E glazing samples had visible spectral transmittance around 80% (single glazed) while the double glazed window assembly with argon gas fill had a transmittance of 70% in the visible. Transmittance in the short wavelength region was lower than for clear glass."

	Clear Glass Transmittance	Low-E Glass Transmittance
Single pane	90%	50-80%
Double Pane	81%	45-72%
Triple pane	72%	22-57%

note: transmittances are in the visible range only; values are approximate and estimated from the product of the transmittances of the individual panes. (Windows: Practical and Research Considerations. Research & Development Highlights. Energy efficient windows, lighting & human health. 1996.)

Also from *Research & Development Highlights: Regulations and standards for Daylighting in Housing in Northern Latitude Countries* "Criteria for light can be categorized under intensity, duration and quality. The daylight factor addresses the issue of lighting intensity and has been used extensively in research and building design. The duration of light is not regulated in housing but is controlled in art museums and the like. Quality of light, in terms of spectral transmittance through windows, is still under much study."

Professor Lee provided *Figure 3. Effects of Light on Plants*. "The growth and health of plants is directly related to the light spectrum. Poor growth (tall, thin, weak, not blossoming) is the result of lighting that is not full spectrum." (personal communication, January 25, 2005) Some plants ("shade" plants) do better in shade or partial sunlight, and we can not assume that the impact on plants would be similar to that on children. A *Survey of Effects of Low-E Windows on the Well-being of Home Occupants* and the survey *Effects of New Window Glazings on Plants and People* both found mixed, inconclusive results, except in one part of the first study where "blind testing in the second phase called for 13 hypersensitive individuals to indicate their sensory perceptions to 4 sets of window glazings. All but one individual, who is photoallergic, expressed a dislike for the low-E assembly. Responses included feeling ill, anxious, and panic stricken when looking through it. This was especially clear when ambient light levels were low due to cloud cover."

Consumer literature from Natural Resources Canada states that "there is usually some loss of solar contribution due to the low-E coating, but while this reduces the benefits of passive solar heat gains somewhat, it is more than offset by the improved insulative value of the low-E window at night." (*Consumer's Guide to Buying Energy-Efficient Windows and Doors*, Natural Resources Canada,

1998. p.30) Indications are that it is not that simple. Depending on the number of panes chosen and the low-E finish chosen, savings refer to heat and energy gains and losses. Without more research on health impacts it is hard to draw conclusions on the relative merit.

School communities contain a cross section of individuals with varying medical conditions. *Lighting and Human Health: A review of the literature* refers to the need for more study of sub-populations.

Research & Development Highlights concludes that "It is evident from these preliminary studies that more research is needed into this area. The impact of lighting on physiological processes is already established but more information is needed on the impact of manipulating daylighting (through windows) on occupants."

Conclusions

The information in this paper is offered as a contribution to the discussion of the potential use of low-E glazing in schools. These schools will be in use for many years, and it is important that they be as energy efficient as possible and also be healthy places. Low-E windows can contribute to comfortable room temperature as well as to energy savings, but will the changes to the quality and quantity of light delivered through low-E coatings have any effect on well-being?

Subtle changes to light can have profound effects on living things. Some effects are visible on the short term and others over the long term. We know that people benefit from having control over daylight levels and over openable windows. We know that levels of light delivered by artificial light are perceived differently and not as positively as the same levels of light delivered by sunlight. Some studies show that the part of the spectrum delivered affects tumour growth in mice, and plant growth and reproduction, but these studies may or may not be relevant to humans. Other studies do show that manipulating the amount and quality of light can affect human hormone levels, mood, behaviour, growth and even tooth decay. We know about the benefits from windows that offer a view, but research is also showing statistically significant improvements to educational performance from increased daylighting with non-glare, diffuse windows or skylights - that is, in addition to normal classroom windows.

Dr. Salares of the CMHC Research Division suggests maximizing all aspects of window energy savings before specifying low-E glazing. How much energy is saved by the low-E alone? Because light levels need to be optimized in the rooms, a high transmitting low-E coating would have to be selected. Look at the light transmittance of the selected low-E coating throughout the spectrum and compare these at increments throughout the spectrum of panes of clear glass and "look for proof that any alteration from that of clear glass has no effect on health at all".

Most sources agree that more research is needed on health and light. Children's bodies continue to grow and develop until their early 20's. Because of this and because of known effects of light on the body, some building environment experts caution that glazing such as tinted windows and low-E not be used in schools until research clarifies whether or not their use may have negative impacts on short-term or long-term health, behaviour, development or performance.

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Research & Development Highlights. CMHC website

- *Energy efficient windows, lighting & human health* includes a report called *the Spectral Transmittance of glazing used in Canadian Houses.*

- *Windows: Practical and Research Considerations. Research & Development Highlights. Energy efficient windows, lighting & human health. 1996.)*

- *Regulations and standards for Daylighting in Housing in Northern Latitude Countries*
- A *Survey of Effects of Low-E Windows on the Well-being of Home Occupants*

- *Effects of New Window Glazings on Plants and People*

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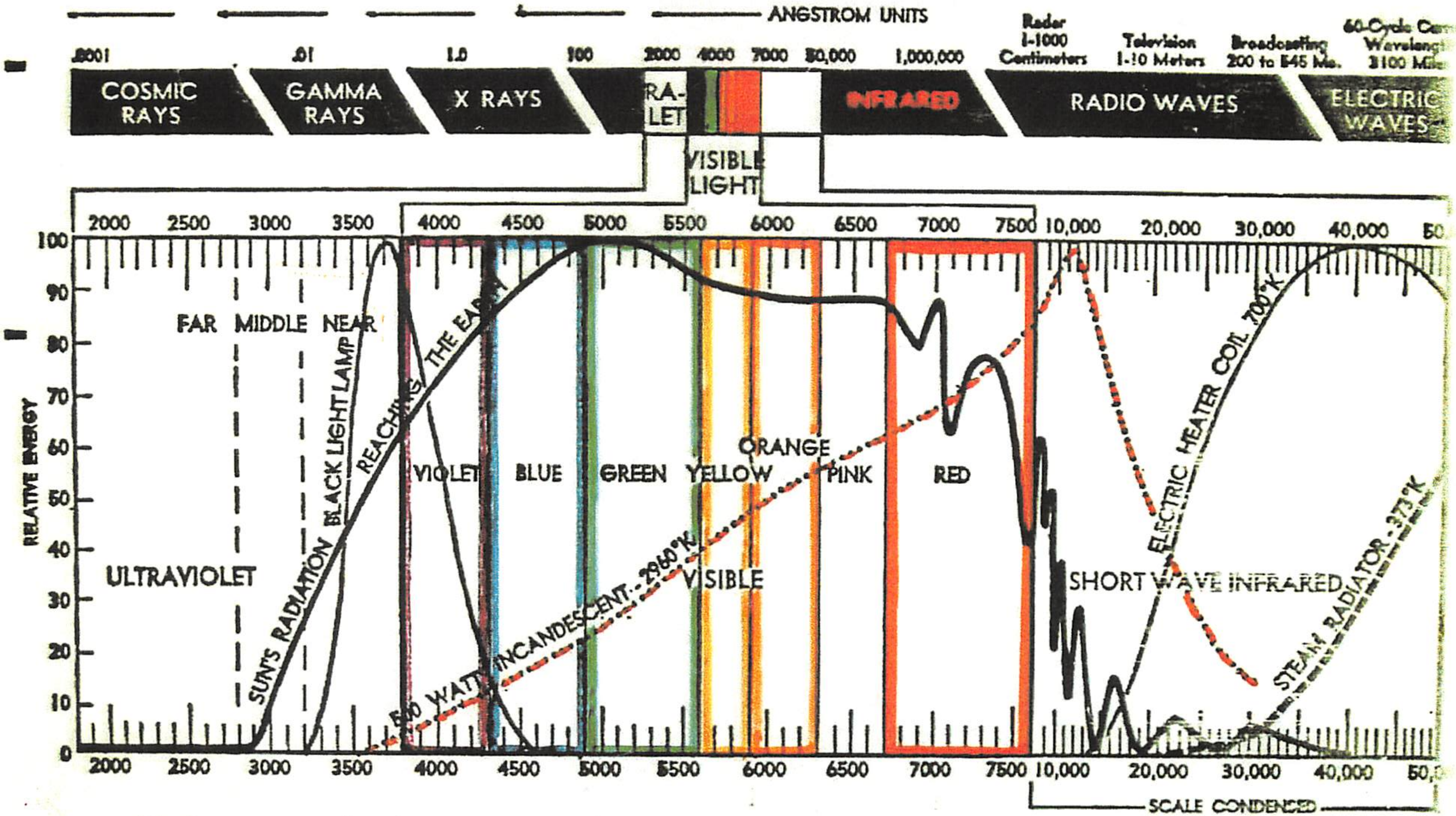
Tang Lee, Professor of Building Science, University of Calgary.(personal communication, Jan. 25, 2005)

