Integrated photometric descriptors for lighting quality research & recommendations

Veitch, J. A.

Integrated Photometric Descriptors for Lighting Quality Research & Recommendations

Résumé

Chairman: Jennifer A. Veitch, Canada

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1.0 INTRODUCTION

Since the workshop held at the 23rd Session of the CIE in 1995, lighting quality has been established as one of the fundamental problems in lighting design, research, and education. The workshop at the 24th Session addressed a topic identified by delegates at the First CIE Symposium on Lighting Quality, held in 1998 [1]: the need to refine our definitions of luminous conditions to develop useful descriptors of the luminous field. Agreement about these photometric descriptors is a necessary first step to the development of research programs to advance understanding of the effects of the luminous environment on human behaviour, mood, and health, and to the development of recommendations for good-quality lighting design.

The workshop summary in Volume 1 of the proceedings described the background for this topic [2]. Based on this background, the goals of the workshop were as follows:

- To discuss the criteria by which to judge the value of various photometric descriptors of the luminous environment;
- to discuss the requirements of researchers and designers for photometric descriptors;
- to begin a catalogue of photometric descriptors of luminous conditions;
- to discuss practical issues relating to the use of these descriptors; and,
- to suggest the terms of reference for a new TC on this topic.

The workshop began with four invited presentations by lighting researchers with divergent opinions about appropriate ways to describe lighting, and then opened for discussion involving the audience and the panel. This report includes summaries of the panellists' presentations and of the discussion and conclusions.

2.0 INVITED PANELLISTS

2.1 David Loe

There is still some confusion over the definition of 'lighting quality' but it is probably more correct to use the term to encourage 'goodness in all aspects of a lit environment'. This means approaching lighting design with a holistic approach rather than just designing for visual function as is often the case. This means considering the following main topics, although others may need to be included in particular situations:

- Lighting for Visual Function
- Lighting for Visual Amenity
- Lighting & Architectural Integration
- Lighting & Energy Efficiency
- Lighting Costs (capital & operational)
- Lighting Maintenance

If this approach is adopted, then not only will the visual task aspect be addressed, but the installation efficiency and economics through life will be considered, as well as the lit appearance of the space that surrounds the tasks including the integration of the lighting with the architecture [3, 4].

The lit appearance of a space is the area many lighting designers are least confident about since we have no way of describing it numerically. Also because illuminating engineers are rarely taught to consider this aspect of design because it falls more in the region of interior architecture or interior design and yet it could well have a bearing on the quality of the lit space and have an affect on performance.

Earlier investigations into the lit appearance of an interior have suggested that people prefer spaces to have a degree of 'visual lightness' and 'visual interest' [5]. This means they like a space to appear 'light' with respect to the application, and to have a degree of visual interest through a measure of non-uniformity of the light pattern which again needs to be appropriate for the application. This study showed that the important area within the normal visual field is a horizontal band 40^0 wide centred at eye height. The work also showed, that for an office to appear light, the average luminance of the 40^0 band needed to be not less than $30cd/m^2$ and for the light pattern to appear interesting, it required that the luminance variation within the 40^0 band should have a ratio of max.lum./min.lum. of not less than 13. This work still needs more investigation although there has been some work in the USA that supports some of it [6].

Recent investigations have shown that a normal cosine corrected photocell mounted vertically, and fitted with a mask to limit the vertical acceptance angle to 40^0 and limited to a horizontal acceptance angle of 90^0 can be used to measure the average luminance of the 40^0 band. Measurements using this device have been compared to a more detailed approach, using a luminance scanner as used in the earlier studies, show an acceptable accuracy.

The masked cell has been used to measure the lighting conditions in a room approximately 4m x 6m in plan when lit in a number of different ways. The floor was divided into a regular grid of approximately $1m^2$ and the average luminance was measured at a height of 1.35m (half way between sitting height of 1.2m and standing height of 1.5m) at the centre of each grid square in four orientations.

The installations were assessed by a number of observers to examine the correlation between the measured values and subjective assessments. Assessments were made using bi-polar semantic differential scales as used in earlier experiments.

The results from this new work are still being analysed but there is an indication that the average luminance of the 40^0 band, measured in this way, correlates very well with the subjective assessment of brightness or lightness. Also that the point above which the interior starts to appear 'light' is about 30-40cd/m^2 a value which agrees with earlier results. There is also a suggestion that the interest factor can be described by the spread of the measured luminance values quantified by the luminance distribution standard deviation.

