Experiencing Wooden Ambiences with Nordic Light: Scale Model Comparative Studies under Real Skies

Geneviève Poirier,* Claude M. H. Demers, and André Potvin

This study explored the potential of natural light to enhance wooden interior environments. Under Nordic light, natural materials such as wood finishes present an opportunity to create warm, bright, and pleasant atmospheres, enhancing psychological well-being and comfort. The objectives of this project were twofold: first, to study the diversity of northern sky conditions in terms of cloud cover and thickness, and, second, to evaluate the impacts of the diversity of natural light on five wooden scale models. The methodology involved weather data collection that took place during the spring equinox in Quebec City. In order to create a cloudiness scale, sky condition data and photometric measurements were collected. A photographic survey occurred in five scale models made with interior wooden finishes of varying color combinations, documenting the impact of sky diversity on brightness, hue, and contrast. Simultaneous scale model studies under a real sky allowed direct comparison under the same lighting conditions. There was a remarkable diversity of visual ambiences for a southeast-oriented space depending on the position of the sun and sky conditions. Gray-dyed wooden finishes created dull and unchanging atmospheres, while yellow oaked surfaces allowed various dynamic ambiences.

Keywords: Color; Wood; Sky cloudiness; Sun; Scale model; Real sky; Daylighting; Ambience; Light; Wood finish

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INTRODUCTION

Contact with nature reduces stress and has positive impacts on psychological health and well-being (Rice *et al.* 2006; Burnard *et al.* 2015). Biophilia, defined as human's inherent inclination towards nature, reveals mankind's dependence on natural settings (Kellert *et al.* 2008). In the northern Canadian metropolis of Quebec City (46°49'N), inhabitants spend up to 80% of their time in interior spaces, and even more time during the cold season (Van den Wymelenberg and Inanici 2009; Jafarian *et al.* 2016), when contact with nature is considerably reduced. Therefore, the use of natural materials for interior surfaces, such as wood, presents an opportunity to create warm, bright, and pleasant ambiences, enhancing psychological well-being and comfort.

Several studies have examined the effect of wood in furniture, decorations, interior floors, walls, and ceiling surface coverings on the perceptions of the inhabitants. The results of these studies were similar: wood was considered a "warm," "pleasant," "natural," and "relaxing" material, creating spaces considered generally more comfortable and preferred than other common building materials (Rice *et al*. 2006; Tsunetsugu *et al.* 2007; Ohta *et al.* 2008; Fell 2010; Burnard *et al.* 2015). Although wood has been compared with other materials in these studies, few have examined the luminous and visual effects of wooden spaces compared with each other, varying by finish and color. Furthermore, these studies have not considered the remarkable diversity of natural light created by different sky conditions and sun positions; most of the spaces examined were artificially illuminated.

Borisuit *et al.* (2014) studied the effect of natural light dynamism on the participants' mood, alertness, and visual comfort in an office environment. Both photometric and qualitative data showed significant changes in results depending on the hour of the day and the weather conditions. The participants' visual comfort and appreciation, as well as the measured luminance, changed depending on the sun position and sky conditions. Van den Wymelenberg and Inanici (2009) evaluated the impacts of natural lighting on visual comfort, revealing significant changes depending on the diversity of sky conditions. Participants had to manipulate blinds in a southwest-oriented office to create a visually comfortable environment during both sunny and cloudy conditions. It was statistically impossible to distinguish the patterns chosen by the participants because they were all exposed under different sky conditions. Although these studies evaluated the potential effects of sky conditions and sun position on the inhabitants' comfort and visual acceptance, the results did not consider the materials in the interior surfaces.

The wall, floor, ceiling color and ability to reflect has the potential to create brighter or darker ambiences, and warm or cold environments, greatly modifying the inhabitants' perceptions. Similarly, the colors of interior surfaces of spaces impact the emotional well-being and mood of the inhabitants (Chain *et al.* 2001; Küller *et al.* 2009; Kuijsters *et al.* 2015). Although many studies have examined the effects of various colors, those surfaces were often fully painted and artificially illuminated. In any case, wood grain provides more detailed and textured surfaces, stimulating the visual and tactile perception of occupants.

Natural light has the potential to warm and enhance interior spaces by bouncing off of natural wooden finishes and surfaces. In that context, a study conducted in Quebec City revealed relevant issues in terms of methods and results. Jafarian (2016) quantitatively compared wooden scale models in terms of brightness, hue, contrast, and visual comfort. The study disclosed how different environments, made from oak, dark walnut, and gray wooden dyed surfaces, with two types of gloss, were defined by interactions with natural light. The comparison of various combinations and positions of these surfaces on floors, ceilings, and walls showed results with remarkably contrasting ambiences, from very dark to very bright, and from very warm to very cold. Results also indicated that overcast skies created colder, smoother, and lower contrast ambiences than clear skies. However, the cited study used a single scale model with a fictive orientation and sun position, which limited realistic and context-adapted results. No direct comparison between the models was possible because the author had to disassemble the scale model before creating another one. Although the effects of sky conditions (overcast and clear) were studied, the specific effects of the sun position on interior ambiences were not examined.

The varying color temperatures of daylighting should affect the ambience of an interior space lit through windows. Whereas artificial light is relatively stable in terms of its color temperature (CT), measured in Kelvin (K) degrees, natural light is remarkably different and creates changing ambiences for inside environments throughout the day. For example, diffuse light under an overcast sky creates an average CT of 6000 °K, sunset orange light can be approximately 2000 °K, and clear blue sky is up to 20,000 °K, as represented in Fig. 1 (Chain *et al.* 2001).

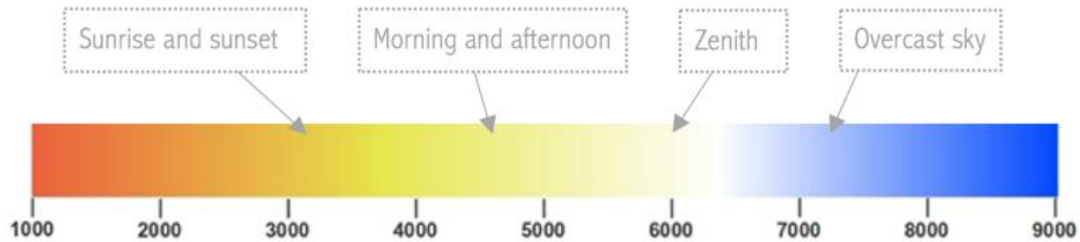


Fig. 1. Usual color temperature (CT) in Kelvin for different sky conditions and sun position (adapted from Chain *et al.* 2001)

Sky conditions and sun position affect color changes in natural light and accordingly create distinct ambiences in terms of brightness, hues, and contrast. Those changes can potentially modify our perception of space. Interior surfaces, such as dyed wooden surfaces, also have an effect on the atmosphere created, depending on their color, position, and combination. There exist several CIE standard sky models used for daylighting predictions and simulations (Li *et al.* 2009; Inanici 2013; Inanici and Hashemloo 2016), but few studies have examined the direct effects of weather conditions on visual ambiences in physical models using both qualitative and quantitative data. Although sky conditions are usually simplified to three types—clear, overcast, and partly overcast—in most applications of daylighting science (Inanici 2016; Jafarian *et al*. 2016), it is well known that various types of cloud coverage can be found throughout a day. Environment Canada uses a vocabulary to classify cloud cover (percentage of cloud coverage compared with clear sky), but mostly addresses cloud thickness (the ability of the sun to break through the clouds and create a sunspot) in terms of sky transparency for astronomic purposes. This research explores cloud thickness for its potential to create various visual ambiences and should be used for daylighting applications as well. Finally, no study has precisely examined the perceived differences in wooden spaces as created by sky conditions throughout the day.