Virginia Salares, Ph.D, CMHC Research Division, Ottawa (personal communication, Dec. 14, 2004)

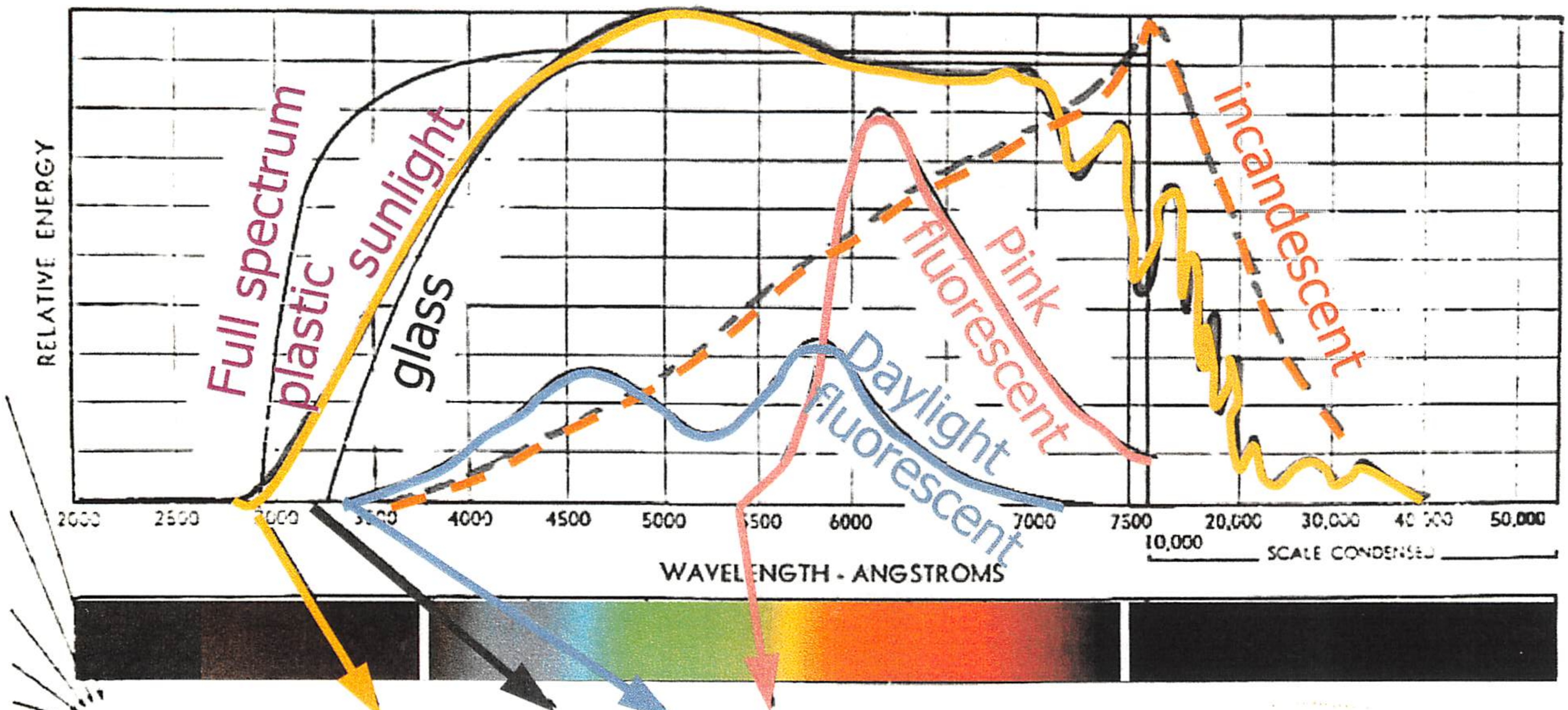
ELECTROMAGNETIC SPECTRUM



The human eye sees less than 1% of the total electromagnetic spectrum. Little is known about the mysterious light sources at either end of the visible spectrum—the ultraviolet, infrared, and so-called background radiation—but evidence now seems to indicate that they exert a profound influence on the physical and mental health of animals, plants and men.

Figure 1
From Prof Tang Lee

Effects of light on animals



Air curtain **16.1** **15.6** **9.4** **8.2** **7.5** months

Average number of months to death from tumours in C_2H mice.

Ott, J.N., Health & Light: The effects of natural and artificial light on man and other living things. The Devin-Adair Company, Old Greenwich, Connecticut, 1973.

Figure 2
From Prof. TangLee

Effects of light on plants

Figure 3
From Prof. Tang Lee

Appendix

EXECUTIVE SUMMARY

A. How Light Affects Human Physiology

This review examines the effects of lighting on human health, with special emphasis on natural illumination and its transmission through window glass. Light in the environment affects human health via three routes. Two of these routes involve the eyes, while one involves the skin. First, light in the visible portion of the spectrum affects receptors in the eyes which convey this information to the brain. Parts of the brain analyse this information and give rise to the conscious awareness of light that we experience as *vision*. The second route by which light affects human physiology also starts in the eyes, but involves different parts of the brain. Light information conveyed by the second route has profound effects on our physiology, of which we are not consciously aware; these are the non-visual or *photic* effects of light. They include effects on mood, synchronization of our daily behavioural and physiological rhythms to the cycle of day and night, and regulation of patterns of hormone secretion. The third route involves the effects of light mediated by the skin, rather than the eyes. These include influences on the skin itself (for example, tanning and allergic responses of the skin to light), as well as important effects on general physiology, such as altering immune system function and stimulating the production of vitamin D.