If these metrics can be used to quantify lighting appearance, at least in a simplistic way, then there is a possibility that lighting design can move forward beyond lighting the task to include lighting for the building. For this to be useful, in a design sense, it will be necessary to be able to calculate these values at the design stage. Initial investigations indicate that these can be calculated using lighting visualisation programs and in this case the program Radiance has been used with encouraging results.

Although the results described are encouraging, it will still require inspired designers to create good designs because the metrics are simplistic relying on average luminance values which will mask complex luminance patterns. This will require designers who have a natural understanding of lighting appearance or who have studied the subject in terms of light patterns. As an aid to this, it might be possible in the future, to provide guidelines in terms of luminance ratios relative to the average luminance of the 40^0 band, which could provide a measure of the adaptation luminance.

2.2 Vincent Berrutto, Ph.D.

2.2.1 Introduction. The present communication brings some comments on the subject of this workshop based on a study completed by the author in 1997 at the National School of State Public Works (France). The aim of that study was to define energy-efficient lighting solutions that satisfy office workers [7].

2.2.2 The luminance mapping syndrome. In an office building, two standard single rooms were equipped with various dimmable luminaires so that people could modify to a very large extent the luminance distribution within their field of view. A total of 73 building occupants were asked to set the lighting they preferred for three different types of tasks: (1) reading or writing on paper, (2) entering data on computer, and (3) receiving visitors. First the people could use all the dimmers as they wished. Then, they were asked to set the lighting without exceeding a given power level.

Once they finished, the chosen luminous conditions were characterised from a photometric point of view. The scope of this characterisation was to go beyond the simple measurement of the horizontal illuminance level.

The idea of using the recently-suggested ratio of the vertical illuminance over the horizontal illuminance was investigated [8]. However this was given up when this ratio was found to be insensitive to very different lighting conditions, even some set at random by the experimenters.

Like in other laboratories [9,10], it was decided to calibrate and use a luminance mapping system. The system was equipped with correcting filters to get a spectral sensitivity close to that of the human eye. It was also equipped with a fish-eye lens so that it could provide the luminance distribution within the whole field of view.

This led to the experience of a two-phase syndrome probably familiar to anyone has been using such a device for assessing lighting quality: first, much enthusiasm because one suddenly gets to know hundreds of thousands of luminance values, then a certain disappointment when one tries to retrieve some information out of these values, because of the lack of agreed-upon descriptor.

Two examples taken from this study illustrate that difficulty and raise some issues that may be inherent to the definition of integrated photometric descriptors.

2.2.3. About integrating the minimum/maximum luminance. When working on computer, people chose a very different lighting than for working on paper. In particular, they paid a special attention to minimise the luminances behind them in order to avoid reflections on their screen. They also chose luminances behind the monitor in accordance with the luminance of the screen.

The screen luminance was around 60 cd/m2. The most common recommendation says that there should not be a ratio of more than 1 to 3 between the visual task luminance and the immediate surround luminance [11, 12]. As other authors have noticed [13], this rule is ambiguous: what is the “immediate surround” ? What luminance values shall be considered ?

Considering spot values around the screen, it was found that people tended to set values that were equal or slightly inferior to the screen luminance (around 50 cd/m2). They also chose a lower illuminance level on the desk compared to what they chose when they were only working on paper. By this way, the luminance of the paper was closer to the luminance of the screen.

Considering minimum values in the scene, they could be much lower than the screen luminance for some relatively small surfaces, e.g. below 5 cd/m2 - which is much below rule's limits - without causing any disturbance.

In fact, if one suggest to use the minimum (or maximum) luminance value of a surface as an input parameter into an integrated photometric descriptor [5], the kind of solid angle the surface must represent to be considered as relevant should probably be specified. Otherwise, it's likely that in some situations misinterpretations are drawn because the field of view contains small dark (or bright) spots with no actual effect on lighting quality.

2.2.4 About integrating the average luminance. To work on paper or receive visitors, people in the same study found much interest in wall washing and wall luminance appeared to be a major quality parameter.

For these activities again it was difficult to characterise the luminance distribution and to figure out which luminances to consider. The average luminance of the walls was about 120 cd/m2 but luminance values at eyes level seemed a more pertinent parameter to consider. They were equal to 60 cd/m2, i.e. half the value of the luminance of the task, which was a ratio consistent with other studies [14,15,16].

