The Application of RADIANCE to Daylighting Simulation

Karl Frost*, Mike Donn*, Robert Amor**
** School of Architecture, Victoria University of Wellington[1]*
*** Computer Science Department, University of Auckland[2]*

The RADIANCE lighting simulation system was used to evaluate the daylighting inside four major buildings being constructed and refitted in New Zealand. This paper describes the utility and useability of such a simulation system for large projects of this nature. The ability to create many virtual snapshots of design alternatives and compare them both visually and numerically is explored, as are the problems Architects will find with describing a model to a simulation system of such complexity.

INTRODUCTION

The RADIANCE Synthetic Imaging System is intended accurately and realistically to model natural and artificial lighting conditions in a scene described by the user. It was developed as a program for lighting design and research, to provide a tool for both the illuminating engineer and the lighting designer. RADIANCE uses ray-tracing techniques to calculate luminance values within a scene, then produces an image of the scene as described by the values. This rendered image is the output from the simulation, and provides both the qualitative and quantitative measurements required by the users (see Figure 1 for the system structure).

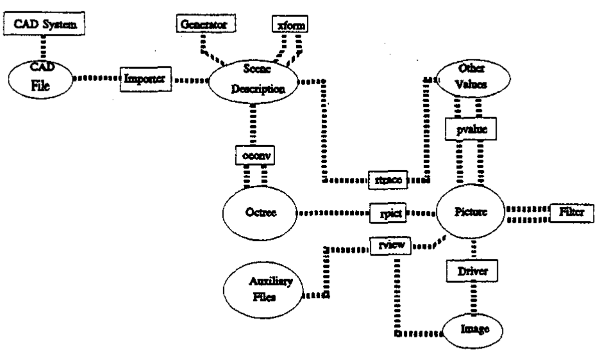

Figure 1 Radiance structure diagram (Ward, G.J., 1990)

The RADIANCE program allowed all of the required data to be obtained using a single model and daylight simulation operation. Previously the simulations would have been performed using a combination of physical and computer or mathematical model. In addition, none of these methods could provide an accurate rendering of a scene. Using RADIANCE saved on preparation time and produced output in a form that the client could easily appreciate.

This improved output, as with all improvements to simulation design tools brings with it complications and unexpected difficulties of interpretation. This paper explores the lessons for designers and for creators of simulation tools from practical application of this tool.

The modelling of four buildings is discussed. The first was the Museum of New Zealand Te Papa Tongarewa to be built in Wellington. The second was the Wellington City Council Art Gallery, involving the remodelling of the former Wellington Public Library. Both of these buildings are to house exhibit spaces, hence the visual environments are critical factors in the designs. The physical scale of the simulations differed greatly between these projects. For the museum, several large

1: PO Box 600, Wellington, New Zealand;
Ph: +64 4 495 5031; Fax: +64 4 495 5233
e-mail: michael.donn@vuw.ac.nz
2: Private Bag 92019, Auckland, New Zealand; Ph +64 9 ; Fax: +64 9
e-mail: trebor@cs.auckland.ac.nz

spaces were modelled while only a single gallery was modelled for the art gallery.

The other two buildings were unique in their own way as well. The first, was a deep plan building in central Wellington to be remodelled for use by a university department. The second was a 4000 square metre regional police station. In each case, a significant feature of the design was an internal atrium space to bring light and sun into the centre of the building.

Museum of New Zealand

The Museum of New Zealand is to house all the displays currently in the National Museum in Wellington. It is, in the New Zealand construction context, a very large building, being capable of handling the display and conservation functions of ethnological, historical and botanical displays for the nation's museological heritage. A consciously bi-cultural building, the design makes considerable use of orientation to the sun and the landscape in its design conception. The architects wished to reinforce this orientation for the user inside as well as outside the building.