EXPERIMENTAL

The first objective of this qualitative and exploratory research was to study the diversity of northern sky conditions in terms of cloud cover and thickness to create a cloudiness scale in relation to the environmental context. The second objective was to evaluate the impacts of daylighting and its diversity on various wooden spaces. More specifically, the study simultaneously compared five wooden scale model ambiences in terms of wood quality (color and reflectance of dyed surfaces), quantity, and combination of surfaces under daylighting.

The research hypothesis was that systematic analysis of wood finishes differing in brightness, contrast, and hue values should result in greater visual ambience diversity depending on sun position, cloud cover, and its thickness. Colors and combination of wooden surface finishes should moreover create various and distinct atmospheres within the spaces. The results would thus present a wide array of the potentials of wood finishes to enhance an architectural ambience in relation to skylight, therefore allowing more flexibility when combining variables. This section is divided into four sections: scale model variables, ambience typologies, environmental context, and experimental procedure.

Scale Models Variables: Dimensions and Wood Surface Types

The physical models used in this exploratory research on ambiences were built at a 1:10 scale that has been shown to provide representative similar results to a 1:1 scale model in terms of luminous patterns and visual ambience quality (Lau 1972; Lam 1977). Lau (1972) experimented with different ways to represent space. By comparing a series of real spaces with scale models, it was shown that evaluations by participants did not change significantly. Scale models were constructed by professional technicians of the Chair on Ecoresponsible Wood Construction (CIRCERB) under specifications and designed by Jafarian (2016). Wooden panels were dyed in three different colors, selected to produce contrasting ambiences (Jafarian 2016): Cape Cod gray (a neutral and cold finish), oak (a yellow, warm, and bright finish), and dark walnut (a brown and neutral finish). Each dyed color was available in two types of finish or glosses: high gloss (90°) and low gloss (12°). Gloss relates to optical properties of a surface to reflect light, whereas higher gloss values generate mostly specular reflections rather than diffuse. Other panels consisted of white and mat painted melamine. The constructive system of the scale models used grooves on the floor and ceiling to insert the panels, thus allowing them to be interchangeable. It was therefore possible to alter the materiality of each surface, creating different combinations of color for each experiment. Based on the results of both Pineault (2009) and Arsenault (2012), who investigated glazing preferences in a northern context, the window unit chosen for this research was composed of a standard doubled glazing with a neutral color to avoid color aberration on the interior ambience and produce more realistic atmospheres (Jafarian 2016).

(a) (b)

Fig. 2. (a) Observation point for photography of model interiors, and (b) a view of Model B April 6th, 8:30 AM, sunny conditions

Ambience Typologies: Combination of Wood Surface Variables

Ambience typologies consist in the selection of five spatial combinations created by wood finishes. These five scale models with contrasting visual ambiences are shown in Fig. 3. Finding a range of relevant variables to assess a set of contrasting effects, while maintaining reduced possibilities, proved challenging. The selection and location of wood finishes for these five scale models integrated conclusions from Jafarian (2016) about the ambience diversity created by the different spatial combinations and were further refined after a pilot study conducted a month prior to the experiments. It consisted in the observation and evaluation of three spatial combinations of wooden panels by eight university students (3 men and 5 women), helped defining the spatial combinations and included a questionnaire review that was tested for another study (Poirier *et al*. 2016). The observers both evaluated the spatial combination proposed by the three pilot models, while testing a questionnaire that is presented in another study by (Poirier *et al*. 2016). Those three scale models were stacked in front of a northwest-facing window, and they were evaluated by the observers through a peephole in the panel (Fig. 2). Conclusions showed that models without a wooden floor were not realistic. Furthermore, color mixing, though interesting, had to be used sparingly to avoid overstimulation. To compare the data and simplify the variables, results from the pilot study provided a base to establish some constants. Every model would have a wooden floor because that represents the surface where wood is frequently located (or expected) in an architectural space. Moreover, the centered front-facing wall would be white, to produce a relatively uniform reference point, and to allow for the comparison of the effects of reflected light. Jafarian (2016) explored over 50 variations and Tsunestugu *et al.* (2007) only three, but this research aimed to reinterpret the most promising combinations and develop more detailed analysis in terms of ambience diversity in relation to daylight, from dark to light and from cold to warm. Figure 3 shows the orderly selection and concepts of the five physical scale models according to the colors that they contained, from neutral ambiances to more complex color combinations.