Beside this, people tended to balance the luminances on the walls located respectively on the left and right side of their field of view. They even used the word 'balance' when they were asked to characterise the lighting conditions in a semantic way. This emphasises the fact that one cannot talk about the luminance dynamics – i.e. the range of luminance values present in the field – without taking into account how these luminance values are distributed within the space.

This may also be an important issue if one thinks of using average luminance value as an input parameter inside an integrated photometric descriptor [5] because the average contains no reference to space considerations.

2.2.5 Conclusion. To conclude, these two examples are illustrations - among others in literature - of the distance still to be covered (and the complexity) to rely on agreed-upon integrated descriptor for the analysis of luminance distributions. The good news however is that powerful metrological tools are now within the reach of many lighting laboratories. Their ability to measure and store luminance distributions could be found all the more useful in the future developments of this subject as it will result in a compendium of "unaltered" photometric information on what people judge as good (or bad) lighting. Such data offers a useful reference to cross-check later on the validity of any integrated descriptor the CIE may come with.

2.3 Yoshiki Nakamura, Ph.D.

2.3.1 Introduction. It might be a good idea to integrate some luminous descriptors in order to specify the lighting condition of high quality lighting. However, the result we can obtain by integrating quantities is deeply based on what we integrate. Therefore, before a trial to find a good integrated descriptor, we should examine the features of luminous condition that can be described by the existing luminous descriptors. The existing luminous descriptors are presumably insufficient to describe basic characteristics of high quality lighting. The author thinks that there is no existing luminous descriptor to describe the characteristics of light distribution, which is essential for understanding lighting quality.

As to distribution we already have uniformity ratio as a descriptor of distribution. However, uniformity ratio is an indicator of how far the distribution is from uniformity. It is a reasonable descriptor when the object of lighting design is uniform lighting, but we all know that high quality lighting is not always uniform lighting. In this paper a descriptor proposed earlier by the author [17] is introduced, by which several features of light distribution may be described with the strength and the edge feature of spatially varied luminance or illuminance distribution.

2.3.2 Spatial frequency and filtering. The idea introduced here is based the fact that any kind of distribution can be reproduced from an infinite number of sine waves with different frequencies. The frequency is the fineness of spatial variation, which is represented by units of cycle/degree in the spatial distribution of luminance and by units of cycle/meter in the surface distribution of illuminance. Based on this fact, we can obtain a sine wave with a specific frequency from any kind of distribution. This procedure is called filtering.

(1) Filter. The author proposed earlier the most appropriate filter to obtain a sine wave luminance variation with a specified frequency from an image of office luminance distribution [17]. This filter can also be applied for illuminance distribution.

(2) Calculation procedure. Filtering can be accomplished by two ways. One way is by Fourier Transformation and the other way is by convolution. Convolution can be described as summing up weighted values around a pixel. When we calculate the sum on every pixel of a distribution image, the filtering is accomplished on that image. The weight value can be represented in a 7 by 7 matrix [17]. The weight values at the central area of the matrix are positive and the values in the surrounding area are negative.

2.3.3 Quantitative description of variation.

(1) Variation strength. According to the matrix, the convolution calculation can be described as obtaining a weighted difference between the central area and the surrounding area if the distribution image is represented by an absolute value, or obtaining weighted ratio between them if distribution image is represented by a logarithm. Therefore by this filtering procedure it is easy to examine whether there is an area in the luminance distribution where the luminance ratio exceeds 3 or 1/3 or 10 or 1/10 [17]. Furthermore by this calculation the effect of the front wall luminance by contrast with the surroundings can also be quantitatively represented. A darker front wall than the side walls, which may lead to a dark impression of room brightness, can be represented as a value, which should be less than 1 [18].

(2) Variation boundary or edge. Using filtering, the sharpness of the luminance or illuminance boundary can be described quantitatively as the range of

frequency where the boundary can be detected. For example, the luminance boundary formed by naked fluorescent lamps can be detected both in filtering of a high frequency and a low frequency. On the other hand, the luminance boundary formed by indirect lighting on the ceiling can be only detected in filtering a low frequency variation [19].

2.3.4 Conclusion. This paper introduces a method for indicating some characteristics of distribution by filtering procedure. Although the descriptors for distribution introduced in this presentation are in the midst of development, the author hopes this idea could help to establish the method for representing distribution, because the author thinks we cannot understand lighting quality without a quantitative description of distribution.

