

Impact of Indoor Use of Wood on the Quality of Interior Ambiances under Overcast and Clear Skies: Case Study of the Eugene H. Kruger Building, Québec City

Hoda Jafarian,^{a,*} Claude M. H. Demers,^a Pierre Blanchet,^b and Veronic Laundry^c

This paper explores the potential of wood for improving environmental quality in interior spaces. In northern climate cities where overcast skies predominate, interior spaces may appear gloomy or dull, since natural light is white and uniform. Nevertheless it is observed that wooden surfaces tend to create warmer and brighter spaces under overcast sky conditions. The objectives of this research were twofold. The first was evaluating the quality of wooden spaces under two sky conditions in terms of color, brightness and contrast. The second objective was to investigate daylight quantity of wooden spaces under diffuse and clear sky conditions. The method involved on site-surveys using Photolux, a calibrated photoluminance meter. Data consist of calibrated digital images that were processed to analyze the quality of spaces based on brightness, contrast, and color. The Kruger Building, with its internal wooden architectural structure and decorative indoor panels, was chosen as a site study for this research. Conclusions suggest that knowing the effect of different sky conditions on wooden spaces can help architects and other professionals in designing more comfortable and efficient ambiances. More particularly, this research addresses issues related to the quantitative effects of wood on daylighting distribution, visual comfort and luminance diversity.

Keywords: Color in space; Direct sunlight; Diffuse light; Digital image classification; Glare Luminance; Overcast sky; Photo luminance-meter; Wood structure; Wood decorative panels; Wood coating

Contact information: a: Laval University, School of Architecture, 1 Cote de la Fabrique, Quebec, G1K 7P4, Canada; b: Laval University, 2425, Rue de la Terrasse, NSERC chair on ecoresponsible wood construction (CIRCERB); c: FPInnovations, 319 Franquet, Quebec, Canada; *Corresponding author: hoda.jafarian.1@ulaval.ca

INTRODUCTION

A connection with nature, even in the modern world, is critical to people's physical and psychological wellbeing. Unfortunately, modern society increases the disconnection from nature. One of the areas where this increasing separation from nature is reflected is through the modern built environment. This is especially problematic because people spend around 80% of their time within buildings (Harijaona *et al.* 2009; Wymelenberg 2012; Veitch and Dikel 2013), a reality that is even more critical during winter in cold climates. There are several ways of emphasizing a feeling of nature inside the built environment. Biophilia design addresses the deficiencies of contemporary building and landscape by establishing a new framework for satisfying experience of nature in the built environment (Kellert 2005; Kellert *et al.* 2008; Kellert and Finnegan 2011; Browning *et al.* 2012). Kellert and Calabrese (2015) categorize these challenges into three sections. First is

through the direct experience of nature, which refers to actual contact with environmental features in the built environment including natural light, air, plants, animals, water, and landscapes. Second is via an indirect experience of nature, which refers to contact with the representation of nature including pictures, artwork, and natural materials such as wood furnishing and wooden fabrics. And finally, the experience of space and place refers to spatial features characteristic of natural environment such and complexity, mobility and way finding.

Emphasizing the feeling of nature inside buildings through the use of natural materials such as wood enhances physical and mental health, and therefore promotes wellbeing. These effects of wood have been studied in recent research. Wood was associated with decreased blood pressure in an Austrian study; high school students who were taught in classrooms with floors, ceilings, and walls finished in real wood had lower heart rates than students taught in classrooms with no wood elements (Kelz *et al.* 2011). Besides having lower heart rates, students in the wood classrooms also reported lower levels of stress than those in non-wood classrooms. Tsunetsugu *et al.* (2006) investigated study participants' responses to being in a room with 0%, 45%, or 90% of surfaces covered with wood. Diastolic blood pressure was lowest in the rooms with 90% wood. However, the 45% coverage room was the one most preferred by participants. When 45% of surfaces were covered with wood people said they felt most comfortable. Fell (2010) studied the autonomic responses of 119 subjects in wood and non-wood offices before, during, and after a stressful mental task. In this study sympathetic nervous system activation was lower in the wood room indicating lower stress. Skin conductance level was lower in the wood office when subjects were alone in the room. Furthermore, the rate of non-specific skin conductance responses, measurable divergent stressful thoughts, in the wood office was less than half the measured values from the non-wood office. In healthcare environments, natural materials such as wood and views outside are associated with better patient outcomes with respect to recovery times, lower pain perception, and positive dispositions (Fell 2002).

Although the impacts of wood on enhancing physical and mental health of buildings' occupants have become known, research on the effect of indoor wood material on visual comfort and energy efficiency of an interior ambiance is limited. This research therefore addresses the notion of visual comfort, which consists of a subjective impression related to the quantity, distribution, and quality of light. When addressed, it could lead to a decrease in external energy demand such as electrical lighting, and help in creating an energy-efficient ambiance.

Visual comfort is reached when objects can be seen clearly, without tiredness and in a pleasantly colored environment (Wymelenberg and Inanici 2009). A visually comfortable environment supports the wellbeing of buildings' occupants and their productivity. On the contrary, space with lighting that is too weak or that is extremely lit favors tiredness. In the long term, or sometimes sooner, these spaces can cause tiredness and other eyes problems, accompanied by a feeling of discomfort and a reduced visual performance (Wymelenberg and Inanici 2009). Absence of glare is one of the key parameters to reach visual comfort within a lit environment. Due to the great variability between individuals as to when they start to perceive a bright surface as disturbing, this research evaluates visual comfort quantitatively by comparing glare indices and also qualitatively by comparing brightness and contrast, as well as color temperature of the

space. Among the glare indices driven from the Photolux measurement system, Visual Comfort Probability (VCP) and Daylight Glare Index (DGI) evaluate glare caused from large sources such as the sun, while Unified Glare Ratio (UGR) is valid for small glare sources. The visual comfort probability (VCP) system evaluates lighting systems in terms of the percentage of the observer population that will accept the lighting system and its environment as being comfortable (Light Guide, 2012). Daylight Glare Index (DGI), however, is developed by Hopkins, and Table 1 shows the scale for DGI proposed by Chauvel *et al.* (1982) to evaluate glare. According to this scale, DGI values greater than or equal to 26 represent an uncomfortable space.