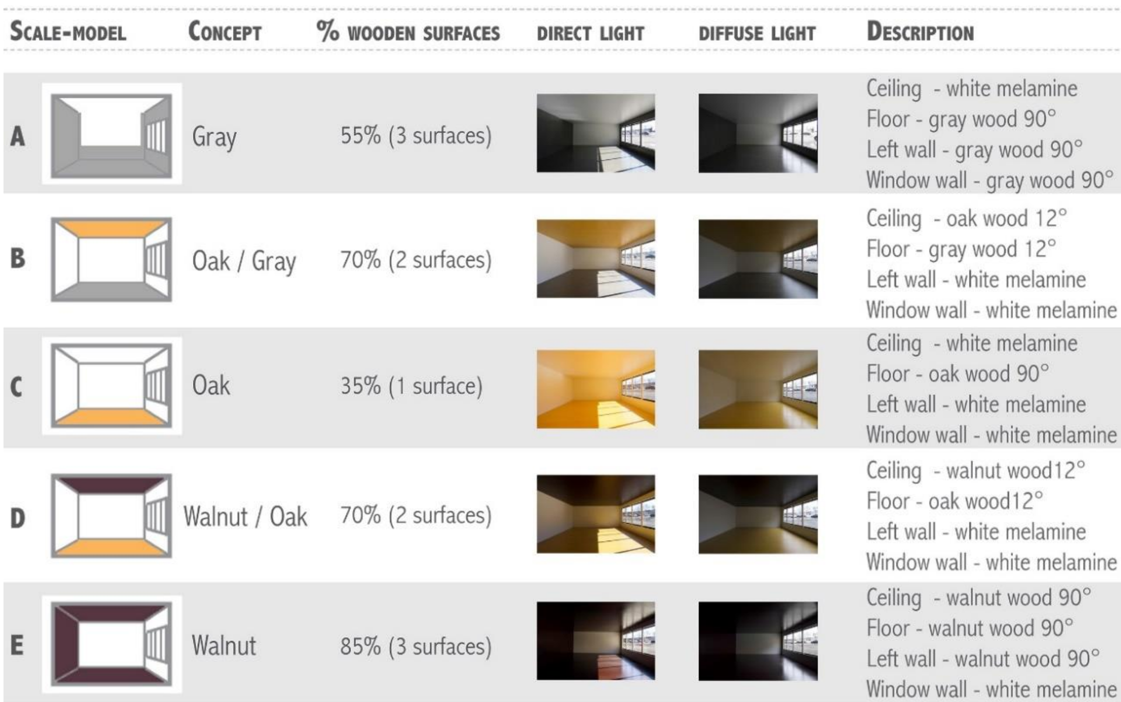


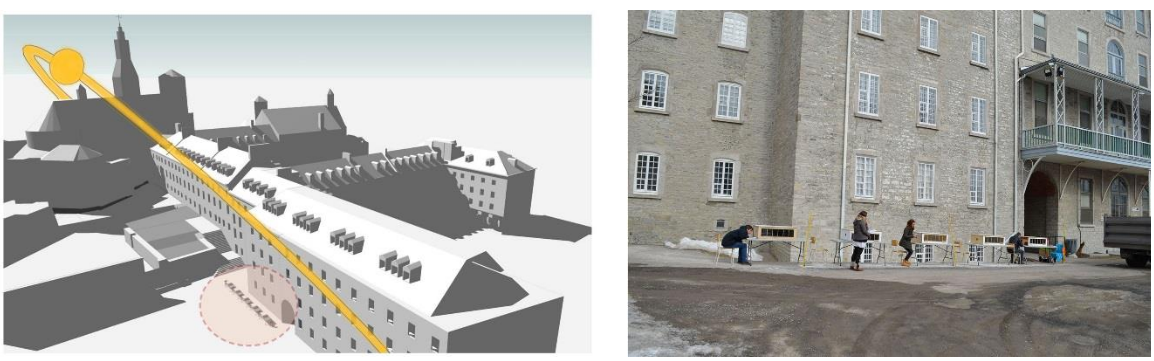
Fig. 3. Selection of wooden surfaces, location, and color combinations of the scale models

Model A is thus the basic combination that corresponds to the gray monochrome space that contains no color, which is characteristic of office spaces and galleries. This neutral selection should effectively reflect the natural colors of sun and sky lighting. The ceiling has a great potential to reflect light and affect interior ambiances, and thus Model B is the gray-yellow color contrasting with model C as the yellow monochrome space. The last two models explore darker ambiances, a result from Jafarian's research (2016) on dark high gloss surfaces to enlarge window space. Model D explores the yellow-oak color combined space, whereas Model E is the Oak monochrome and darkest space that could potentially associate with a resting room. This selection moreover reflects the pilot study results:

- The proportion of wood in relation to the total area of interior surfaces ranged from 35% to 85%.
- Three models (A, C, and E) were monochrome, so it was possible to isolate them in terms of hue value. Model A consisted of a neutral and gray environment, while Model C represented a space typically found in buildings, made from yellowish floor and white walls and ceiling and Model E suggested a dark environment in dark walnut color. Those three monochrome models were all composed of high gloss (90°) wooden surfaces.
- The two other scale models (B and D) represented a mix of colors between the ceiling and floor. The B and D models were similar, differing only in that their dark and pale colors were reversed. Those two color-combined scale models were composed of low gloss (12°) wooden surfaces.

Environmental Context: Physical Description

The experimental procedures were carried out in the parking lot at the School of Architecture of Laval University, located in Old Quebec City (46°49’N). This outdoor open space with minimal obstructions offered southeast sun exposure surrounded by old heritage buildings, including a cathedral, a seminary, and a priest’s residence. Figure 4 shows a rendering of the general settings and sun path during the experimentation, as well as the actual setting with participants in relation to the unilaterally lit models. These conditions provided access to the diffuse light of the celestial vault and allowed direct sun rays to penetrate into the models. The view offered through the windows of the scale models often included far away parked cars, helping to create a more realistic environment for the observers.



(a) (b)

Fig. 4. (a) Representation of the experimental environment with the sun’s course on March 21st, and (b) five-scale models aligned in the parking lot, southeast-facing, for photographic data acquisition.

Experimental Procedures

The experimental process was divided in two parts: weather data collection and visual ambiences data acquisition and analysis. First, a weather data collection established the generation of an innovative and contextual scale of sky cloudiness to relate to the scale model ambiences. This scale, discussed below, was inspired by Environment Canada’s widely accepted definitions of cloud covers. Secondly, a daily systematic photograph collection was made for every scale model, allowing for the direct comparison between the visual ambiences of interior spaces.

Weather data collection

The data collection for the sky cloudiness scale presented in the results section took place during six consecutive days from March 21st to March 29th, 2016, corresponding to the spring equinox in the Northern Hemisphere. During the equinox, there is an interesting diversity of skies, representative not only of spring and fall seasons, but also including the more uniform sky conditions found during the winter time. Pictures of the sky were taken systematically, and hourly illumination levels provided with a luxmeter were recorded (Fig. 5). Sky condition data was collected (cloud coverage and thickness) every 30 min, as well as lighting levels produced by the sky using a calibrated photometer. This first step was exploratory; it elucidated the diversity of sky cloudiness and natural light that can be typically observed during a week in a northern location such as Quebec City. Understanding how the weather, cloud cover, and thickness affected the illuminance transmitted by the sun helped to relate weather data and visual ambiences that were experienced in the interior environments. It could moreover become relevant in further studies considering environmental satisfaction. Poirier *et al*. (2016) precisely used this tool, linking the natural light diversity and the interior color temperature of spaces with the perception and appreciation of users.

(a) **(b)** **(c)** **(d)**

Fig. 5. Diverse sky conditions experienced during data collection (a) with a clear sky, (b) with a partly clear sky, (c) with a partly covered sky, (d) with an overcast sky

Visual ambiences data acquisition and analysis

Photographs of the five physical scale models were taken on April 6th, 2016. The models faced southeast and were analyzed simultaneously (Fig. 4). This orientation allowed direct sun penetration within the spaces in the morning, which was validated through computer simulations before experimenting in outdoor conditions (Fig. 6a).

(a) **(b)** **(c)**

Fig. 6. Computer renderings of the location of the sunspot in a scale model throughout the day of March 21st: (a) 9:30 AM, (b) 11:30 AM, and (c) 1:30 pm

Hourly data acquisition included a variety of sunspot areas on the floor, which progressively decreased until disappearance at approximately 3:00 PM. Figure 6 shows a representation of the variations of the sunspot in the scale models throughout a day.

Photographic data from the viewfield of an observer were taken every hour, and weather condition information was gathered to evaluate the impact of the diverse sky conditions in relation to visual ambiences. The photographic method allowed prompt data acquisition, as well as the direct and simultaneous comparison of precisely the same sky conditions and sun position between those five wooden environments. The camera used consisted of a fish-eye lentil with automatic settings.