2.4 Christopher Cuttle

The Ottawa seminar was good, and I look forward to a lively discussion at this meeting. One of the main efforts so far has been to define Lighting Quality, and although proposals for a definition have been advanced, I feel that we still have some way to go. I note that some want to include lighting economics in the definition, but I cannot see this to be a component of lighting quality. If some designers are capable of achieving high quality lighting at low cost, then good luck to them, but lighting quality is not related positively or negatively to the cost of its provision. Also, some want to have integration with architecture included in the definition. There are some applications for which this will be an important design objective, but I believe that our aim should be to devise a definition that is independent of application.

Our chairperson has posed the question, “How can we describe what people are seeing using photometric values?” I see two stages in developing an answer to this question. The first stage is that we need descriptors of how lighting can influence what we see, and the second is to devise metrics that relate to these descriptors.

For addressing the first stage, I look back to Lam’s observation [20] that there is lighting to see by, and there is lighting to be seen. While I commend Lam’s brevity, for teaching lighting design I make the distinction that we can see lighting both as the medium that makes things visible, and as a visible medium. There is no contradiction in these two statements: they describe alternative ways of seeing lighting. Also, both ways of seeing lighting are relevant, and their relative importance depends on the application.

Let’s consider “Lighting as the medium that makes things visible.” I came into lighting as an electrical engineer who found illumination engineering more interesting than power distribution, and at the time I would have accepted this statement as summing up the essentials of lighting practice. The thinking that underlies this attitude is entirely logical. People light buildings so they can see. Good lighting is lighting that enables them to see well. Vision is a process of discrimination, and good lighting provides well for visual discrimination, and in particular, for discrimination of luminance contrasts and colour differences. The positive factors are task luminance, contrast rendering and colour rendering, and the negative factors are disability and discomfort glare. These factors neatly define the purpose of illumination engineering.

There is nothing wrong with the illumination engineering approach except that there is more to lighting, and this leads us to consider “Lighting as a visible medium.” Lighting does not simply make things visible: it affects the appearances of everything we see. While architects agonise over space and form, and interior designers debate colour and texture, a lighting designer brings to the design process another dimension of the overall concept. Variations of the spatial distribution, directional nature, and colour characteristics of lighting serve not only to reveal properties of illuminated surfaces and objects, but also to create overlaying patterns that have their own visible identities. These patterns may be perceived to vary with time, whereas the surfaces and objects that comprise the environment are generally perceived to retain constant properties. It is in this sense that we see lighting, and that lighting is perceived as a visible medium.

We do not have an established discipline concerned with lighting perceived as a visible medium, but there are many sources within the literature that are relevant to this issue. A concept that I find particularly relevant is that of Modes of Appearance, as I have explained in a paper that has been accepted as a displayed paper at this conference [21]. As you have the text in the conference proceedings, I will give only a brief description of the concept.

The stimulus for vision is the retinal image, and this can be defined in terms of luminance and chromaticity. When a retinal image stimulates the perception of a scene comprising recognised objects and surrounding surfaces, these objects and surfaces are perceived to have certain attributes. The attributes that may be associated with an object depend on the mode in which it is perceived rather than the photometric properties of the corresponding part of the retinal image. In the paper I review proposals by R.M. Evans and D.B. Judd as well as more recent research at the Lighting Research Center, and I propose a matrix of six modes of appearance and their associated perceived attributes. The modes are listed below.

2.4.1 Six modes of appearance.

1. Non-located illuminant mode. Examples: sky; ambient fog; integrating sphere.

2. Non-located illumination mode. Example: ambient illumination, such as the general lighting within a room.

3. Located illuminant mode. Examples: a lamp or a luminaire; a self-luminous object.

4. Located illumination mode. Examples: a patch or pattern of light focussed onto a surface or object.

5. Located Surface mode. Example: an opaque surface or object seen by reflected light.

6. Located Volume mode. Examples: a cloud, a plume of smoke, a transparent or translucent medium.

For example, if a fluorescent lamp is placed before you and you are asked to assess its lightness, or perhaps its reflectance, you can see that it has a white surface and you would assess its lightness to be similar to that of white paper. If the lamp is now switched on, it becomes impossible to assess lightness. Of course the luminance of the lamp has changed, but what matters is that the mode of perception has changed from located surface mode to located illuminant mode. When perceived in the surface mode the lamp has the attribute of lightness, but when perceived illuminant mode it has the attribute of brightness [22]. Perceived brightness may be related to luminance, and perceived lightness may be related to reflectance.