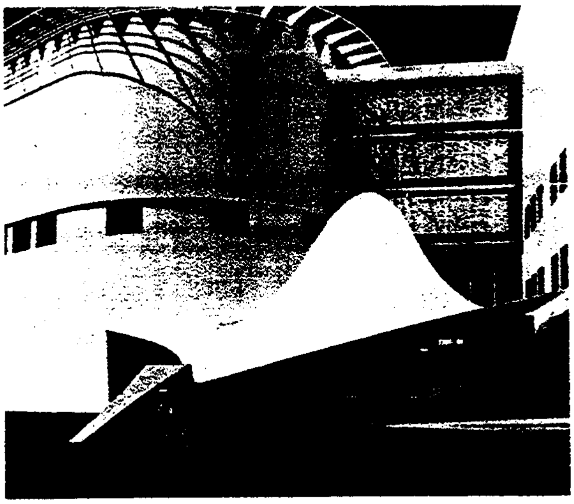

Figure 2 Exterior view of Museum of New Zealand - te Papa Tongarewa

A key factor of the design is a central spine along which visitors promenade diverting off into galleries as they wish and according to the decisions they make based on information provided by display boards and staff. The spine is defined by its orientation to the harbour and the sun. At every point along it views to the outside are provided by large view windows. The architects wished to explore how much sun and light they could deliberately allow into the space without compromising the conservation functions of the museum in the adjacent galleries through spill of high intensity light. (see Figure 2 for the simulated museum exterior view).

In addition to this spine, a number of orientation views are provided from specific points in other galleries. These provide access to views of the city of Wellington, but as a consequence allow sun and light into the galleries.

The simulations of the museum spaces were aimed at assessing the extent of sunlight penetration into these key public circulation and gallery spaces. The major concern was the visual implications of sunlight penetration. While the thermal implications would be significant, they were to be explored by the mechanical consultants for the job.

This work began towards the completion of the developed design stage, hence the lighting design decisions had been made. All of the major glazed areas incorporated louvres or sunscreens to reduce the extent of sunlight penetration, particularly in the summer. The simulations were intended to visualise and clarify the situations created by the design. The aim was to identify where further lighting controls might be required, based on the extent and duration of sunlight penetration into the spaces.

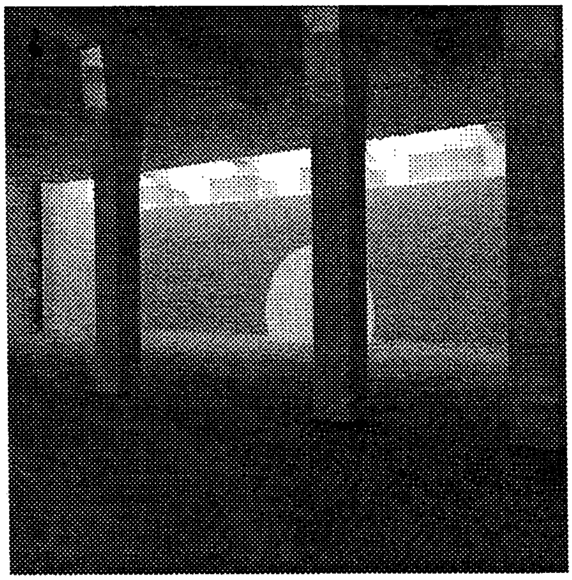

Figure 3 Wellington City Council Art Gallery, Exhibition space, lighting option 1.

Wellington City Council Art Gallery

The simulations for the Wellington City Council Art Gallery were performed at an early stage of the refit design. The interior of the Wellington Public Library was to be remodelled to become a new art gallery as part of the new Civic Square in downtown Wellington. This 2-storey concrete building has large windows, allowing plenty of daylight and sunlight into the building. Curtains

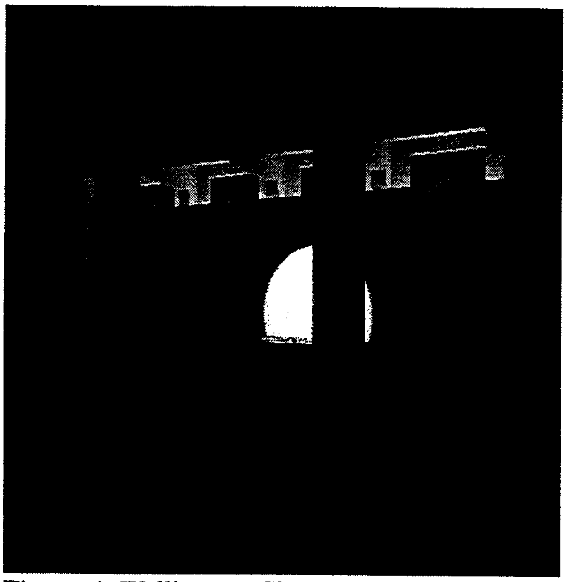

Figure 4 Wellington City Council Art Gallery, Exhibition space, lighting option 2.

were used to reduce the intensity of natural light and the damage done to books.