A series of photographs taken under different sky conditions were analyzed at the following times: 9:30 AM, 10:30 AM, 11:30 AM, 1:30 PM, and 3:30 PM. This selection allowed the comparison of the five models under different visual ambiences created by the daylighting diversity throughout a day. The changing size of the sunspot represented in Fig. 6 had the potential to create significant changes in the visual ambiences experienced throughout the day, while the cloud cover and thickness could have potentially presented illumination with different intensity and hue, creating various atmospheres. The digital image data of interior wooden ambiences were analyzed and compared in terms of hue, brightness, and contrast. To evaluate the color temperature under different sky conditions, the hue (color wavelength), saturation (color purity), and lightness (quantity of white in the color of the surface) (HSL) system was used. This system uses the parameters of hue (H, from 0 to 360° in the color wheel), saturation (S, from 0 to 100), and lightness (L, from 0 to 100). Brightness (intensity of the light source) and contrast (scale difference between white and black in the image) were analyzed using a classification system of images from dark to bright and from low contrast to high contrast (Demers 2007; Jafarian 2016).

RESULTS AND DISCUSSION

Experimental results were divided in two parts: weather data collection and digital image analysis of the wooden spaces. Results of the weather data collection are summarized in Fig. 7, showing the cloudiness scale. The digital image analysis compared the various spaces in terms of brightness, contrast, and hue for the different sky conditions and corresponding sun position.

Weather Data Analysis

A remarkable diversity of sky conditions was experienced during the data collection in both the cloud cover and cloud thickness, affecting the visual appearance of wooden spaces. Different types of skies were analyzed throughout the days, demonstrating that weather was a dynamic variable that modified interior ambiances and could potentially have an impact on human perception. Figure 7 summarizes the weather data collection taken from March 21st to March 29th, 2016. The cloud coverage was recorded on a 0 (clear sky) to 10 (overcast sky) scale (Environment Canada).

Cloud thickness is a weather variable that is not often mentioned in daylighting studies. However, it greatly affects daylighting availability because it represents the quantity of sunlight that breaks through the clouds, and its potential to create a sun patch. A scale (Fig. 7) was established according to the conditions that were observed during the experimentation. It defined the cloud cover thickness from 0 (perfectly thin) to 10 (perfectly thick). The two scales were independent and greatly dynamic depending on the clouds and their movement throughout a day. As an example, a perfectly covered sky (10) could be composed of very thin clouds (2), whereas a partly covered sky (6) could have perfectly thick clouds (10). Consequently, a covered sky with thin clouds had the potential to create a sunspot and ambiences that were similar to a clear sky.

The horizontal illumination values measured on the exterior of the models were also dynamic, and depended both on sky conditions and sun position. Figure 7 shows the mean lux value measured during the experimentation for a southeast orientation, as well as examples of the cloud cover and cloud thickness photographs taken during the data collection. It illustrates different types of skies, including an overcast sky, a partly covered sky, a partly clear sky, and a clear sky.

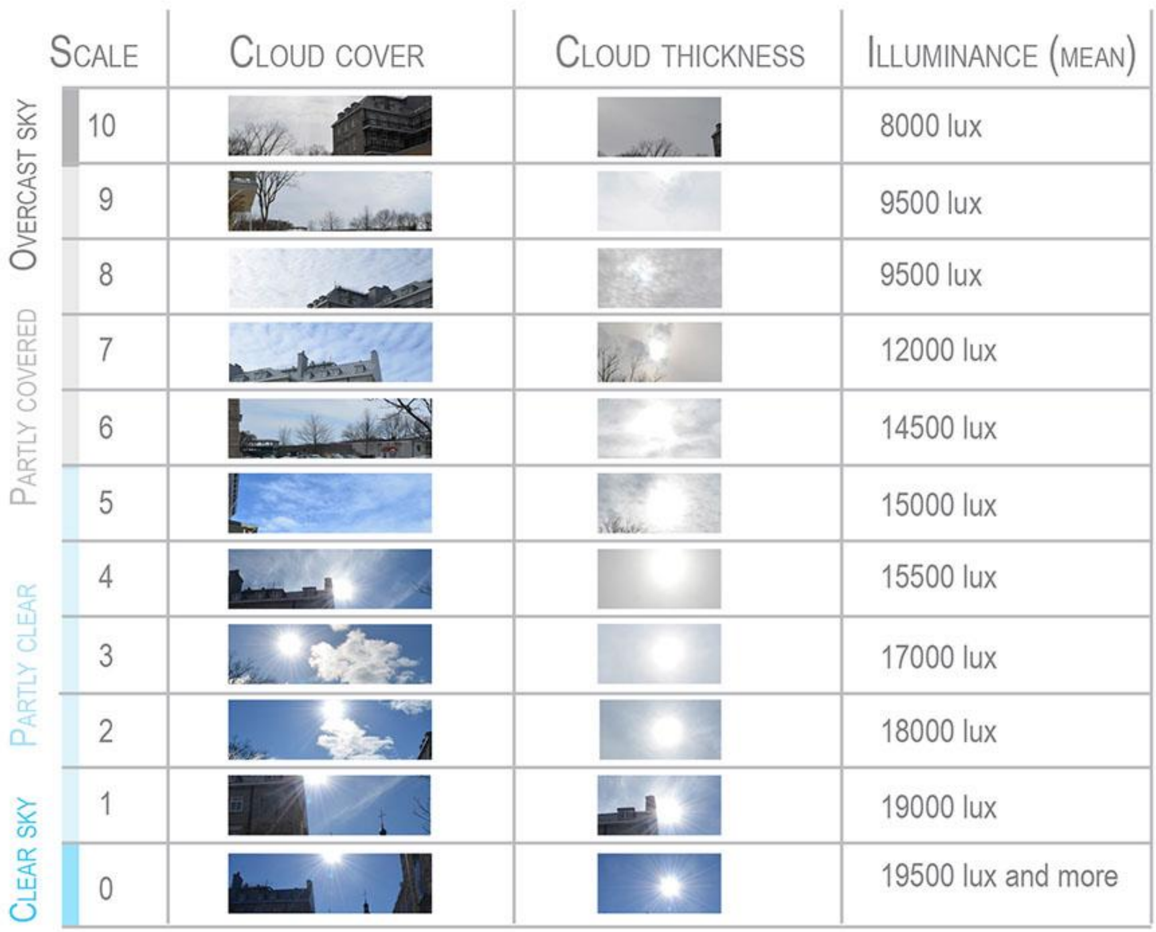


Fig. 7. Cloudiness scale according to weather data in Quebec City, March 21st to March 29th

Results showed that the illuminance levels were generally more influenced by the cloud thickness than by cloud cover. As an example, many overcast skies occurred during the data collection. When the cloud thickness approached 10/10, the illuminance typically varied from 8000 lux to 9500 lux.

However, an overcast sky with a thin cloud cover (around 4/10) produced a noticeable higher illuminance of approximately 15000 lux. During the measurement, cloud presence was less important than cloud thickness in impacting sunlight transmission. This observation emphasized the importance of considering cloud thickness during visual data acquisition in further studies, especially when eventually dispensing questionnaires to users. Poirier *et al*. (2016) evaluated the impact of the natural light diversity on the perception and appreciation of observers of wooden spaces. This scale was used as a qualitative representation of cloudiness for this study under real skies.