Table 1. Daylight Glare Index Scale (Chauvel *et al.* 1982)

Glare Criterion	Daylight Glare Index (DGI)
Just perceptible	16
Just acceptable	20
Just uncomfortable	26
Just intolerable	28

Therefore, this research aims to study visual characteristics of a wooden built environment under two sky conditions. For this reason, the Pavilion Eugene H. Kruger, a structure made with black spruce (*Picea mariana* Mill.) and Douglas fir (*Pseudotsuga menziesii* Mirb.), mostly covered with indoor decorative yellow birch (*Betula alleghaniensis* Britt.) and medium density fiberboard (MDF) panels, was chosen. This all-wood structure is known for its environmental control strategies, which led to a 32% reduction in operating energy consumption compared with a reference building, as defined by the Canadian building codes (Potvin and Demers 2007).

To take advantage of the benefits of the visually comforting characteristics of wooden spaces, it is necessary to know the effect of sky conditions on the wood and on the visual perception of wood in interior spaces. Therefore, on-site surveys were performed under two sky conditions, overcast and clear. Overcast skies are a critical consideration for daylighting strategies implemented in spaces located in northern latitudes, such as Canada. In Quebec City, overcast to partly overcast skies are dominant, and occur 63% of the year (Demers 2001). The diffuse light of the overcast sky is uniform, with lower lighting levels than sunlighting, and is generally associated with low contrast values. Interior spaces may be perceived as being gloomy and dull under overcast sky conditions, and therefore affect people's moods and atmosphere of spaces (Lam 1977). It is therefore important to study the effects of wooden spaces under the critical but characteristic conditions of the diffuse light, while still including the clear sky condition in order to cover different sky conditions throughout the year.

The main objectives of this research were to analyze visual characteristics of a wooden lit environment both quantitatively and qualitatively and its impact on reducing the demand for artificial lighting. Quantitative analysis used statistical information driven from Photolux photoluminance meter. The qualitative analysis was performed by comparing brightness, contrast, and color temperature values of an interior space. It was hypothesized that knowing the impact of daylight on wooden spaces would help architects and other professionals to produce visually comfortable and energy-efficient spaces by

decreasing the demand for artificial lighting.

EXPERIMENTAL

Wood Material: Surfaces and Light within the Space

The Eugene H. Kruger Building, especially its first floor, includes large areas of yellow birch surfaces distributed in a series of public places such as the cafeteria, atrium, and corridors. Six strategic viewpoints that provide a complete 180° overlook of those places were chosen. Figure 1 shows a schematic plan of the first floor and the location of those views that were selected according to the diversity of the location, the number of wood surfaces, the typology of the window system, as well as for their role in the daylighting system. Windows are mainly oriented on the southeastern facade, except for the atrium space where bi-lateral daylighting provides two facing window-walls. In all cases, windows are double-glazed clear with low-e coating and aluminum frames. Electric light sources were not present in the spaces during the experiment.

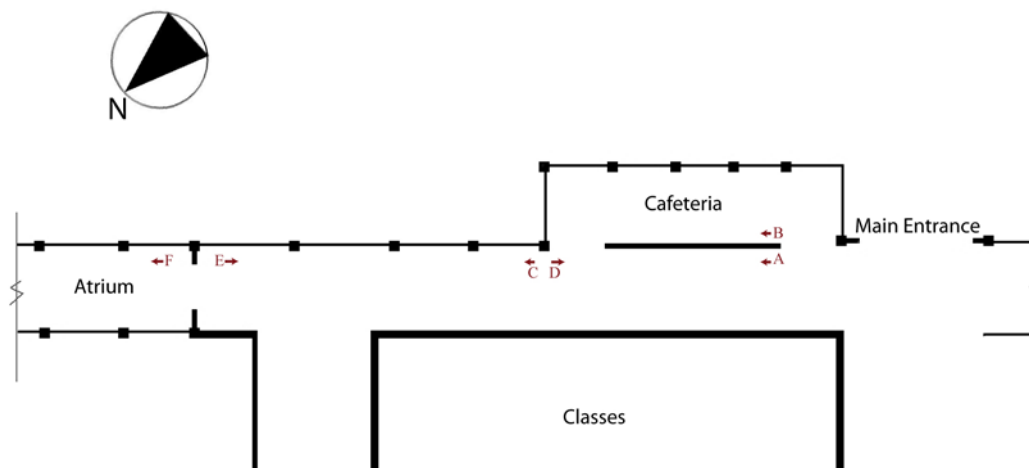


Fig. 1. Schematic plan of the first floor showing the location of 6 viewpoints: a) Viewpoint A shows the corridor without direct access to daylight, b) viewpoint B shows the cafeteria, c) viewpoint C shows the corridor, d) viewpoint D shows corridor and cafeteria, e) viewpoint E shows the corridor f) viewpoint shows the atrium.

Figure 2 shows all viewpoints and the main variables related to space and windows. Viewpoint A shows the corridor surrounded with 3 wooden wall surfaces without any direct access to daylight. The window is linear, located in the upper southeastern (right) side of the space. Viewpoint B shows the cafeteria and has 2 wood surfaces with direct access to daylight with a window-wall surface. Viewpoint C shows a corridor with direct access to daylight and has two wood surfaces. Viewpoint D shows the corridor (facing A) and cafeteria with direct access to daylight and has two wood surfaces. Viewpoint E shows the corridor with direct access to daylight and has two wood surfaces, mainly located in the upper parts of the space. Viewpoint F shows the atrium with direct access to views and daylight on two opposite window-walls and the wood surface essentially consists of the ceiling. For each point, an image resulting of multiple exposures with different settings was captured and later assembled into HDR (high dynamic range) images for analysis. Figure 3 shows the exposure parameter for HDR images of each viewpoint.

View	A	B	C	D	E	F
Diffuse Light						
Direct Light						
Variables	3 wood surfaces No view to outside Corridor Indirect daylighting Linear Window to wall ratio: 25%	1 wood surfaces 1 view to outside Cafeteria Direct daylighting Lateral Window to wall ratio: 90%	2 wood surfaces 1 view to outside Corridor Direct daylighting Lateral Window to wall ratio: 90%	2 wood surfaces 1 view to outside Corridor adjasunt Direct daylighting Lateral Window to wall ratio: 90%	2 wood surfaces 1 view to outside Corridor Direct daylighting Lateral Window to wall ratio: 90%	1 wood surfaces 2 view to outside Atrium Direct daylighting Bi- Lateral Window to wall ratio: 2x90%

Fig. 2. Six viewpoints from the first floor of the Pavilion Kruger under clear (direct sunlight) and overcast (diffuse light) skies