For the refit a major question was whether or not to allow daylight into gallery spaces at all. To use the spaces for exhibition of artwork required a greater control of the visual environment. Assuming that daylighting was to be used some options for allowing daylight, but not sunlight, into gallery spaces were tested, but again the program was not used to design the lighting system. The aim was to compare the quality of the visual environments created by the daylighting options.

Architecture School Victoria University

The School of Architecture is to be moved into a downtown location in late 1993 as part of an expansion of the Victoria University of Wellington campus expansion. It is to occupy what was formerly a freight forwarding and office building. The concrete frame building is currently on 3 floors, one of which is partially below ground, and has floors approximately 55m by 60m with glazing on the East West and North. For the refurbishment, a design is planned which will add a further floor, and carve a central light well (atrium) through the top three floors.

For the study reported here, thermal and daylighting modelling was conducted of the glazing options for the additional floor and for the optimum configuration of the atrium glazing in the roof and between the atrium and the adjacent offices and studios.

Regional Police Station

With the assistance of the Electricity Corporation of New Zealand (ECNZ), thermal and daylighting studies were conducted of a proposed regional police station in a provincial town of approximately 15,000 people. The site was constrained, so the 4000 square metres of the building had to be placed on two floors, limiting the access of some of the areas to light and air. A further complicating factor was the limits on the design options imposed by the security requirements of the occupants.

The simulation efforts concentrated on a number of

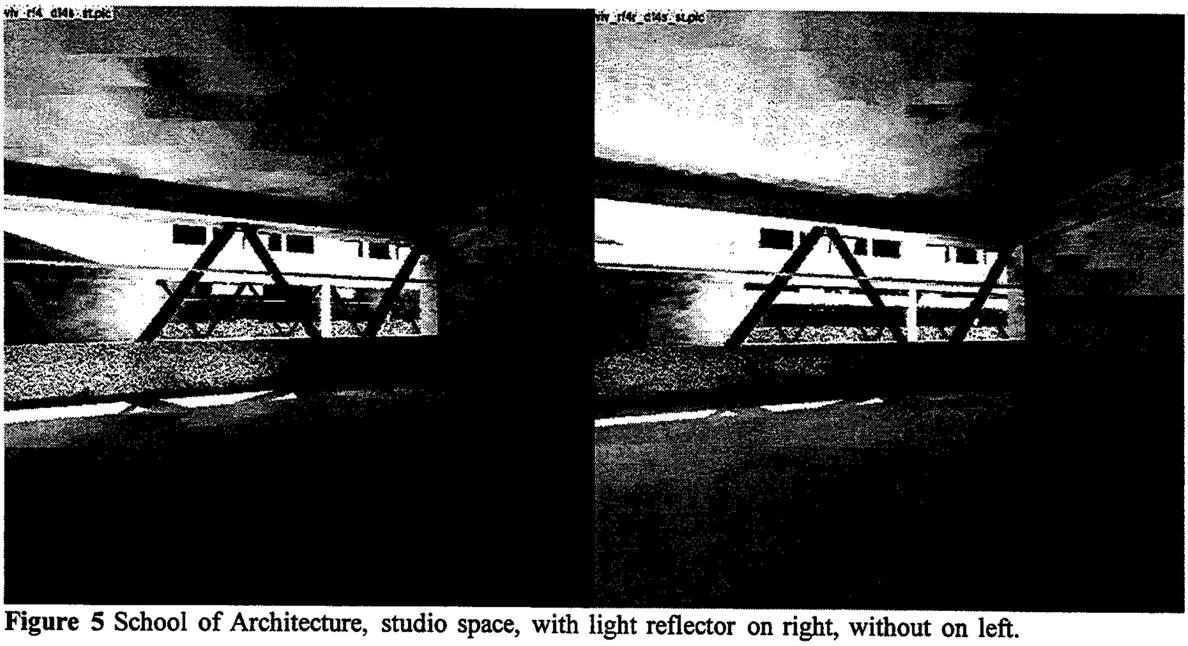

Figure 5 School of Architecture, studio space, with light reflector on right, without on left.