Photography Analysis

The series of images issued from April 6th shows the variation inside the five scale models with a southeast orientation. As observed in Fig. 8, scale models created various ambiences in relation to wood, depending on the hour of the day and the sky cloudiness. Figure 8 shows cloudiness (cloud cover and thickness) during the data collection and the series of photographs analyzed for all the interior spaces.

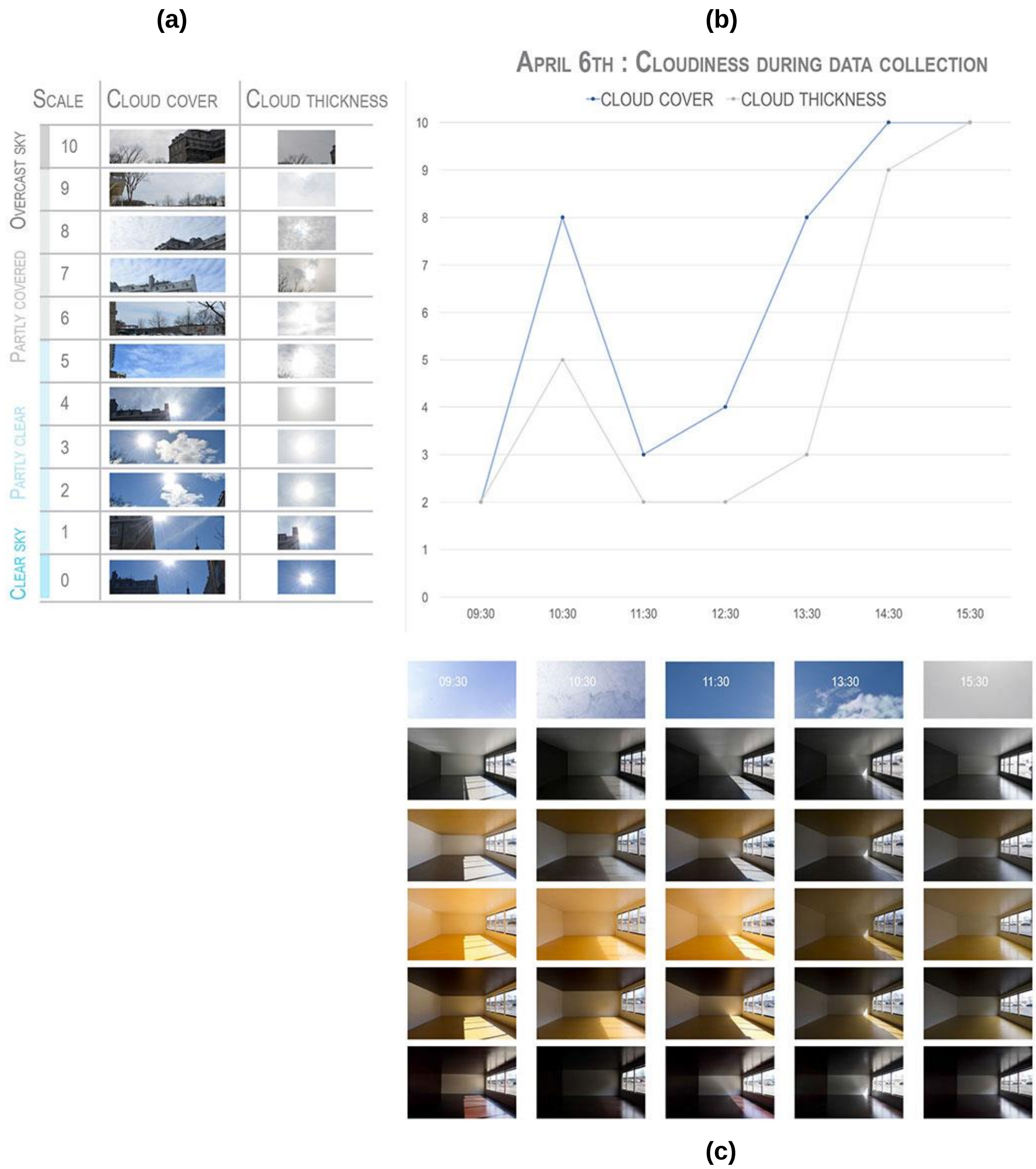


Fig. 8. (a) Scale of cloudiness in relation to (b) hourly cloudiness experienced during data collection (April 6, 2016) and to (c) photographic data of wooden ambiences

The weather and the sky cloudiness had the potential to create varying ambiences. Early in the morning, an almost clear sky was experienced, while the cloud cover increased around 10:30 AM, with a higher cloud thickness. The sunspot was well defined and bounced light onto the ceiling. The cloud cover progressively decreased at noon to produce a partly clear sky, but it became denser with increased thickness until it reached the overcast sky condition at the end of the day, with darker and more uniformly lit interior ambiences. Relating the photographs to the scale of cloudiness clarified the variation that can be experienced throughout a day in an interior environment depending on the daylighting quality and the illumination levels, as well as the overall color of the interior finishes in the visual field. Sun position was also a determining factor in exacerbating those variations.

Sky cloudiness and sun position impact

By selecting relevant points in the photographs (center of the ceiling, floor, the left wall, sunspots, and window reflections), the color palette corresponding with the HSL system was extracted for each atmosphere using the Adobe Color CC tool. Selected points appear as circles in Figs. 10, 11, and 12. Sky cloudiness generally had a noticeable impact on the visual ambience. Higher color temperature provided by overcast skies light created generally colder wooden atmospheres, while lower color temperature light from a morning sun created warmer ones. Graphs in Fig. 9 plot hue and lightness values, using the HSL system, for the five scale models under clear and overcast sky. They clearly indicated that most hue values were associated with warm tones (Fig. 9a), when the morning sun entered the scale models, whereas the overcast sky (Fig. 9b) created colder atmospheres.

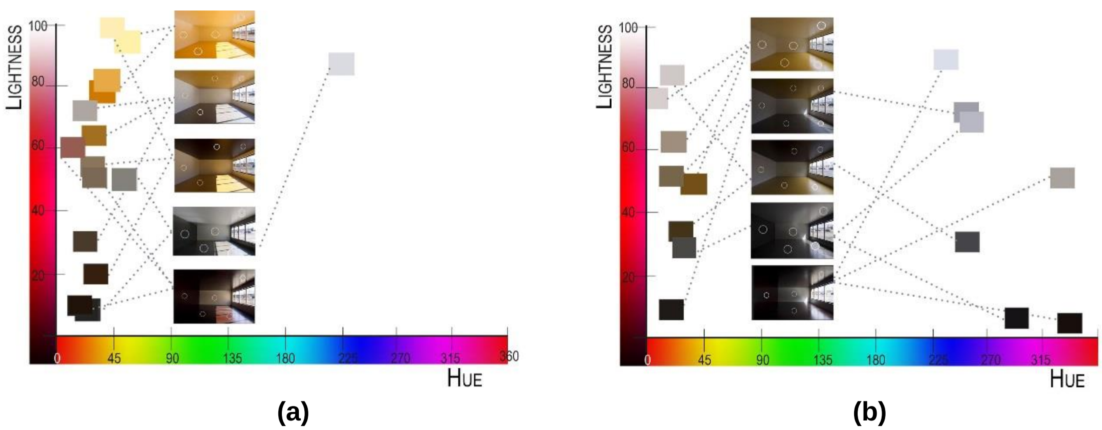


Fig. 9. Lightness and hue values of the five scale models for (a) direct light from a clear sky, and (b) diffuse light from an overcast sky