B. Conclusions

1. The human visual system can adapt to a wide range of background illumination intensities and colours. We can, therefore, perform ordinary visual tasks (reading, writing, sewing, *etc*) at a great variety of light levels above a minimal threshold intensity.

2. Photic (non-visual) effects of light mediated by both the eyes and skin may not show similar adaptation to levels of background illumination. These effects may depend to a larger extent on the absolute light levels experienced. Reduced lighting intensities (such as those found indoors) that are compatible with normal, conscious visual function may not be adequate to meet the photic requirements for maintenance of normal daily rhythms, mood and arousal.

3. Light can alter states of physiological arousal, probably via the autonomic nervous system and by regulation of the hormone melatonin. The potency of these photic effects and the degree of variability among people in their sensitivities to them have not been studied extensively.

4. The use of tinted and coated window glasses can screen or filter some wavelengths of light as well as reducing general illumination levels. As a result, room occupants may respond by increasing the use of supplementary artificial lighting indoors. The potential physiological effects of the particular artificial systems available then become indirect consequences of window tinting.

5. Certain populations are at higher risk than others for experiencing inadequate lighting. Aging populations are particularly vulnerable because there is a dramatic reduction of light transmission through the eyes during normal aging, and with age-associated abnormalities of the eyes (e.g., cataracts, glaucoma, diabetic retinopathy). In addition, more sedentary lifestyles and chronic illnesses can further reduce natural light exposure for some seniors, particularly during winter months and in inner-city environments. Poor diets may further exacerbate the problem by providing inadequate dietary vitamin D levels. The re-emergence of rickets in some inner-city populations in North America, and evidence of bone demineralization in the institutionalized elderly (resulting from vitamin D deficiency) testifies to the need for more appropriate diets and light exposure in order to maintain adequate vitamin D levels.

6. The evidence that light therapy is an effective treatment for one significant form of clinical depression, seasonal affective disorder (SAD), indicates that light can have profound effects on mood at least in this substantial subset of the population. The characteristics that distinguish such light-sensitive people from others are unknown.

7. Field studies of the effects of different lighting systems, including so-called "full-spectrum" fluorescent lighting, altered spectral characteristics resulting from window tinting, and windowless environments are generally either lacking or so poorly conducted as to not permit any firm conclusions.

8. There are suggestions in the literature that artificial indoor lighting may contribute to the experience of some symptoms associated with "sick-building syndrome", although the issue has not been studied extensively.

C. Recommendations

1. Further research is needed on several aspects of the physiological effects of light on normal people. These include studies of physiological arousal caused by light exposure and of the effects of light on daily rhythms, the characteristics of effective light, and the underlying physiological mechanisms mediating the effects of light.

2. A great deal more information is needed about the range of variation in pattern and intensity of daily light exposure experienced by people in the home, the workplace and outdoors. The changes in exposure with season of the year and at different stages of life need to be investigated.

3. Populations at higher risk for inadequate exposure to light, including seniors and people who are institutionalized, require particular study and attention. More adequate light exposure and improved diets may be needed to maintain health in these populations.

4. Identification of sub-populations with unusual sensitivities to light exposure or to inadequate lighting should be pursued, along with investigations into the mechanisms underlying such sensitivities.

5. Appropriately designed, executed and analysed field studies of the effects of different lighting environments on human health and behaviour are needed in order to assess claims that have been made based on previous inadequate studies.

the plane of polarization anyway. Some improvement in readability of text on shiny paper held at a particular angle of incidence might be expected in polarized light (analogous to removal of road glare), but would likely be offset by reduced efficiency of the "full-spectrum" source, compounded by the light losses inherent in polarizing its output. Re-adjusting the tilt of the page under standard lighting would be a more intelligent solution.

4. Effects of glass windows and optical filters

Synopsis: Ordinary glass windows have little effect on wavelengths in the visible spectrum or the infrared range, while they exclude UV wavelengths below 380 nm rather sharply. Elements in the human eye also act as selective wavelength filters. Measuring the filter properties of window glass accurately requires careful attention to the angles at which measured light reaches the glass.

Light sources are often modified by interposed filters, including windows. Thin panes of common glass in windows and in the envelopes of lamps attenuate a small amount rather uniformly across the visible spectrum, depending on the thickness. They therefore modify the spectrum of sunlight, skylight and lamp light very little in this range. They start to absorb ultraviolet significantly below about 380 nm, however, and increasingly attenuate this radiation towards shorter wavelengths. As light enters through the windows of a house, the glass acts as a rather sharp "cut-on" filter because of attenuation of the short wavelengths, compared to the very gradual effect at the other end of the spectrum. Most untinted glasses transmit infrared well, out to wavelengths of a few micrometers, and do not cut off suddenly. Although this IR radiation is invisible, it can contribute significantly to the heat balance of a dwelling, especially where this is a deliberate design feature.

Filter transmission characteristics are most easily measured from UV to near IR, on pieces of the filter placed normal to the measuring beam in an automated commercial spectrophotometer, usually relative to a comparison beam passing through air. The measuring beams are collimated (parallel ray paths), so the result is valid for light incident at right angles (normal) to the glass surface. Certain types of thin-film elements in optical filters do not behave simply as the angle of incidence is varied, because of optical interference, and much of the radiation reaching windows arrives at non-normal incidence. It is important to make sure that this is not a complicating factor when assessing new materials like coated glasses, by running spectrophotometric checks at different angles of incidence, or by using a different measuring system incorporating a good (Lambertian) diffuser before the glass, to allow integration across all practically significant angles of incidence.

Filter transmission characteristics are sometimes given using a linear scale of the *transmittance* T (percent transmission, relative to the measurement in air with no filter present) of the filter as a function of wavelength, λ (T_λ). Sometimes transmittance is given normalized. More usually a logarithmic scale of *optical density* (OD_λ) against wavelength is employed, sometimes called *absorbance*, where

$$OD_\lambda = \log_{10} (100/T_\lambda)$$

The OD scale is practical to use because the overall OD of several filters in series is simply the sum of the individual densities at the wavelength in question, while transmittances are multiplicative and so less intuitive. A logarithmic scale also gives a much more readable printout for examining blocking zones where a filter transmits below a few percent of the incident light, which will plot unusefully close to zero on a linear spectrophotometer scale; some filter manufacturers even use a double-log scale for this reason. Optical elements in the eye, notably the lens, macular pigment and visual pigment all behave in some respects like optical filters, and so their transmission characteristics also are often expressed conventionally in units of optical density (often abbreviated to "density").

C. Measurement of Light

1. Energy or quanta? Radiometric and photometric units

Synopsis: There are two commonly used systems for measuring light intensity. The radiometric system measures the energy of the light without reference to human or any other species' sensitivity to the light. The photometric system relates light measurement to the relative effectiveness of light of different wavelengths for the human eye at daylight intensities. Illuminance is the photometric measure, expressed in lux, which is used to describe lighting levels in the home and workplace. In general, people prefer illumination sources with a higher colour temperature at higher light intensities. This preference may have implications for lighting choices in situations where window coatings alter both the intensity and spectral properties of light entering a room.