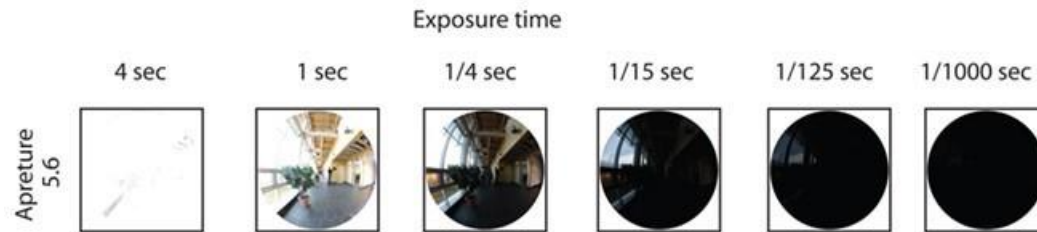


Fig. 3. Exposure parameter for Photolux photoluminance meter using HDR images

Methods

The research involved collection of large field-of-view luminance maps and illuminance measurements in interior spaces. The research setting (Fig. 2) consists of corridors, cafeteria, and atrium with southeast facing window exposure in Quebec City (46° 49’ N and 71° 13’ W), described in the previous section (Figs. 1 and 2). The study was performed during the late Fall season under two different sky conditions. A clear sky refers to 0 to 25% of cloud covering during daytime (e.g. 45 to 60 minutes of sunshine per hour); an overcast sky reflects 75 to 100% of cloud covering (e.g. 0 to 15 minutes of sunshine per hour) (Borisuit *et al.* 2014). This research addresses issues related to types of skies in terms of its effects on the visual character of wood, space, and light. Although interesting, it was not necessary to ensure that surveys were actually performed on the equinox, since the location and orientation of the sunlighting pattern was not at stake and thermal issues were not discussed. Also, the most critical condition correspond to the diffuse light of the overcast sky, which varies in terms of cloud covers independently from the time of year. The first series of images was captured on November 25th 2013 from 11:30 to 12:30 with overcast sky (approximately 90% cloud covering) during data collection, while the second series of photos was captured on December 5th 2013 from 11:30 to 12:30 with a combination of clear sky and direct sunlighting (approximately 5% cloud covering).

The method includes a contrast analysis of the pictures. A HDR photography

technique was used to collect luminance data in a large (180° by 180°) field of view (Inanici 2005). The Photolux photoluminance meter consists of a calibrated Canon EOS 50D equipped with an EF lens was used to produce High dynamic range (HDR) images consisting of different luminance ranges. This system was used to collect multiple exposure sequences and was fixed in place throughout the data collection for each viewpoint. Figure 3 illustrates an example of a series of 6 photos used to capture a different luminance range and the exposure sequences that were assembled into an HDR image using computational methods (Ward 2009). The resultant HDR photograph is an accurate luminance map of the scene, where pixel quantities closely correspond with physical quantities of luminance. The HDR photograph of each viewpoint was used for qualitative and quantitative analysis. This method enabled the quantitative investigation of wooden spaces with regard to sky condition. This procedure provided numerical data for each point of the wooden space and enabled the comparison of lighting distribution and the luminance of any point under different sky conditions.

HDR images were transferred into gray-scale mode images in order to study the luminance distribution on the surfaces of a space. This type of images do not produce any subjective response of the eye, as does the chromatic contrast found in color photographs (Demers 2007). False color images were used to analyze the viewpoints based on the daylight distribution within the space to evaluate the luminosity and visualize the spatial luminance and illuminance distributions (Inanici 2005).

Experimental Procedure

Over the course of the two-day study, HDR photographs and illumination data were analyzed in order to see which viewpoints best explained the effect of physical environment (direct/indirect access to daylight, number of wooden surfaces) on visual characteristics of the wooden built environment. Comparing glare indices for view point A and E under both sky conditions emphasize their great differences in terms of statistical information related to daylighting and glare variables. Table 2 shows the visual comfort probability (VCP) and direct glare index (DGI) results for all viewpoints of the study, highlighting the most contrasting locations for A and E.

Table 2. Statistical Information extracted from Photolux photoluminance system

Sky	Viewpoints	VCP	DGI
Diffuse	A	98%	18.9
	B	94%	28.6
	C	90%	26.6
	D	84%	28.2
	E	86%	30
	F	94%	21.8
Clear	A	90%	28.7
	B	66%	35.9
	C	81%	35
	D	52%	37.8
	E	62%	41.4
	F	79%	38.2

The physical analysis for these two points made it possible to observe significant differences, for which a more detailed analysis is performed in the following sections. For instance, viewpoint A has indirect access to daylight and the largest number of wooden surfaces (three). Meanwhile, viewpoint E has direct access to sunlight and views and only one wooden surface located on the ceiling of the space. These differences in terms of window typology, location, and number of wood surfaces create distinct ambiances which are discussed quantitatively and qualitatively in this paper.

To study the luminance diversity of wooden spaces under overcast and clear skies, Demers' daylight classification system was used (Demers 2007). This system of classification allows the comparison of brightness and contrast patterns of indoor surfaces in the presence of direct sunlight and diffuse light. This daylight classification system categorizes images of interior architecture by plotting the mean brightness of each composition against the standard deviation of its luminance values. This method is useful in creating an early schematic design tool for comparing contrast-driven architectural types, as well as providing comparative data on the luminous composition of a single space under varied lighting conditions. The system provides a schematic scale of global contrast, which identifies related perceptual aspects that have been recognized in association with the general visual appearance of space by scientists and architects (Demers 2007).

To evaluate the Color Temperature (CT) of wooden spaces under different sky conditions, the CIE $L^*a^*b^*$ system was used. Color is a subjective experience of the stimuli received by the human eye in the form of electromagnetic waves. The color of a space is another parameter that affects the perception of space and can also indirectly impact the amount of energy usage. As the perception of color is a psychophysical phenomenon and cannot be measured with exactitude, the international commission on illumination (CIE) developed a method to measure illumination, color, and colorimetry. CIE $L^*a^*b^*$ is a commonly used standard system that uses the parameters L^* , a^* , and b^* . L^* stands for the lightness of color (0 perfect black, 100 pure white), a^* refers to the position of the color between red (+100) and green (-100), and b^* defines the position of the color between yellow (+100) and blue (-100) in Fig. 4.