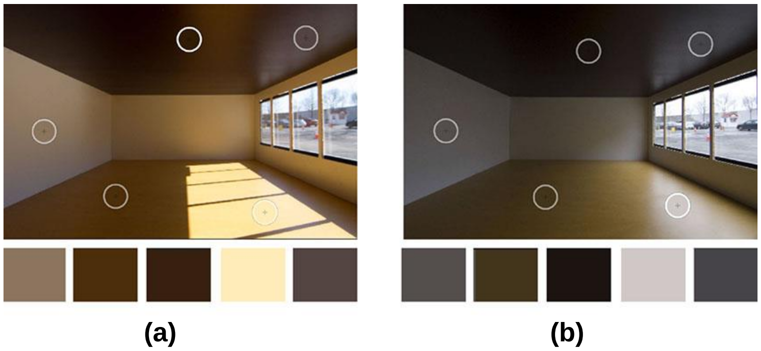
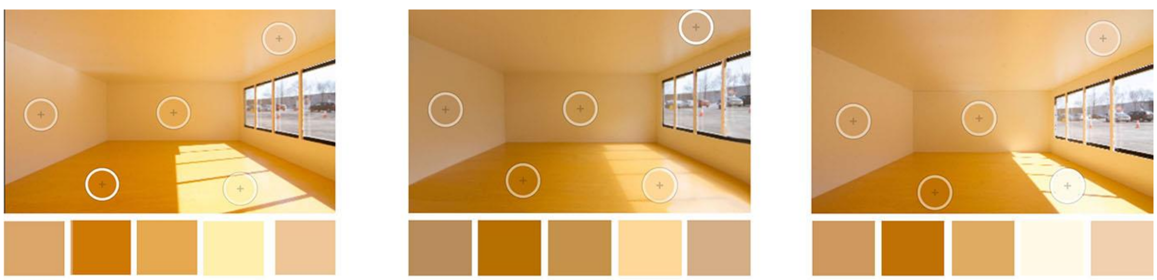


Fig. 10. Direct light from (a) morning sun at 9:30 AM, and (b) diffuse light from an overcast sky 3:30 PM, for Model D

Figure 10 provides a more detailed demonstration of the above graph. The comparison of the clear and overcast skies in Model D emphasized the differences and diversity between the visual ambiences on a single day. The morning sun (low color temperature) fully entered the model (Fig. 10a) and helped to create a much warmer ambience than the late afternoon diffuse light (high color temperature) produced by an overcast sky (Fig. 10b).

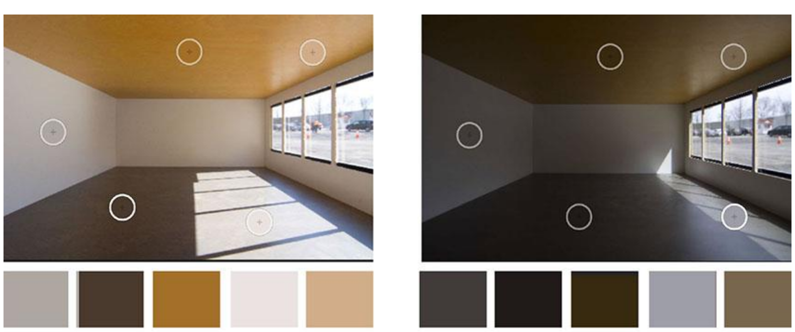
Visual ambiences were similar in terms of hue, lightness and saturation for a short period of time within similar sky conditions. Figure 11 shows that Model C created similar visual ambiences at 9:30 AM and 11:30 AM, as the cloudiness was almost the same in both coverage and thickness. The 10:30 AM visual ambience (Fig. 11c) represented a partly covered sky (8/10 cloud cover) with very thin clouds where the sun still managed to create a sun patch (5/10 cloud thickness). The hue created by this visual ambience was almost identical to the 9:30 AM clear sky conditions. This similarity emphasized the importance in considering both cloud cover and thickness in weather data collection because a cloudy sky produced an atmosphere similar to that of clear sky when the clouds were thin. Moreover, these results suggested that further research could simplify the methodology, considering that during short periods with similar weather conditions the natural lighting produced similar experiences and atmospheres.



(a) (b) (c)

Fig. 11. Model C ambience at (a) 9:30 AM (clear sky), (b) 10:30 AM (partly covered), and (c) 11:30 AM (clear sky).

The sun altitude throughout the day greatly affected the visual ambiences. Morning sun fully entering the scale models created warmer ambiences, while afternoon sun patches were less important and created colder atmosphere. The afternoon ambience was similar to the overcast sky for most of the models. Figure 12 shows the exceptional and unanticipated atmosphere variations created for Model B under direct morning and afternoon direct sun.



(a) (b)

Fig. 12. Model B ambience at (a) 9:30 AM and (b) 1:30 PM

Where other studies simply differentiated overcast from clear skies, these results starkly demonstrated that it was greatly important to consider a more rigorous cloudiness scale (cloud cover and cloud thickness) when undertaking weather data collections. Also, morning and afternoon sun created contrasting atmospheres that should be considered when performing data collection with a day-lighted environment. However, these results were valid only for a southeast orientation in which the sun fully entered the model during the morning. It would be useful to validate these ambiences for other orientations.

In terms of brightness and contrast, important changes were observed when comparing clear sky conditions and overcast conditions. Figure 13 uses Demers' (2007) light classification system to analyze wooden ambiences. The system compares lighting patterns in five brightness levels, and compares the mean brightness and standard deviation (contrast) of the photographs. The red curve represents the maximum image brightness and contrast values. High contrast ambiences are positioned in the top portion of the graph, whereas low contrast ones are located in the lower part. Bright ambiences are located in the right part of the graph and dark ones are located towards the left. The blue dashed square represents the extent of the clear sky results collected during the study, and the gray dashed square represents the extent of the overcast sky results. Plotted results show that clear sky produced a higher level of diverse experiences in terms of brightness and overcast skies produced ambiences that were systematically darker. Sky conditions and sun position proved to be major determinants of the interior atmosphere throughout the day.