The results above are conventionally measured and quoted in *radiometric* units. These would be derived originally from some measuring device like a thermopile that is blackened to make it absorb different wavelengths uniformly, and that has been calibrated indirectly with reference to the original internationally recognized standard. Most modern instruments use a more sensitive silicon photodiode that is not spectrally flat, but is either calibrated by wavelength or preceded by a compensating optical filter. The most sensitive devices at short wavelengths are still photomultiplier devices. The result from each is an electrical output that can be interpreted as radiant energy delivered over a time interval, and over some area or solid angle, for example, Watt meter^{-2}, identical to Joule sec^{-1} m^{-2}. There is great variation in spectral output between the different sources above and even some between lamps of similar manufacture, so the *total* energy count does not necessarily provide useful information about the stimulating power for human vision. The energy of light sources is therefore most useful when tabulated per unit wavelength interval, usually in bands 10 nm wide.

Photoreception in animals, including humans, is not a direct energy-absorbing process like that in a thermopile, which causes increased thermal motion of atoms. Instead it depends upon the capture of individual photons (quanta) by single visual pigment molecules in the cones. Each capture alters the electronic structure leading to a change in conformation of this protein molecule, and this starts the visual process (Abrahamson and Japar, 1972); see III.B.2. Therefore, to estimate the relative effectiveness of radiation at two different wavelengths, what is needed to express stimulating power is not the *relative energy* but the *relative numbers of photons*. These are simply related because the energy delivered when one photon is captured is $E = hC/l$, where h is Planck's constant, so a spectral energy scale can be converted into a relative numbers-of-photons scale simply by dividing by the associated wavelength. A source emitting equal energy at 380 nm and 760 nm, for example, would contain twice the number of photons

Canada

Research & Development Highlights

ENERGY EFFICIENT WINDOWS, LIGHTING & HUMAN HEALTH

Introduction

In a well-insulated building the greatest percentage of heat loss occurs through windows. This has created a large industry to improve the thermal performance of windows. Of the many technological advances in this area, the most heavily promoted windows are thermally sealed units containing one or more panes of glass with a low-emissivity coating . also known as low-E windows. Other advances include the development of insulated frames, thermally efficient spacers, inert gas filler between panes, and multiple pane assemblies.

Spectral transmittance of glazing is defined as a measure of the fraction of light that passes through it. Coatings or tintings on the glazing act as a filter, changing the glazing's spectral transmittance and therefore, the light that is available to the occupants. No attention has been given to how the altered transmittance may affect occupants. Due to the widespread use of low-E windows, the possibility of an impact on occupant health demands attention. As well, building codes should be examined as current codes reflect window materials that have been used in the past, namely clear glass, and do not account for these new types of glazing.

CMHC has initiated a number of projects to examine this issue. This document was created to provide an overview of this research and includes a synopsis of 5 recently completed projects which investigate various aspects of lighting, low E windows and health.

Lighting and Human Health examines the known effects of light on human physiology, specifically vision, endocrine system, and general physiology. While the visual system can adapt to a wide range of light levels, the non-visual processes involving light seem to work best under higher absolute light levels. The non-visual effects of light include influences on mood, synchronization of daily rhythms to the cycle of night and day, and production of hormones.

The report provides an overview of current knowledge in this area. Topics discussed in this review include:

- the physical characteristics of light and methods of measurement;
- .the structure and function of the visual system and physiological mechanisms involved in
- colour perception, brightness, and
- contrast sensitivity;
- the physiological processes involved in light exposure;
- the influence of light on mental health and sleep patterns; and
- the use of windows in the home and workplace.

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Research is required to gain a better understanding of the impact of light (in terms of intensity, spectral range and duration) on health. This is particularly important for those at risk of inadequate exposure to light such as the aged, institutionalized, and individuals with sensitivities to light.

The Spectral Transmittance of Glazing Used in Canadian Houses examines a variety of glazing types used in Canada. Clear, tinted and low-E glass were tested for their spectral transmittance, based on glazing thickness and number of panes used in the window assembly. Samples of clear glazing gave visible transmittances in the visible around 90%, while lower transmittances (as low as 50%) were seen for tinted glass and glass with increased glazing thickness. The low-E glazing samples had visible spectral transmittances around 80% while the double-glazed window assembly with argon gas fill had a transmittance of 70% in the visible. Transmittance in the short wavelength region was lower than for clear glass.

Regulations and Standards for Daylighting in Housing in Northern Latitude Countries
This report examines standards for daylighting in housing in Canada and other countries. Current and future design regulations are presented, as are current and future rating systems and regulations for window glazing.

Criteria for light can be categorized under intensity, duration and quality. The daylight factor addresses the issue of lighting intensity and has been used extensively in research and building design.

The duration of light is not regulated in housing but is controlled in art museums and the like. Quality of light, in terms of spectral transmittance through windows, is still under much study.

Regulations for daylighting in housing have historically been based on window opening size. Canada, Denmark, Finland, the Netherlands, Norway and the United States all stipulate minimum window size as a percentage of floor area .usually around 10%.

France, Germany, Japan, and Sweden include a number of alternate criteria to window size. These include stipulations for area of window opening, transmittance of diffuse light, depth of room, minimum duration of exposure to sunshine, daylight factor, and illumination distribution. Sweden and the United Kingdom have standards to ensure good daylighting for new and existing buildings.

Of the countries surveyed, France has corrected the window opening size for transmittance. Denmark is planning changes to their daylighting criteria based on the effects of high performance glazing systems. Sweden is moving towards a minimum transmittance of 0.60.

A Survey of Effects of Low-E Windows on the Well-Being of Home Occupants lists the responses to a survey- of 51 homeowners living in homes built or renovated with low-E windows. Of this group, 37 were new houses, 11 had some windows replaced with low-E windows, and 3 had all windows replaced with low-E windows. The questionnaire used in the survey was based on standard questionnaires which look at human responses to seasonal changes. The purpose of the questionnaire was to assess homeowner satisfaction with their windows. Questions directly pertaining to their health were not asked.

The questions included house characteristics (i.e. house age, duration of occupation, window type, and number of windows replaced in retrofit), observations of interior space (i.e. brightness, use of interior lighting), impact of weather on occupant's mood, impact of seasonal changes on occupant's mood, and general observations.

The respondents expressed satisfaction with the thermal efficiency of their new windows. They also reported positive perceptions of spaciousness, comfort and brightness, but these may be due to improvements in house design, location or orientation with the previous house.

The survey found that occupants are affected by changes in the seasons, but it did not find correlation between seasonal effects and the type of windows.

Responses to a question of growth of houseplant ranged from improved growth, to no change, to poor growth.