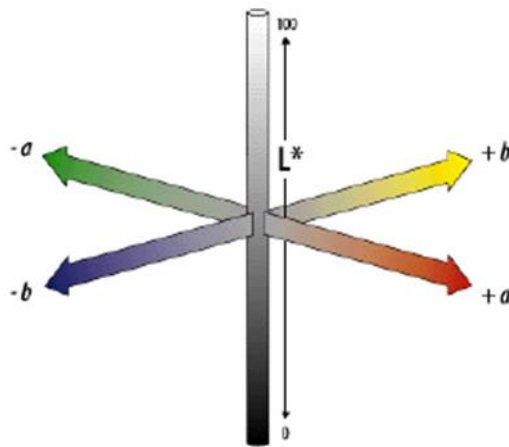


Fig. 4. CIE LAB Color Space (source adobe.com)

In this research, the value b^* was used to evaluate the color temperature of the images. Positive values refer to yellow, and negative values refer to blue. Therefore, higher b^* values indicate a yellowish and warm color, while lower b^* values point to a bluish and colder color (Troland 1922).

The CT for viewpoints A and E was analyzed using the Adobe Color CC software, which enables extracting b^* value of each image. This software also enables the selection of 5 punctual area or points, on each photograph. A selection of 5 identical points were selected on photos taken on clear and over cast sky conditions. These points were selected considering the relation between sky condition and the location of wood on affecting the color temperature of the space. More precisely the study compared the b^* values of each 5 points on overcast sky images with the b^* value of the identical points from clear sky image to figure out the effect of sky conditions and luminous reflections in the wood on the overall CT of the space. HDR images were used for this purpose as they reach the higher level of accuracy in color rendering of daylight.

RESULTS AND DISCUSSION

Knowing the effect of light from different sky conditions in spaces that include wooden surfaces is important for choosing the right material for a particular climate. The following section discusses the results for viewpoints A and E, which were found to be the most contrasting in terms of ambiances, and challenging in terms of visual perception and glare (refer to Table 2). The quantitative analysis addresses glare issues in relation to luminance maps, while the qualitative analysis include notions of global assessment of brightness and contrast, as well as color.

Quantitative Analysis

In Fig. 5, the selected viewpoints A and E are shown under overcast and clear skies. Calibrated high dynamic range (HDR) images, grey scale mode and false color image of these viewpoints are used in order to have a more detailed perspective of the viewpoints.

The false color images issued from the Photolux photoluminance meter analysis of viewpoint A showed a uniform ambiance in terms of daylighting under both sky conditions, which was a result of the use of more extensive wood surfaces as well as the indirect access to sunlight. It also showed the higher level of visual comfort probability, since the eye may perceive several low reflectance (about 39%) surfaces consisting of the decorative wood indoor panel (reflectivity of about 15%).

Viewpoint E, however, showed two different quantitative results under the discussed sky conditions and also exhibited distinct architectural ambiances with regard to the quantity of daylight distributed within the space. In other words, when viewpoint E was observed under clear skies, it was found to be a luminance space with harsh shadows, whereas when viewpoint E was observed under overcast skies, it was found to have a more uniform ambiance. A comparison of the false color images between viewpoint A under clear skies and viewpoint E under overcast skies showed the same range in color and, therefore, the same quantity of daylight in the space. This showed that increasing the quantity of yellow birch wood used within the space did not decrease the quantity of daylight.

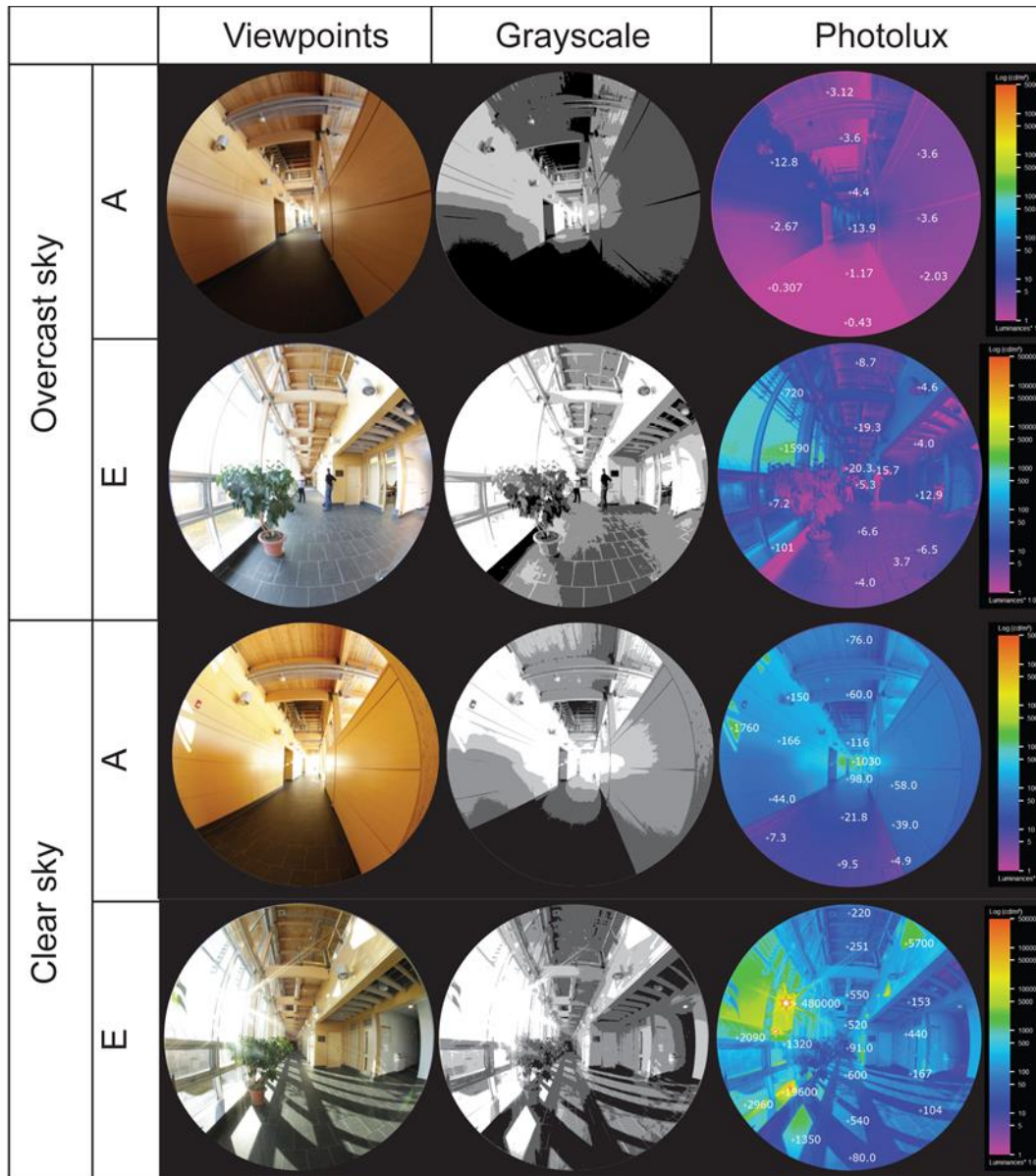


Fig. 5. Visual results from Photolux photoluminance meter analysis: high dynamic range (HDR) image (left), gray scale mode (middle), and false color (right) images of the selected viewpoints