The usefulness of the modes concept can be examined by considering further the lightness versus brightness example. There are many examples of recommendations for lighting practice being stated in terms of luminance ratios for objects and adjacent surfaces, and some have proposed that entire scenes should be designed as compositions of brightness by application of brightness/luminance functions. These proposals have not been without critics. P.A. Jay has described reading a newspaper while sitting in the shade of a tree in his garden [23]. The shaded newspaper appeared white, and he speculated that a lump of coal placed in the full sunlight would have appeared black despite having higher luminance. While Jay used this observation to question the validity of luminance as a predictor of visual effects, the modes of appearance concept offers a basis for understanding the situation that he described. Both the newspaper and the coal would have been perceived in located surface mode, and would have had the attributes of lightness (white/black) but not brightness. Of course the difference of lighting for the two objects would have been readily visible, and this would have been perceived in located illumination mode, for which brightness is a perceived attribute. While some authors have argued strongly that it is luminance that is seen and that illumination is invisible, it is common experience that differences of illumination are readily perceived.

When we consider lighting as a visible medium, we move beyond analysis of what is visible to consider what is perceived. The modes of appearance concept provides a basic framework for understanding how the different interpretations that are placed on the components of a scene may give rise to certain perceived attributes. While it should not be expected that subjective assessment of these attributes will be governed by simple relationships to photometric values, the modes approach gives guidance on what roles lighting can play in influencing perceptions of the visual environment. My paper [21] discusses implications for lighting design, and I propose to pursue this line of study in my future research. Meanwhile, I commend the modes of appearance concept as a useful framework for developing descriptors of how lighting influences what we see. This has the prospect of providing a basis for understanding where we can expect some correspondence between those factors and photometric values.

3.0 AUDIENCE DISCUSSION

This is an abstracted, summarised form of the discussion that followed the panellists' presentations.

- Are there really any fundamental descriptors of lighting? What good is data reduction? Don't such simple descriptors limit consideration to functional aspects of lighting, ignoring more complex issues like information content of scenes? Aren't we seeking a Holy Grail, perfection in lighting quality?
- David Loe disagreed, arguing that practical and widely useful measures are important tools for addressing visual amenity; we can improve upon horizontal illuminance even if we can't reach the ultimate goal.
- Vincent Berrutto added that digital image analysis allows for the development of more complex descriptors that researchers can use, as well as rules of thumb that designers can use.
- The modes of appearance framework intrigued some, but raised questions from others. Dr. Einhorn wondered how it would be applied in a practical way to the functionality of lit scenes. Kit Cuttle argued that functional issues are overemphasised in current recommended practice documents, but that his modes of appearance approach would allow broader considerations to be included.
- Anders Liljefors argued that this approach, defining light as that which gives appearance, could shift the emphasis from the definition of light as visible radiation (which he thinks is confounded) to a differentiation between the physical stimulus and what we see. David Loe pointed out that lighting designers must concern themselves with the illuminated space, not only appearance of objects in space.
- Warren Julian saw the issue as a division of processes, between describing vision in biological terms and characterising edges, reflectance, and surfaces in the technical terms of lighting physics. He hoped that a new TC could unravel these, ultimately to provide design guidance for everyday applications. However, at its best (as at the ballet performance of the previous evening), he argued, lighting elicits too many responses, and responses that are too complex, for complete analysis.
- Daylighting shouldn't be ignored. Some audience members argued that photometric descriptors for daylighting must differ from those for electric lighting, because its perception is different.

Moreover, the variation of light across time is part of what we like about daylighting. David Loe and Kit Cuttle thought that their approaches could encompass daylighting, although work is needed to extend to dynamic effects (e.g., time as another lighting mode).

- In response to questions about daylighting, Vincent Berrutto said that his experiments had been conducted with artificial light only, and added that he didn't know whether the same results would also apply to daylight. His feeling (which he emphasised is just a feeling), based on the studies which have shown in the past that daylight is usually associated to a higher degree of tolerance, is that the same results would only partly apply to daylight. However, results based on spaces without daylighting are interesting because in most cases artificial lighting systems are designed for night-time conditions.
- Peter Boyce summarised his view of how photometric descriptors might work: We need definitions of visual fields, a variety of important viewing locations and scenes for each application. The definitions would include the bounding surfaces of the space, objects in the space (including other people), and be specified in terms of what light is received at the eye. Then, we would characterise that system, using a minimum of data reduction in reporting (so that readers and others can reach their own conclusions), and in terms of mutually supporting, repeatable photometric values. Ideally this would include several kinds of measurement, such as cubic illumination [24], digital image analysis, and complex calculations that could be computed using post-processing [e.g., 17]. The specified viewing points defining visual fields could be input into lighting calculation software, so that the chosen photometric descriptors could be calculated for lighting installations at the design stage.