Effects of New Window Glazings on Plants and People is a follow-up to the previous survey in order to assess the effect of glazing on plants. A second objective was to determine the effect of glazing types on a panel of environmentally hypersensitive individuals. Of the *45* responses to plant growth, *25* indicated no change, 16 indicated increased plant growth, and 4 indicated poor plant growth. Four additional cases of impaired plant growth were directly reported to CMHC. These responses are due to a combination of factors including: window size and orientation, transmission capabilities of the window glazing, and individual plant requirements. Design features consisting of larger window size and better solar orientation in new houses will lead to increased amounts of light, while the lower transmittance properties of low-E windows will lead to decreased amounts of light.

The reported improved growth of houseplants in the new houses can be explained by a net increase in the amount of light, i.e. the positive effects of the design features exceed the reduction in transmittance due to the low-E glazings. In some cases, there is also a better fit of the lighting requirements of certain plants with the filtered light provided by the low-B windows. The lack of observed changes in plant growth in twenty-five houses is very likely due to a canceling of the two opposing effects. The reported impaired growth of plants in eight houses can be explained by a reduction of light and, in the new houses where plants died, positive design features were not sufficient to offset the reduced transmittance of the low-E windows.

The blind testing in the second phase called for 13 hypersensitive individuals to indicate their sensory perceptions to 4 sets of window glazings. All but one individual, who is photoallergic, expressed a dislike for the low-E assembly. Responses included feeling ill, anxious, and panic stricken when looking through it. This was especially clear when ambient light levels were low due to cloud cover.

Windows Practical and Research Considerations

This final report provides a summary overview on the considerations involved with the use of low-E windows in current housing. There are variations in transmittance of low-E coatings; some have lower transmittance than others.

	Clear Glass Transmittance	Low-E Glass Transmittance
Single Pane	90%	50-80%
Double Pane	81%	*45-72%*
Triple Pane	72%	*22-57%*

Note: transmittances are in the visible range only; values are approximate and estimated from the product of the transmittances of the individual panes.

A triple-pane low-E window (with poor transmitting low-E coating) transmits less than a third of that transmitted by triple pane clear glass.

The contribution of low-E coatings to the heating load of a well insulated house (the Toronto Healthy House) was estimated. A high performance assembly (fiberglass frames, argon-fill, warm-edge insulating spacers) not using low-E will result in 11% increase in energy consumption, while lower performance spacers would result in a 22% energy increase.

Impact on the Housing Industry

It is evident from these preliminary studies that more research is needed into this area. The impact of lighting on physiological processes is already established but more information is needed on the impact of manipulating daylighting (through windows) on occupants. Some countries are already developing standards for daylighting in housing that reflect the reduced transmittance of low-E windows. Canada needs to review its daylighting regulations. Performance criteria will likely be a balance between lighting and energy efficiencies that meet health, safety, energy and comfort requirements. Until such time consumers should be made aware of individual glazing transmittance capabilities when building or renovating their homes.

Project Manager: Virginia Salares

Research Report: Energy Efficient Windows, Lighting & Human Health (1996)

A full report on this research project is available from the Canadian Housing Information Centre at the address below.

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Under Part IX of the National Housing Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research.

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3. DISCUSSION AND CONCLUSIONS

The results of the analyses of the three districts are remarkably consistent: all show positive daylight effects with highly significant results. The actual magnitude of the effects is less important than the observation that a consistent effect can be found in three very different school districts.

We began this study uncertain that we would be able to find any significant effects of daylighting using the statistical analysis methodology. We pursued the study of three school districts in the hope that at least one district would be amenable to this analysis technique.

From this study, we have made a number of important findings:

- We found a uniformly positive and statistically significant correlation between the presence of daylighting and better student test scores in all three districts.
- We found that the positive effect of daylighting was distinct from all the other attributes of windows.
- We found that this methodology of using large, pre-existing data sets can be a successful and powerful tool for investigating the effects of the physical environment on human performance.

There are many other lesser findings that can also be derived from this study. We refer the reader to the more detailed report for full discussion. This type of statistical study has many limitations. It cannot prove the "cause" for an effect. It merely shows the magnitude of an effect and the certainty of an association between variables. However, questions about a mechanism that might "cause" such an effect quickly arise in most readers minds. Here, in conclusion, we offer a few observations about the most successful daylighting designs, and some educated guesses about how such a "daylighting effect" might function.

3.1 Lessons about Daylight

We cannot easily compare between the districts because the data sets are so different. However there are some lessons within each district that may have broader validity.

In Capistrano the daylighting effect is seen to be slightly larger than the window effect. This one finding strongly suggests that there is indeed a specific daylight effect, as opposed to a window effect, and that the amount of daylight provided in a classroom is important.

The positive effect seen for skylights in all three districts also reinforces the thesis that daylighting in and of itself is important, in addition to whatever other attributes of windows may influence behavior, such as view, communication, ventilation, or status.

Capistrano has the largest number of skylit classrooms, and the greatest variety of skylight types. This greatly strengthened the analysis for the Capistrano district. Seattle had relatively few skylights, and Fort Collins had only one type, which made it more difficult in those districts to distinguish between the effects of the windows versus other sources of daylight.

The results of the analysis also suggest some lessons specific to the design of skylights and windows. We discuss these design issues here for the sake of school officials and designers who wish to consider including more daylighting in the design of schools[7]. It is clear from our analysis that some of the skylighting systems considered in this study perform well and some do not. In our observations of schools for this study it was clear that successful daylighting systems (Skylight Type A in Capistrano, sawtooth monitors, clerestories and skylights in Seattle) blocked the penetration of direct sunlight into classrooms and allowed the teacher to have control over the amount of daylight entering the class. The skylighting systems that did not perform as well (Skylight Type B in Capistrano, sawtooth monitors in Fort Collins) created patches of very bright light or allowed direct sunlight in. Also, these poorer performing skylights did not have a system to allow teachers to fully modulate the amount of daylight entering the classroom.

3.2 Possible Explanations

This study has established a positive correlation between higher test scores and the presence of daylight in classrooms. However, this type of study cannot prove that daylighting actually causes the students to learn more or perform better. Other types of studies are required to identify what it is about daylighting that might cause such an effect. Daylight is quite a complex phenomenon and there are many mechanisms that it might have an effect on human beings. We also do not know if it has a uniform effect on people, or influences some people more than others. Below, we discuss a number of possible explanations. At this point, they are at the level of informed guesses.

3.2.1 Improved Visibility Due to Higher Illumination Levels

Higher illumination levels have repeatedly been shown to increase the visibility of tasks, and the speed and accuracy of people performing those tasks[8].

It is clear, from our illumination measurements of the skylit classrooms in all three districts, that they tend to have significantly higher illumination levels than other classrooms. At peak conditions, average illumination levels in these skylit

[7] Readers who are interested in design issues are urged to consult some of the many excellent texts on daylighting, including *Tips for Daylighting with Windows* downloadable from http://eande.lbl.gov/BTP/pub/designguide/ or the *Skylighting Guidelines*, downloadable from www.energydesignresources.com.

[8] See page 91, *Lighting Handbook*, 8th Edition, Illuminating Engineering Society of North America, 1993.

classrooms are two to three times higher than in classrooms with electric lighting. Daylighting levels from windows probably tend to be somewhat lower and more variable, but windows are still likely to contribute to significantly higher illumination levels than classrooms without windows.