Analyzing visual characteristics of wooden spaces in the presence of direct daylight and diffuse skylight based on statistical information extracted from the Photolux photoluminance meter system revealed differences in terms of interpretation of the glare indices. According to Table 2, discussed in the previous section to determine the most challenging spaces, viewpoint A on a cloudy day (overcast skies) represented an ambiance in which 98% of occupants could expect to be comfortable, and this was illustrated with its DGI of 18.9. As shown in Fig. 6, this confirmed that the level of glare was acceptable. However, this consistency between glare indices did not exist for viewpoint E for the same cloudy day. At viewpoint E, the DGI value of 30 indicated the existence of an intolerable glare within the space, even though the VCP predicted that 86% of occupants would be comfortable visually within the space. The presence of large window walls in the viewfield

probably accounts for much of these differences. The higher location of wood surfaces, away from the center of the visual field, could not provide the needed visual rest to diminish glare. These difference in glare results existed between the VCP and the DGI of viewpoints A and E for the sunny condition as well. For instance, the VCP of viewpoint A referred to a space in which 90% of the occupants could be expected to be comfortable, while its DGI value of 28.7 referred to a space in which the glare had reached an intolerable rank. Glare indices obtained from the Photolux photoluminance meter system showed that analyzing visual comfort of a space based on statistical information obtained from computational software was not absolute, and remained largely dependent on the location of windows and wood surfaces in the visual field.

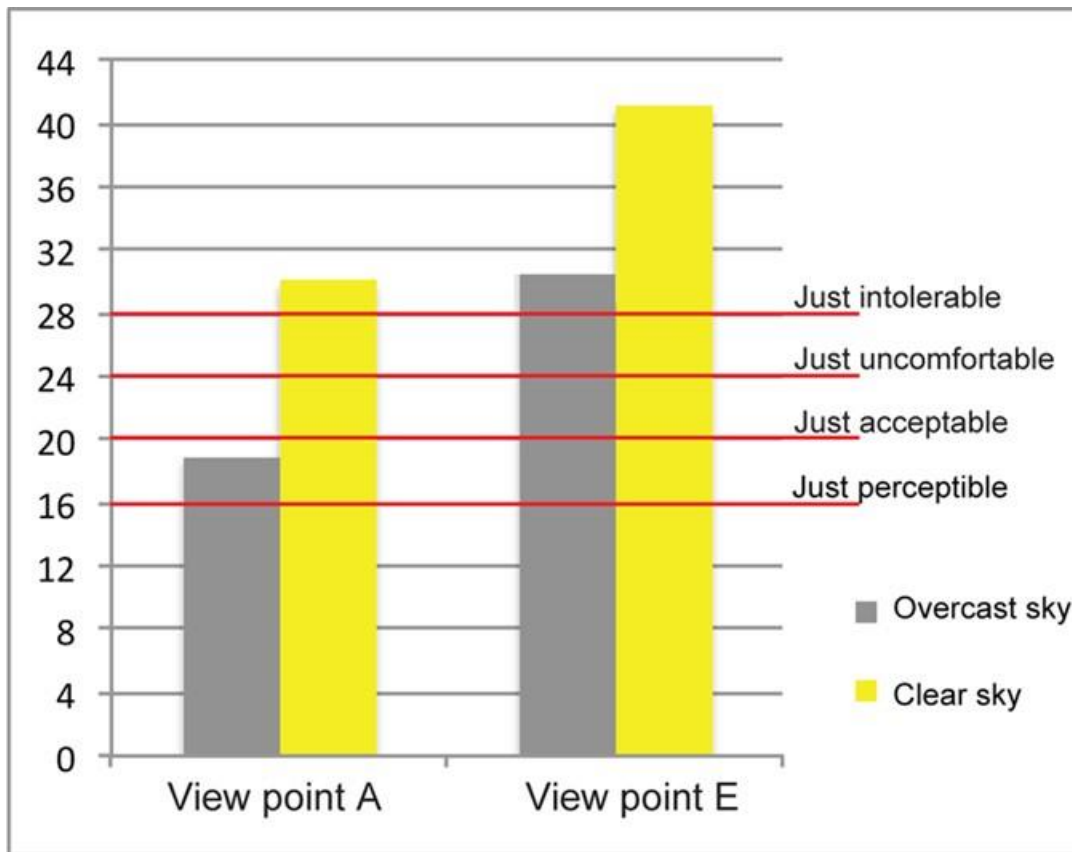


Fig. 6. Direct glare index (DGI) for viewpoints A and E under clear and overcast skies

Qualitative Analysis – Color of the Space

In Nordic and cold climate countries with predominantly overcast skies, the risk of creating gloomy, dull, or even cold ambiances is high. To address this problem, architects and interior designers should be aware of the impact of materials on creating ambiances that enhance the users' mood and enrich their experience within the architectural environment. Color temperature of the space aims to show the impact of three types of wood as commonly used material in built environments, their position, sky conditions and daylighting ambiances on the color of the whole space.

HDR images enable studying color of other surfaces by the light reflected from wood surfaces coming from the structure and indoor decorative panels. For this reason

HDR images of selected viewpoints were imported into Adobe Color CC. As it could be expected, Figs. 7 and 8 showed that the b^* value for the 5 selected points of diffuse light was lower than that of the direct sunlight. Therefore, viewpoints A and E on a sunny day seemed warmer than a cloudy one. However, a comparison of these two viewpoints showed that viewpoint A, with its 3 wooden surfaces and indirect access to sunlight, was more greatly affected in terms of CT than was viewpoint E, with its two wooden surfaces and access to direct sunlight. The effect, therefore, of the higher wood ratio in increasing the CT of the space was even greater than the effect of direct sunlight. This showed the significant impact of wood in improving the CT of the entire space.