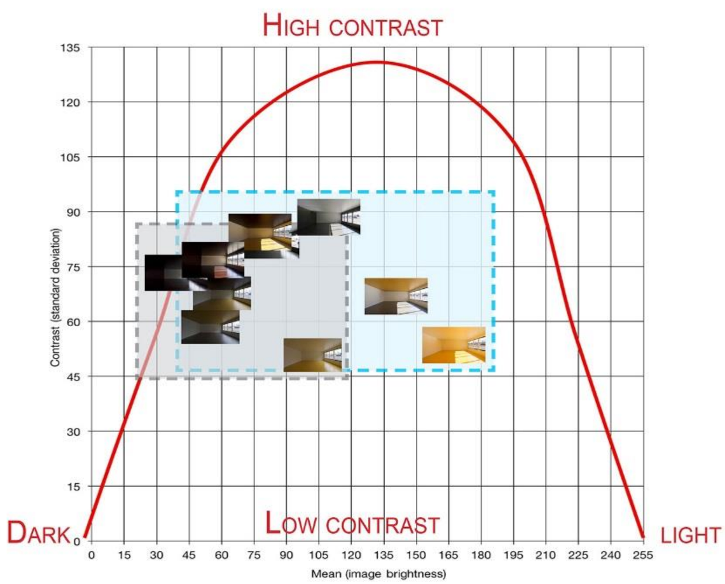


Fig. 13. The range of contrast and brightness values of the daylight classification system from Demers (2007) showing clear sky conditions (blue square) and overcast conditions (gray square)

Color impact of wood surfaces

The chromatic selection of interior wooden dyed surfaces generally had an impact on the perceived visual ambience. Figure 14 shows the position of those spaces in the Demers' light classification system. In terms of contrast and brightness, Model C was the brightest and least contrasted (Fig. 14, lower right image). Model E with dark walnut finishes was the darkest (Fig. 14, left image), and Model A (top image) in gray scale had the highest contrast under sunny conditions.

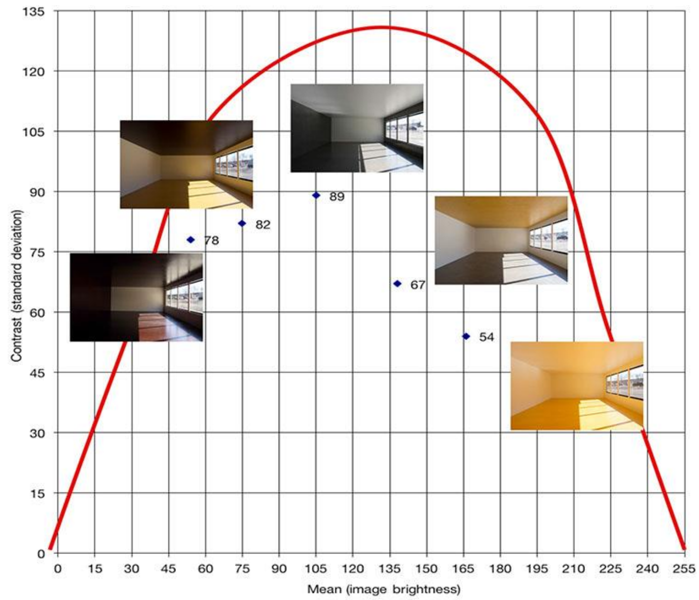


Fig. 14. The range of contrast and brightness values of the daylight classification system from Demers (2007) for clear sky conditions (April 6th, 9:30 am).

Model A, with a grayish wood finish, was the only model that did not undergo a noticeable change in its visual ambiences throughout the day (Fig. 15), when comparing to other models. Morning sun, afternoon light, and overcast sky created similar atmospheres in terms of their hue, lightness and saturation. This observation supported the idea that spaces made with gray wood dyes tended to create dull, cold, and unchanging visual ambiences throughout different sky cloudiness and orientation. This model also had the highest contrast because of its dark floor and bright ceiling.

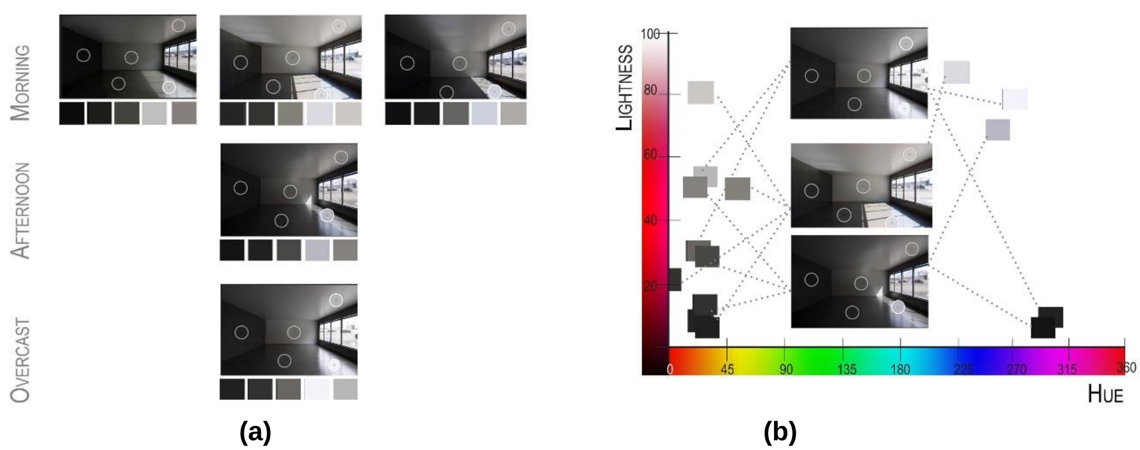


Fig. 15. Model A (Cape Cod gray) and the variation of (a) the visual ambience throughout the day and (b) the lightness and hue changes for morning, afternoon and overcast conditions

The visual ambiences of Model C with yellowish oak finish were remarkably different throughout the day (Fig. 16). If the contrast remained relatively unchanged and hue values corresponded to warm tones, the lightness and saturation greatly decreased. Different ambiences were created in terms of hue and lightness depending on the sky cloudiness and the sun's position. This scale model was also the brightest and had the lowest contrast. These results suggested that warmer wood finishes created atmospheres that emphasized the lower hue values of the entire interior environment in relation to hours of the day and sky conditions. The oak surfaces helped create warmer and fluctuating environments. Further research should include natural wood tones to validate the potential to warm spaces without the use of yellow hues.