3.2.2 Improved Visibility Due to Improved Light Quality

It has been hypothesized that, compared to electric lighting, daylight has better "light quality" that is more appropriate for human visual tasks, thereby increasing the visibility of the task, independent of the illumination levels. "Light quality" is a holistic term which typically includes a number of attributes of the lit environment that are generally considered to be favorable. These are often described to include:

- Better distribution of light
- Better color rendition
- Absence of flicker
- Sparkle or highlights on three-dimensional objects

We'll discuss each in turn.

Better distribution of light relates to how the light falls in a space, and which surfaces are well illuminated. In electric lighting design for the typical office (after which many classroom lighting systems are patterned) most of the light is directed downwards towards the desk top. Thus, horizontal surfaces are more brightly illuminated than vertical surfaces.

In contrast, daylight is a very diffuse source of light, and tends to more evenly illuminate surfaces in all directions—up, down and sideways. Daylight entering from a window also tends to most brightly illuminate vertical surfaces, such as walls and the sides of people's faces.

Since classroom tasks involve a great deal of looking at people, and learning from material displayed on the walls of the classroom, it may be that the stronger vertical component of daylight improves visibility in this way.

Better color rendition relates to the way colors tend to look more vivid under daylight. Daylight includes a continuous spectrum of light wavelengths, whereas most electric sources are strong in some areas of the spectrum and weak in others. Therefore, daylight renders all colors well, and in tones that we tend to consider most "natural." Better color rendition may improve the visibility of the learning environment by making colors more vivid and true.

Absence of flicker relates to the very rapid fluctuations in light levels that can occur in electric lighting due to the alternating electrical current. People have complained that flicker is responsible for a multitude of problems, including headaches, eye strain, and attention deficit problems.

Daylight does not flicker. In contrast, fluorescent lamps run on magnetic ballasts can have a noticeable flicker. Fluorescent lights run on electronic ballasts cycle hundreds of times faster, and so have dramatically reduced flicker problems. Incandescent lamps generally are not perceived to have flicker problems. Studies have shown that people working under fluorescent lights with electronic ballasts have higher productivity than people working in similar conditions under lights with magnetic ballasts[9]. Thus, it may be that the reduction of flicker due to the presence of daylighting has a similar effect.

If we were able to distinguish daylight effects between classrooms with and without magnetic ballasts, we might be able to isolate this potential mechanism.

Sparkle or highlights on three-dimensional objects may be another aspect of lighting quality from daylight. Since a daylight source (window or skylight) is generally the brightest surface in the room, it tends to cause highlights and soft shadows. This might also be described as semi-directional lighting. Artists will tell you that they prefer daylight in their studios partly for the way the shadows and highlights make objects more attractive and easier to understand three-dimensionally. A similar effect may make objects more memorable and the setting more lively for students in the learning environment.

3.2.3 Improved Health

Daylight might improve performance through better long term health. A number of researchers have attempted to demonstrate these connections. While exposure to daylight is widely believed to promote health, the actual biological mechanisms are less certain. Exposure to daylight is known to increase the production of Vitamin D. The high illumination levels associated with daylight have also recently become recognized as a treatment for seasonal affective disorder (SAD). The timing of exposure to high illumination levels seems to be key to helping regulate our circadian rhythms[10]. Bright light suppresses the production of melatonin, a brain hormone, and increases alertness. Melatonin, which is secreted primarily at night, triggers a host of biochemical activities which may effect our immunological functions, including the production of estrogen. A recent article in *Science News* summarizes medical research on the relationship of exposure to light and cancers. A number of studies conducted in England and Sweden suggest that there may be a relationship between exposure to light and some types of estrogen-related cancers[11]. While these studies are somewhat controversial, what is certain is that there are complex biochemical pathways whereby exposure to light may influence our overall health.

[9] Veitch and Newsham, "Lighting Quality and Energy-Efficiency Effects on Task Performance, Mood, Health, Satisfaction and Comfort," IESNA Journal, Vol 27, Number 1, Winter 98.

[10] Boivin, D.B., Duffy, J.F., Kronauer, R.E., Czeisler, C.A., "Sensitivity of the Human Circadian Pacemaker to Moderately Bright Light", Journal of Biological Rhythms, Vol 9, Nos 3-4, 315-331, 1994.

[11] Rafoff, J "Does Light Have a Dark Side?" Science News, Volume 154, No 16, October 17, 1998.

3.2.4 Daylight Deprivation

The larger performance effect found for windows and daylight in Seattle and Fort Collins might be a function of greater sensitivity to indoor daylight exposure than exists in Capistrano students.

The Seattle and Fort Collins schools are very different from the Capistrano schools in one very important way: they tend to have more indoor facilities, such that children can spend all day indoors. This is, of course, necessary in a rainy or cold climate. Capistrano schools, on the other hand, typically have no interior hallways, play spaces, or eating areas. Therefore the Capistrano school designs require a student to go outside five or six times a day, for every recess, lunchtime, trip to the bathroom, or visit to the library or administration offices. The climate in Capistrano is also more amenable to outdoor play. It rarely rains, never snows, and is sunny and warm most of the year. Furthermore, as the most southerly of the districts, the days are significantly longer during the winter. Thus, Capistrano children are inevitably exposed to the daylight outdoors much more frequently than Seattle or Fort Collins children.

If frequent exposure to daylight improves long term health, then it would follow that the children in Seattle and Fort Collins, who see less sun overall, might be more sensitive to daylight exposure in their classrooms, and would show a greater magnitude of positive effects from a daylit classroom.

3.2.5 Improved Mood

Most people will tell you that they like daylight because it is more "natural[12]." When asked to elaborate, they are likely to say, "it just makes me feel better," or happier, or more content. While the exact mechanism may be unclear, it is certain that they think daylight improves their mood.

Daylight may help the students directly by improving their mood, or indirectly, by improving the mood of the teachers. Most teachers we interviewed felt that windows and daylight improved the mood of their students, keeping them calm and improving their attention spans. Indeed, a number of teachers we interviewed in daylit classrooms specifically manipulated the lights to affect the children's mood. They frequently turned off all the electric lights during story time or art periods, to help the children calm down and expand their imaginations.

The teachers that we interviewed were absolutely sure that a view through a window lowered their personal stress level. One teacher in Capistrano summarized this experience well: "When I've had it with the kids and I can't answer another question, I just take a minute, look out the window at the view, and then I'm OK. I'm calm and ready to go back into the fray."

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[12] Heschong Mahone Group, "Skylighting Baseline Study," December 1998 for Pacific Gas and Electric, contract 460 000 8215. 67% of people interviewed sited "more natural light" as the primary advantage of skylighting.

3.2.6 Higher Arousal Levels

It is know that high illumination levels cause higher arousal levels by suppressing the production of melatonin (see above). Thus, it is possible that the higher illumination levels in daylit classrooms simply help to keep children more alert and capable of absorbing new information. If this is true, then merely providing more illumination, from any source, should have positive consequences.

However, it would seem that the variability of daylight may also contribute to higher arousal levels. By creating an environment that is non-uniform in time, it may engender greater interest throughout the day. A number of classic studies have shown that patients in hospitals recover more quickly and have fewer complications when they are treated in rooms with daylight and/or a view[13]. The positive treatment results are generally interpreted to be a result of the added stimulus from the variability of daylight or a view. In one study patients with a view of trees did better than those with a view of a brick wall. In another study, patients with an obscured window that only allowed in diffused daylight did better than those with no window.