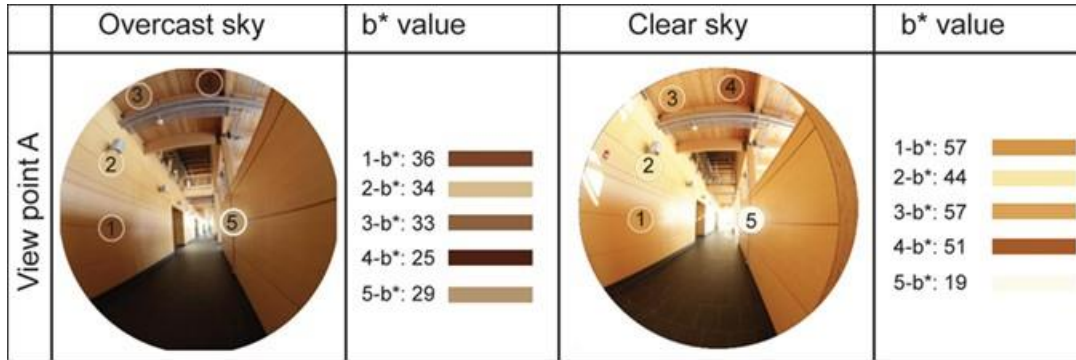


Fig. 7. The b^* values of the five points in image A under direct sun and diffuse light

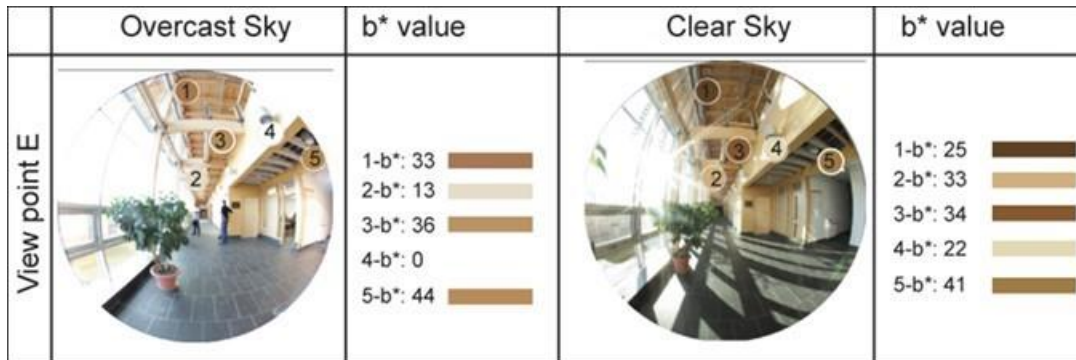


Fig. 8. The b^* values of the five points in image E under direct sun and diffuse light

Qualitative Analysis – Brightness and Contrast

Classification of images based on their brightness and contrast assists architects and professionals to identify the main elements of such analysis and allows the comparison of design hypothesis or existing spaces in a systematic manner (Demers 1997). Such classification should unify the language of luminous ambiances in architecture. More particularly, the following classification method is helpful in order to compare the impact of each variable on the brightness and contrast of the space. It should be reminded that the brightness of an image is different from the brightness perceived by the users since the latter is a sensation. However, since the experimental research is not evaluating the perception of the users, it remains the best way to study and compare the overall quality of the space through its brightness and contrast values.

Figure 9 shows a classification system of images (Demers 2007) from dark to light and from low contrast to high contrast. The entire range of brightness and contrast values collected during the comparison of overcast (diffuse light) and clear (direct daylighting)

sky conditions lies within the dashed square in Fig. 9. The enlarged dashed square and the classification of both series of images are shown in Fig. 10.

Brightness and contrast affect the way a person perceives architectural space and how the space will affect the users. Spaces with direct access to sunlight, like viewpoint E, are considered to have higher brightness and contrast values than spaces with indirect access to sunlight, like viewpoint A. A comparison of the brightness and contrast of viewpoints A and E showed that viewpoint A, under both conditions, was located in the low brightness, low contrast zone. Meanwhile, viewpoint E was found to be located in the high brightness, high contrast zone under both clear (direct sunlight) and overcast (diffuse light) conditions.

This classification illustrated that the viewpoints from the overcast sky have higher brightness contrast value than those obtained from a clear sky. This result showed the effect of sky conditions on the brightness and contrast of spaces containing wood surfaces. In other words, in the wood-characterized space with a direct view to the outside, higher brightness and contrast values were found on a cloudy day than on the sunny day. Therefore the higher values for brightness and contrast will result in a decrease on the demand for external energy from the users of the space. However, in wooden spaces with only indirect access to daylight, that is, viewpoint A, the light was reflected off the wood surfaces of the corridor and the result was the opposite: brightness and contrast were higher under the clear sky conditions than under the overcast condition. When the wood surfaces were more extensive within the space, the difference between the two sky conditions became greater.

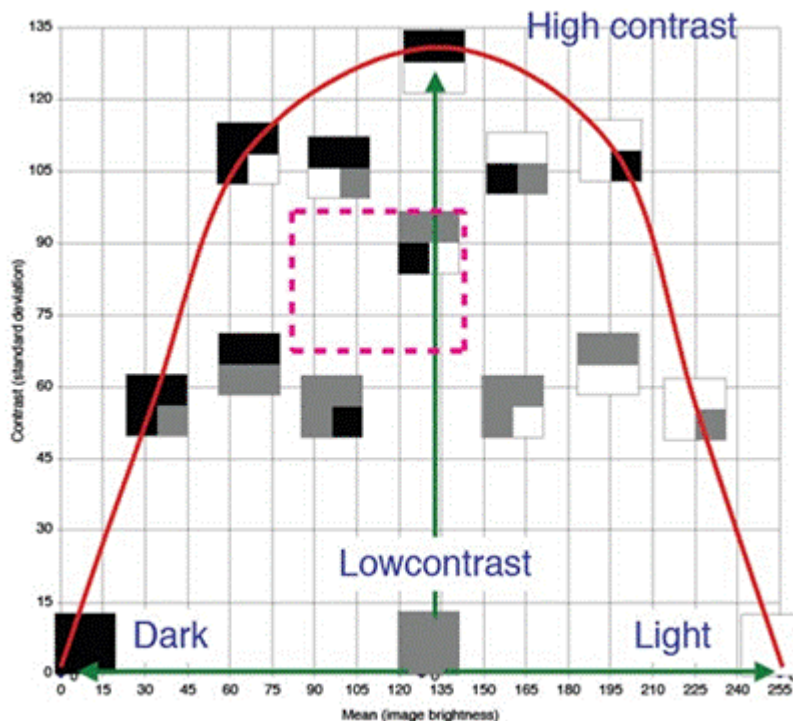


Fig. 9. Range of contrast and brightness values of the daylight classification system and those that were observed in this research (dashed square)