4.0 CONCLUSIONS

4.1 Criteria for integrated photometric descriptors

Based on the discussion and the panel presentations, a set of criteria emerged as necessary characteristics of useful photometric descriptors for studying and establishing lighting quality recommendations.

- application-independent - what is needed are descriptors of lighting.
- validity - the measures must be mutually supporting (consistent) and inclusive (not excluding dimensions of visual experience that are potent influences on design goals or human behaviour).
- reliability - the measures must be repeatable, applicable to any field of view and any application, and have a low error rate.
- applicability - the measures must meet designers' needs for simple tools and for measures that can be predicted prior to installation; and also meet researchers' needs for complete information to allow replication and re-analysis.

Potential descriptors include:

- modes of appearance
- illuminance or luminance measured using a shielded photocell, systematically measured in various orientations at specified points in space
- luminance calculations from specified views in digital image analysis
- spatial frequency calculations (also from digital image analysis)
- cubic illuminance and derived illuminance values and ratios
- luminance patterns, such as ratios of maximum to minimum luminance in a field of view

4.2 Terms of reference: Protocols for describing lighting

The desired outcome of the workshop was the development of terms of reference for a new technical committee. This outcome was achieved when at the subsequent meeting of Division 3 a new technical committee was proposed, TC 3-34, "Protocols for Describing Lighting", with the following terms of reference:

"Several CIE events have established a framework for lighting quality and a list of important characteristics of lit scenes. These include workshops at the 23rd and 24th CIE sessions (New Delhi, India, 1995; Warsaw, Poland, 1999), the First CIE Symposium on Lighting Quality (Ottawa, Canada, 1998), and the invited address by N. Miller and T. McGowan at the 24th Session. This TC will build on this foundation to achieve the following goals:

"1. To establish a catalogue of application-independent descriptors of lighting.

"2. To provide relevant, specific, objective definitions of supporting concepts (e.g., 'field of view').

"3. To develop a measurement protocol for each of the descriptors, with the goal of achieving protocols for use equally by researchers, in recommendations, and in design.

"4. To prepare a strategy and action plan for widespread promulgation and application of these protocols and definitions by researchers, journal editorial boards, lighting educators, CIE technical committees and standards, and in other lighting organisations.

"The purpose of this endeavour is to establish a common ground for describing lighting so that further discussions of lighting quality issues are based on the same vocabulary and measurement system, rather than upon arbitrarily-chosen, idiosyncratic values that are unrepeatable. The protocols will not preclude the development of new, additional descriptors of lighting, but will establish a minimum requirement for specifying and describing lit scenes."

This technical committee is chaired by Jennifer Veitch (Canada) and proposes to complete its work in time to present a final report at the 2001 mid-term meeting in Istanbul, Turkey.

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CONTACTS

Jennifer A. Veitch, Ph.D.
National Research Council of Canada
Institute for Research in Construction
Bldg M-24 1500 Montreal Road
Ottawa, ON K1A 0R6 Canada
tel. +1 613-993-9671 / fax +1 613-954-3733
E-mail: jennifer.veitch@nrc.ca

David Loe
Building Research Establishment,
Garston, Watford, WD2 7JR, UK.
tel: +44 1923 664767 / fax: +44 1923 664097
E-mail: loed@brc.co.uk

Vincent Berrutto, Ph.D.
European Commission - Joint Research Centre
Environment Institute, T.P. 450, 21020 Ispra, Italy
tel. +39 0332 78 9688 / fax +39 0332 78 9992

E-mail: vincent.berrutto@jrc.it

Yoshiki Nakamura, Ph.D.
Tokyo Institute of Technology
4259 Nagatsuta Midori-ku Yokohama 226 JAPAN
tel: +81 45 924 5667 / fax: +81 45 924 5574
email: yoshiki@human.enveng.titech.ac.jp

Christopher (Kit) Cuttle
School of Architecture, The University of Auckland
Private Bag 92019
Auckland New Zealand
tel. +64 (9) 3737 599 / fax +64 (9) 3737 694
E-mail: k.cuttle@auckland.ac.nz