3.2.7 Improved Behavior

Some people believe that daylight improves behavior overall. The phrase "walk on the sunny side of the street" captures common wisdom that people tend to have a more positive outlook under sunny conditions.

Two researchers in Sweden conducted a study of 90 elementary school students and carefully tracked their behavior, health, and cortisol (a stress hormone) levels during a one year period in four classrooms. The four classrooms had different combinations of daylighting and fluorescent lighting conditions. They concluded that there were strong correlations between the amount of daylight and a student's behavior, especially when ranked for sociability and concentration. Children in classrooms with daylight or daylight-mimicking fluorescent lights tended to have typical seasonal and daily rhythms, while children in the classroom with only warm white fluorescent light showed aberrant patterns of both behavior and cortisol production. This study takes a holistic view of student performance, recognizing that there is a time for both arousal and calm, a time for cooperative social behavior and individual concentration. The authors concluded: "The results indicate, work in classrooms without daylight may upset the basic hormone pattern, and this in turn may influence the children's ability to concentrate or cooperate, and also eventually have an impact on annual body growth and sick leave.[14]" A study such as this, however, may be limited by not accounting for daylight exposure outside of the classroom.

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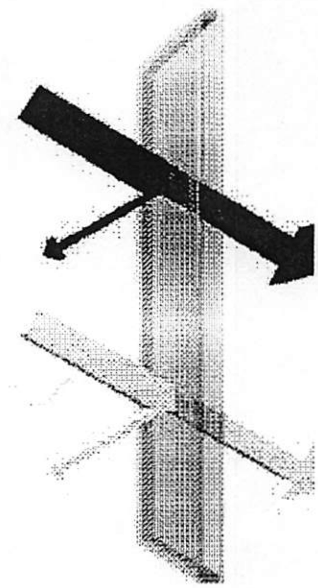
[13] Wilson, L.M., "Intensive Care Delirium. The effect of outside deprivation in a windowless unit" Archives of Internal Medicine, (1972) 130 225-226. Also: Ulrich, R., "View Through Window May Influence Recovery from Surgery", Science, Vol. 224, 420-421, 1983, and Keep, P., James, J., Inman, M., "Windows in the Intensive Therapy Unit", Anathesia, Vol 35, 257-262, 1980

[14] Kuller, R and Lindsten, C "Health and Behavior of Children in Classrooms with and without Windows", Journal of Environmental Psychology, (1992) 12, 305-317.

Window Technologies: Low-E Coatings

Low-emittance (Low-E) coating are microscopically thin, virtually invisible, metal or metallic oxide layei window or skylight glazing surface primarily to reduce the U-factor by suppressing radiative heat flow. mechanism of heat transfer in multilayer glazing is thermal radiation from a warm pane of glass to a cc glass surface with a low-emittance material and facing that coating into the gap between the glass laye significant amount of this radiant heat transfer, thus lowering the total heat flow through the window. L transparent to visible light. Different types of Low-E coatings have been designed to allow for high sola solar gain, or low solar gain.

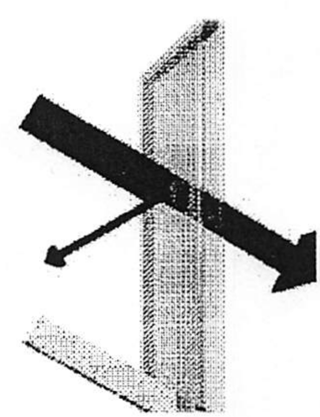
Double-Glazed with High-Solar-Gain Low-E Glass



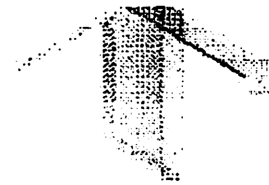
This figure illustrates the characteristics of a typical double-glazed window with a high-transmission, Low-E glass and **argon gas fill**. These Low-E glass products are often referred to as pyrolitic or hard coat Low-E glass, due to the glass coating process. The properties presented here are typical of a Low-E glass product designed to reduce heat loss but admit solar gain. High solar gain Low-E glass products are best suited for buildings located in heating-dominated climates. This Low-E glass type is also the product of choice for passive solar design projects due to the performance attributes relative to other Low-E glass products which have been developed to reduce solar gain.

In heating-dominated climates with a modest amount of cooling or climates where both heating and cooling are required, Low-E coatings with high, moderate or low solar gains may result in similar annual energy costs depending on the house design and operation. While the high solar gain glazing performs better in winter, the low solar gain performs better in summer. Low solar gain Low-E glazings are ideal for buildings located in cooling-dominated climates. Look at the energy use comparisons under **Window Selection** to see how different glazings perform in particular locations.

Double-Glazed with Moderate-Solar-Gain Low-E Glass



This figure illustrates the characteristics of a typical double-glazed window with a moderate solar gain Low-E glass and **argon gas fill**. These Low-E glass products are often referred to as sputtered (or soft-coat products) due to the glass coating process. (Note: Low solar gain Low-E products are also called sputtered coatings.) Such coatings reduce heat loss and let in a reasonable amount of solar gain and are suitable for climates with both heating and cooling concerns. In heating-dominated climates with a modest amount of cooling or climates where both heating and cooling are required, Low-E coatings with high, moderate or low solar gains may result in similar annual energy costs depending on the house design and operation. Look at the energy use comparisons under **Window Selection** to see how different glazings perform in particular locations.



Double-Glazed with Low-Solar-Gain Low-E Glass (Spectrally Selective)

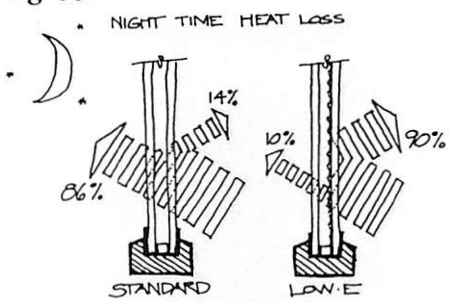
This figure illustrates the characteristics of a typical double-glazed window with a low solar gain Low-E glass and **argon gas fill**. These Low-E products are often referred to as sputtered (or soft-coat) due to the glass coating process. (Note: Moderate solar gain Low-E products are also called sputtered coatings.) This type of Low-E product, sometimes called spectrally selective Low-E glass, reduces heat loss in winter but also reduces heat gain in summer. Compared to most tinted and reflective glazings, this Low-E glass provides a higher level of visible light transmission for a given amount of solar heat reduction.

Low solar gain Low-E glazings are ideal for buildings located in cooling-dominated climates. In heating-dominated climates with a modest amount of cooling or climates where both heating and cooling are required, Low-E coatings with high, moderate or low solar gains may result in similar annual energy costs depending on the house design. While the high solar gain glazing performs better in winter, the low solar gain performs better in summer. Look at the energy use comparisons under **Window Selection** to see how different glazings perform in particular locations.