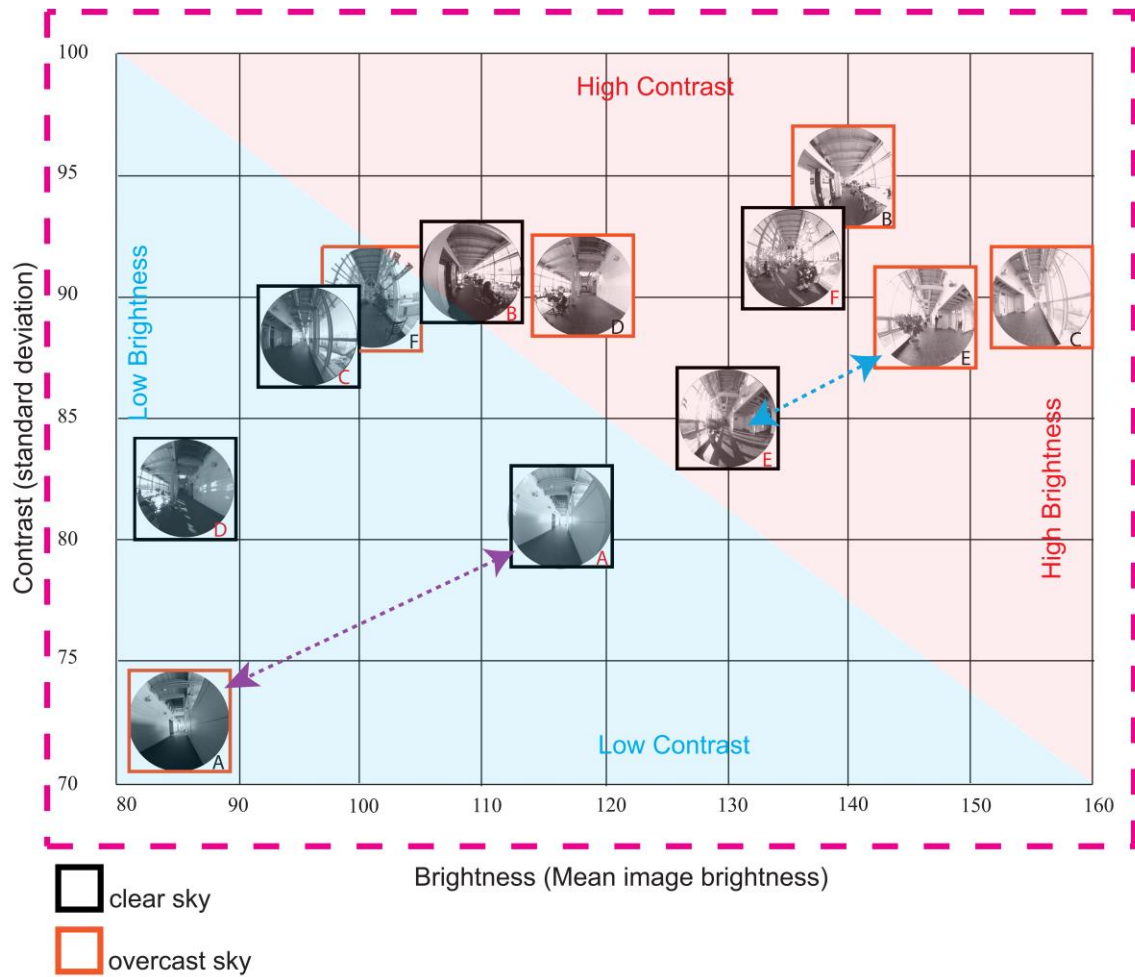


Fig. 10. Classification of the 6 viewpoints in relation to contrast and brightness for overcast (cloudy) and clear (sunny) sky conditions. (Enlarged dashed square illustrated in Fig. 9)

CONCLUSIONS

This study used the Eugene H. Kruger Building, located in Quebec City, as a successful project in which wood is used as the main material. The research studied the visual characteristics of a wooden space in the presence of direct daylight from the clear sky and diffuse light of the overcast sky in terms of quantitative values related to glare indices as well as qualitative parameters such as brightness and contrast and color temperature of a space. It is important to take into consideration that visual comfort depends on physiological and psychological factors related to each individual and is also affected by physical factors such as his age, visual acuity or the possibility to have access to views to look outside.

1. This research showed that in the presence of indirect natural lighting, increasing the quantity of decorative Yellow birch panels used in a space decreased the contrast within the space and provided a more equal balance of lighting across the space, facilitating greater uniformity within the space. Therefore, increasing wooden surfaces in the space

decreased both the contrast and the harsh shadows while increasing the brightness and luminance values. Other types of wood and finishes would need to be studied to validate these positive effects on visual perception.

2. This paper also shows the impact of luminance variability on visual comfort when indoor decorative wooden panels were applied using Demers' system of classification. This classification, which enables to compare all 6 viewpoints, showed that wooden spaces were brighter under overcast than clear skies (shown in figure 10). Although individuals can react differently to the same environment, using yellow birch decorative panels appeared to be good choices in this project, as Quebec City has a predominant diffuse sky light in winter. Other types of wood would need to be studied to validate these effects. This figure shows that the type of wood used in the Eugene H. Kruger building was helpful in creating a brighter space under overcast sky condition. The demand for electrical energy on overcast sky days is higher than clear skies. The above-mentioned findings support the idea that using yellow birch or a similar wood type should promote the creation of a brighter space under both overcast and clear sky conditions and therefore decrease the demand for electrical energy.
3. The relationship between sky condition and the color of wooden spaces was studied. It was shown that although direct sunlight increased the b^* value and helped in creating a warm ambiance, the impact of yellow birch used in this project optimized the quality of the space by increasing its color temperature, which attained even higher levels than the effect of direct sunlight.
4. Analyzing the quality of interior ambiances based on statistical information obtained from computation software is not a reliable way to qualify the interior ambiances. For instance, statistical information driven from Photolux photoluminance analysis software predicted the existence of an intolerable glare in most of the viewpoints (6 viewpoints, each photographed under 2 types of sky conditions). However the users' tolerance toward glare from daylighting is higher than the glare from electrical lighting. Their tolerance also depends on the time of the year as well as the climatic zone of the project. The study suggests that studying visual characteristics of an interior ambiance needs a detailed analysis, which should take into consideration several aspects such as the time of the year, usage of the space and climate.
5. Although this research showed the effectiveness of yellow birch in improving the quality of the ambiance by increasing the brightness of the space on overcast sky conditions and increasing the color of the space, further studies would be necessary to investigate the impact of other commonly used wood types on the quality of the built environment. By encouraging a consideration of the use of the space and the climate situation, this information should help designers and architects to choose the right amount and type of wood necessary to give the interior the ambiance they have in mind.
6. Achieving that balance of energy efficiency and while having visually comfortable spaces should be primarily done through the wits of architects, engineers and designers. That manipulation of different types and ratio of wood generate the desired visual impact to an interior of an architectural ambiance.