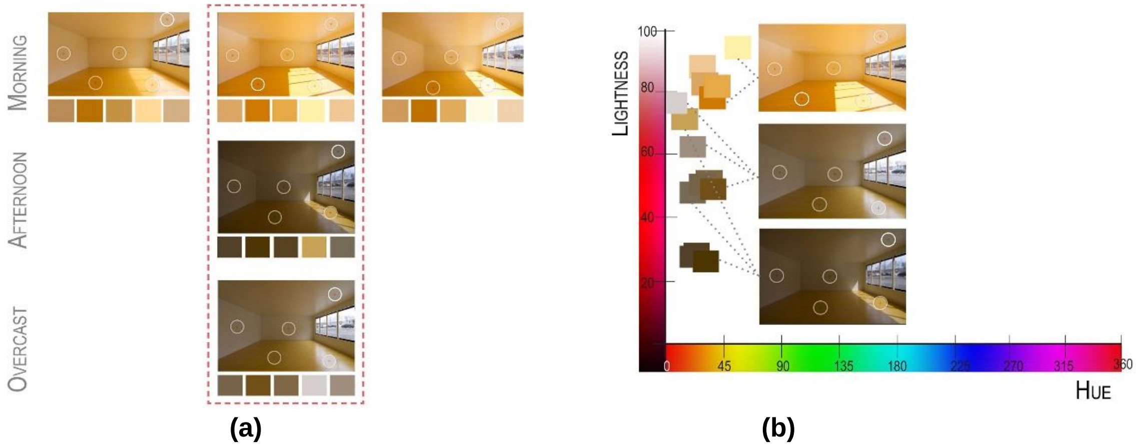


Fig. 16. Model C (oak) and the variation of (a) the visual ambience throughout the day and (b) the lightness and hue changes for morning, afternoon and overcast conditions

Model E, which consisted of dark walnut wooden surfaces, created the darkest environment. It was also one of the models with the highest contrast, as the floor, ceiling, and wall had lower lightness values than the high brightness of the incoming light from the window (Fig. 17). However, hue values were most remarkably different depending on the sky conditions and sun position: morning sun created warm hue surfaces, whereas cloudy afternoon and overcast sky conditions created a colder atmosphere.

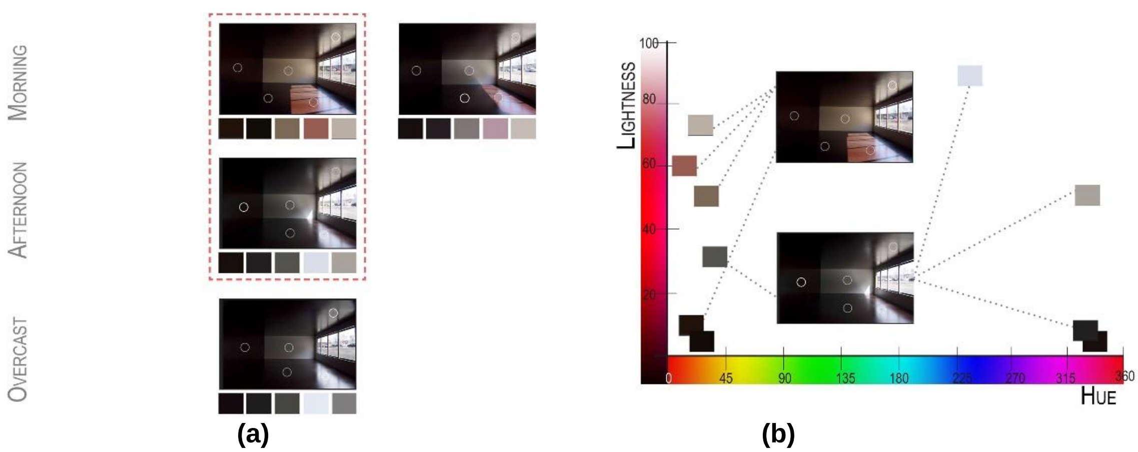


Fig. 17. Model E (dark walnut) and (a) the visual ambience throughout the day and (b) the lightness and hue changes for morning and overcast conditions

Models B and D, which combined different surface colors, created unexpected visual ambiences. The position of the oak surface within the model had an impact on the general hue. Model B featured an oak ceiling and a gray floor, and created a relatively more stable ambience than Model D, which featured a walnut ceiling and oak floors. Therefore, floor hue had a greater impact on warming the visual ambiences than the ceiling.

Moreover, the dark ceiling had a greater impact on brightness and contrast than the dark floor, creating a darker atmosphere. The wood gloss finishing seemed to impact brightness and contrast for overcast skies, but this variation was not noticeable. The color-combining Models B and D, as described on the methodology section, were made with low gloss (12°) wooden surfaces, while the monochrome Models A, C, and E had high-gloss (90°) wooden dyed surfaces. Under direct sun, the high-gloss surfaces and low gloss surfaces were equally bright. Under indirect daylighting, the high-gloss surface seemed to create more light reflections. Therefore, wooden surface hue appeared to affect more importantly brightness and contrast than the gloss. Because many variables were changed depending on the spaces, other types of wood and finishes need to be studied to validate these hypotheses. Further research by Poirier *et al.* (2016) developed a questionnaire to enquire about observers' appreciation of those specific wooden environments, depending on sky conditions and natural light.

CONCLUSIONS

Conclusions about sky cloudiness and sun position:

1. Sky cloudiness generally had an impact on the light color temperature, therefore affecting visual ambiences in interior wooden spaces. Overcast skies created colder atmospheres, while morning sunlighting created warmer visual ambiences.
2. The location of the southeast-facing window impacted some of the models' visual ambiences. The morning sunlight that fully entered the scale models created warmer atmospheres for all types of wood finishes, while the less important afternoon sun patches created colder ambiences, similar to those experienced under an overcast sky.
3. The visual ambiences for all models were similar in terms of hue, contrast, and brightness for each specific short observation time period within similar sky conditions. However, over a longer period of time, the ambiences observed were noticeably different.
4. Overcast skies with a thin cloud layer that allowed a sun patch into the interior spaces created visual ambiences almost identical to those under clear skies.

Conclusions about interior surfaces:

5. In general, the hue value (color) of the interior wooden dyed surfaces had a considerable impact on visual ambiences.
6. The Cape Cod gray wooden Model A was the only model that did not undergo a noticeable change in visual ambiences throughout the day, creating cold and uniform visual ambiences throughout varying cloud covers.
7. The yellowish oak wooden Model C, the brightest and with the lowest contrast, was remarkably different in terms of saturation and lightness throughout the day, depending on the sky conditions.
8. The hue value of the oaked floor produced a greater impact than ceilings for visually warming an ambience (Models B and D).
9. The dark walnut wooden Model E created one of the most highly contrasted and darkest

environments. Its hue values were the most different in terms of variations, depending on the sky conditions and the sun's position.

10. Wooden surface hue seemed to have more impact on brightness and contrast than the type of gloss.
11. Wooden surfaces helped create interesting ambiences that changed depending on the sky cloudiness and sun's position. Furthermore, wood grain provided a more detailed and textured environment.

Conclusions about methodology:

12. Simultaneous comparison of five scale models in an outside environment under natural light was validated. Throughout the day, sky diversity and cloud cover conditions created remarkable daylighting changes and experiences, and the simultaneous comparison allowed precise analysis, based on the same light at the same time. Weather data collection allowed the creation of a cloudiness scale, considering both cloud thickness and coverage, which allowed more realistic results.
13. The use of scale models proved to be a relevant method, allowing a degree of detail, precision, and diversity in environmental conditions that are not available in a laboratory or with simulations.

LIMITATIONS OF THE RESEARCH

Experimentations using scale models were conducted during spring equinox for a southeast orientation, which provided a wide array of sky cloudiness conditions. Moreover, the study was limited to three wood finishes. Further studies could explore other finishes, involve other building orientations and seasonal conditions for more complete analysis. Evaluation of lighting quality and interpretation of interior ambiences on human perception should ultimately be confirmed by participants.

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