Variants on low solar gain Low-E coatings have also been developed which lower solar gains even further. However this further decrease in solar gains is achieved by reducing the visible transmittance as well - such coatings, which may appear slightly tinted, are best suited for applications where cooling is the dominant factor and where a slightly tinted effect is desired.

7.1 Low-E Coatings

Fig. 33



Standard window glass easily allows the sun's energy to pass through it. However, at night, it is equally effective at emitting infrared heat energy back through it to the exterior through the process known as radiative heat loss (**Fig. 33**). This *high-emissivity* characteristic of conventional glazing has led researchers to develop *low-emissivity* (low-E) coatings.

A low-E coating is a thin, invisible metallic layer—only several atoms in thickness—applied directly to glazing surfaces. In a typical double-pane application, the low-E coating is normally applied to the exterior face of the interior glazing (**Fig. 33**).

A low-E coating works in an ingenious way: while it is *transparent* to short-wave solar energy, it is *opaque* to long-wave infrared energy. What this means is that a low-E coating allows most of the sun's solar spectrum (including visible light) to pass through the window to the interior. But the coating reflects most heat energy (from room temperature objects) back to its source, which is a benefit both in the winter, because it keeps the heat in (**Fig. 34**), and in the summer, because it keeps out the heat radiated from warm objects outside (**Fig. 35**).

Fig. 34

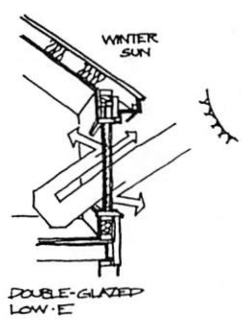
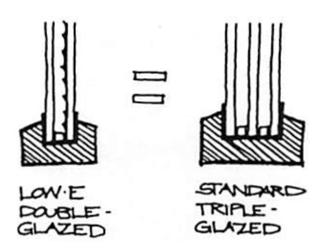


Fig. 35

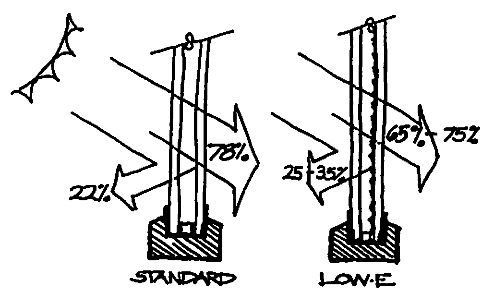
A low-E coating on one pane in a double-glazed window can give the window an insulating value about the same as a standard triple-glazed unit, without the added weight of a third glazing (**Fig. 36**). The lower weight reduces wear and tear on the window's hinges, casement cranks, etc.—making it easier to operate and giving the window longer life. It also reduces transportation costs, which means lower prices.

Fig. 36



There is usually some loss of solar contribution due to the low-E coating (**Fig. 37**). But while this reduces the benefits of passive solar heat gains somewhat, it is more than offset by the improved insulative value of the low-E window at night. An added bonus is that fewer UV rays make it through, which can mean less fading of carpets and fabric.

Fig. 37



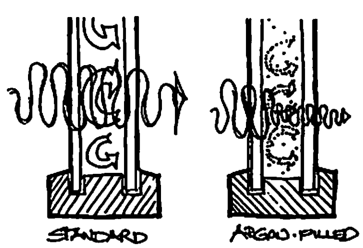
There are now many different types of low-E coatings with different performance characteristics. *Northern* low-E coatings are probably your best compromise in a heating climate like Canada's. They maximize solar heat gains and reduce heat loss at night. *Solar control* low-E coatings might be justified on west-facing windows when no other means of solar control is possible. These reduce solar heat gain as well as visibility, and are often tinted.

In most cases, the consumer has little control over window location, especially in an existing home. However, if you're designing a new home you may wish to use the ERS rating to compare different glazing options in different orientations.

7.2 Gas Fills

The other big advance in window technology has been the introduction of *inert gas fills* into the space between glazings (**Fig. 38**). The term *inert* refers to a class of chemically stable, non-reactive (safe) gases. Argon and krypton are the usual choice, with argon being the most common and cheapest.

Fig. 38

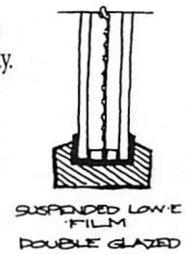


Filling the space between glazing layers with argon gas does two things: 1) it reduces *conduction* heat loss, because argon has a lower conductivity than air; and, 2) it reduces *convection* losses, because it is heavier than air and suppresses gas movement between the glazings (**Fig. 38**).

Krypton gives slightly better performance than argon and permits a smaller optimal spacing between panes (about 8 mm or a third of an inch). A narrow pane space requires less of this much-more-expensive gas, and allows multiple-pane systems with less chance of stress breakage. Since argon is more cost-effective, an increasing number of manufacturers offer it either as a standard feature or as an inexpensive upgrade.

7.3 Special Films

Fig. 39



Low-E coatings are also applied to thin sheets of transparent polyester, and suspended in the cavity between glazings (**Fig. 39**) or directly on the glass surface. This combines a high solar transmission with a low emissivity. Some films are designed to combine low emissivity with *reduced* solar transmission, making them ideal for southern climates or west-facing windows if solar gains are a severe problem during the summer.

While these films are effective in certain applications, you need to be sure that both you and the window supplier or manufacturer select the right film for the right application.

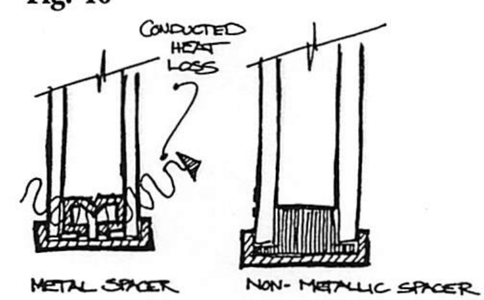
Researchers are working on exciting new categories of *smart* windows—*electrochromic, thermochromic* and *photochromic*—referred to as "switchable" glazing.

The most promising are electrochromic films that allow the amount of sunlight passing through windows to be controlled by means of a small current running through a transparent electrolite layer in the window. The biggest application for these films in the residential sector will be in buildings with large amounts of west glazing, where overheating in the summer is a problem.

Be careful about the pressure-sensitive after-market films which can be applied directly to existing windows. They are normally designed for the commercial building market. While some of these solar control films do have low-E coatings, they also have very low solar transmission factors. In other words, the energy saved in heat retention may be more than offset by the large reductions in solar gains. Use of these films are recommended for residential applications in only very specific cases such as a sunroom which tends to overheat in the summer.

7.4 Low-Conductivity Spacers

Fig. 40



Once radiation losses have been reduced through low-E films, and convection and conduction losses through the glazing have been reduced by gas fills, the *spacer* at the perimeter of the window becomes the weak thermal link in the window unit. As discussed in Section 3.4, most spacers have traditionally been made out of hollow aluminum. Although lightweight and durable, this metal is, unfortunately, very effective at conducting heat.

From an energy efficiency point of view, the new low-conductivity spacer is a major improvement. Many different approaches and materials are appearing in the marketplace, but performance varies considerably. Generally speaking, these spacers can improve the