LIMITATION OF THE RESEARCH

The evaluation of visual comfort of interior ambiances would ultimately need to be confirmed by participants performing their own assessment on the visual preferences of the ambiance. Questionnaires would provide actual visual impressions of users to confirm observed lighting patterns discussed within the present research. At the moment, the results are limited to measured data and evacuate the complexity of the visual experience. Further studies would be necessary to evaluate visual preferences of users, conducting for instance a limited series of experiments selected from this study. Furthermore, knowing the impact of other types and colors of wood enables to confirm the significant effect of wood on enhancing visual comfort within an architectural ambiance.

The research addresses energy efficiency only in its relation to the contribution of indoor decorative panels to optimize daylighting. Further studies should also include the thermal potential of wood to integrate bioclimatic solutions adapted to low energy buildings.

ACKNOWLEDGMENTS

The authors would like to thank the Natural Sciences and Engineering Research Council (NSERC) of Canada for its support under the Industrial Research Chair Program IRCPJ 461745 as well as the chair industrial partners.

REFERENCES CITED

- Borisuit, A. F Linhart, J-L Scartezzini and M Münch. (2014). "Effects of realistic office daylighting and electric lighting conditions on visual comfort, alertness and mood," *Lighting Research and Technology*, 47(2), 192-209.
- Browning, W .D., Ryan, C., Kallianpurkar, N., Laburto, L., Watson, S., and Knop, T. (2012). *The Economics of Biophilia, Why Designing with Nature in Mind Makes Financial Sense*, Terrapin Bright Green, New York.
- Chauvel, P., Collins, J. B., Dogniaux, R., and Longmore, J. (1982). "Glare from windows: Current views of the problem," *Lighting Research & Technology* 14(1), 31-46. DOI: 10.1177/096032718201400103
- Demers, C. M. H. (2007). "A classification of daylighting qualities based on contrast and brightness analysis," ASES 2007: American Solar Energy Soc. Inc., Cleveland, OH.
- Demers, C. M. H. (2001). "Études environnementales pour l'édifice de la Caisse et de Dépôt et de Placement du Québec à Montréal," *Research report*, Groupe de recherche en ambiances physiques, École d'architecture, Université Laval, Québec, Canada.
- Fell, D. R. (2010). *Wood in the Human Environment: Restorative Properties of Wood in the Built Indoor Environment*, Ph.D. dissertation, Univ. of British Columbia, Vancouver, BC.

- Fell, D. (2002) "Party platform change in Taiwan's 1990s elections," *Issues & Studies*, 38 (2):31-60.
- Harijaona, Z. Cantin, R., and Guarracino, G. (2009). "Numerical modeling of impact of radiation exchanges between wood and building thermal comfort," *Advances in Computational Tools for Engineering Applications*, Zouk Mosbeh, 15-17 July. DOI: 10.1109/ACTEA.2009.5227920
- Illuminating Engineering Society of North America (IESNA). (2008). *IES Lighting Handbook Reference Volume*, J. E. Kauffman (ed.), Illuminating Engineering Society of North America (IESNA), New York.
- Illuminating engineering society: <http://www.ies.org/> [Accessed on June 2015]
- Inanici, M. (2005). *Per-Pixel Lighting Data Analysis*, Ernesto Orlando Lawrence Berkeley National Laboratory, Berkeley, CA, pg. 29. DOI: 10.2172/891345
- Kelz, C., Grote, V., and Moser, M. (2011). "Interior wood use in classrooms reduces pupils' Stress levels," *Proceedings of the 9th Biennial Conference on Environmental Psychology*, Eindhoven Technical University.
- Kellert, S. and B. Finnegan. 2011. *Biophilic Design: the Architecture of Life*. A 60 minute video. www.bullfrogfilms.com
- Kellert, S., Heerwagen, J., and Mador, M. (eds.) (2008). *Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life*, John Wiley, Hoboken, NJ.
- Kellert, S. (2005). *Building for Life: Understanding and Designing the Human-Nature Connection*, Island Press, Washington, DC.
- Kellert, S. and Calabrese, E. 2015. *The Practice of Biophilic Design*. www.biophilic-design.com
- Lam, W. M. C. (1977). *Perception and Lighting as Formgivers for Architecture*. McGraw-Hill: New York.
- Lawrence Berkeley National Laboratory (LBNL) (2002). "A quick and easy web-based assessment tool for day/electric lighting," *Environ. Energy Technol. Div. News* (3)4.
- Light Guide: Controlling Glare (2012) <http://www.lightsearch.com> [Access Sept. 2014]
- Potvin, A., and Demers, C. M. H. (2007). "Passive environmental control strategies for a cold climate the Eugene-H-Kruger building at Laval University," Paper presented at the ASES 2007: American Solar Energy Society Inc., Cleveland.
- Tsunetsugu, Y., Miyazaki, Y., and Sato, H. (2006). "Physiological effects in humans induced by the visual stimulation of room interiors with different wood quantities," *Wood Science* 53(1), 11-16. DOI: 10.1007/s10086-006-0812-5
- Troland, L. T. (1922). "Report of Committee on Colorimetry for 1920-21," *Journal of the Optical Society of America* 6(6), 527-96. DOI:10.1364/JOSA.6.000527
- Veitch, J. A., and Dikel, E. E. (2013). "Imagining the future of office lighting: Smart, sustainable, solid-state," *Light: The Official Newsletter of the Indian Society of Lighting Engineers* 13(4), 10-22.
- Ward, G. (2009). 17th Color Imaging Conference HDRI Tutorial (2009). Available at: <http://anywhere.com/gward/pickup/CIC17HDRcourse.pdf>.
- Wymelenberg, K. G. V.D, and Inanici, M. (2009). "A Study of Luminance Distribution Patterns and Occupant Preference in Daylit Offices," Paper presented at the PLEA2009 - 26th Conference on Passive and Low Energy Architecture, Quebec City.

Wymelenberg, K. G. V. D. (2012). *Evaluation human visual performance in an office environment using luminance-based metrics*, Ph.D. dissertation, University of Washington, Seattle, WA.

Article submitted: July 31, 2015; Peer review completed: September 23, 2015; Revised version received: November 17, 2015; Accepted: November 21, 2015; Published: January 4, 2016.

DOI: 10.15376/biores.11.1.1647-1663