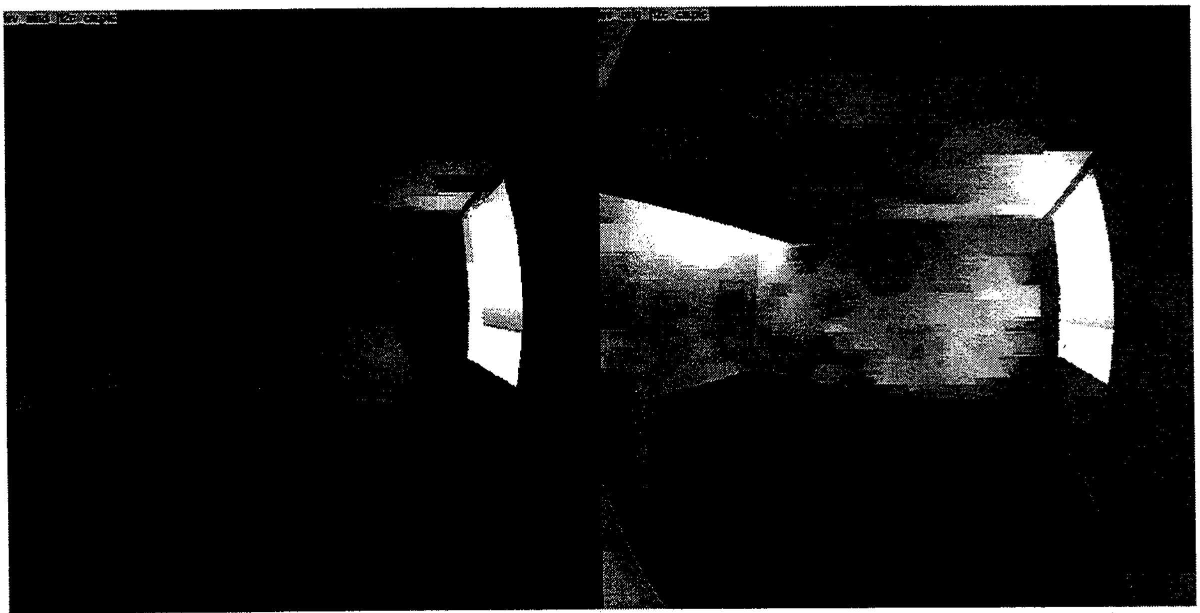

Figure 6 Levin Police Station, view of office interior on top floor, with and without clerestorey window.

separate questions: access to light and air for the watch room at the centre of the ground floor via a central light well; the conflict between access to light for and overheating for the perimeter offices. The design for the offices on the top floor incorporated windows oriented to the outside of the building and high level clerestories oriented towards the centre of the building. (Figure 6 shows a view of the interior of the building on the top floor)

Daylighting analysis

For each project a report was produced consisting mainly of images created by RADIANCE. These images were organised in time sequences to show the extent of sunlight penetration into the spaces, or in design option sequences for comparison of the visual environment.

The issue of predictive accuracy or certainty of the results obtained was highlighted in the course of these projects. For its initial release RADIANCE simulations were compared to scale model measurements and different lighting calculation programs. The results showed good correlation between RADIANCE and these alternatives. However, like other simulations the complexity of the program creates uncertainty in the results.

RADIANCE has a very large number of input variables describing a scene. This provides the user with an apparently infinite number of ways of 'getting it wrong' or 'getting it right'. The uncertainty is typically compounded by the complexity of the definitions of the environment variables in the input, and that there are no absolute 'real world' settings.

Much of the work currently being put into development of improved interfaces for building performance simulation engines tries to improve their accessibility. Provision of libraries of materials, collections of real climate data, and tools for graphic analysis of the results are seen as making computer simulation programs more user-friendly. With Radiance, this last aspect of the simulation is highlighted by the fact that its principal output is graphic: pictures or renderings of the appearance of a space under the given illumination. The results from the projects described above demonstrate some of the difficulties that remain to be addressed if building performance simulation engines are to be truly user-friendly. These difficulties are described in the following paragraphs.

The RADIANCE program permits the user to produce pictures which contain more than just the normal visual messages implied by contrasting luminances of adjacent pixels in computer graphics. Daylight factor analyses, glare calculations for large (typically windows) and small (typically electric lamps) sources of light; and actual luminances (in nits) of adjacent surfaces can be extracted from the pictures produced by the ray-tracer section of the program.

For all four projects discussed, the models were generated in AutoCAD. Within AutoCAD the model had to be organised to simplify the transfer to and use of the model in RADIANCE. Objects and plane polygons (faces) were grouped primarily by material, and the surface normals of these faces had to be oriented correctly to ensure the realistic physical appearance and properties of the surfaces.

The next step was to convert the AutoCAD models into RADIANCE models. RADIANCE accepts models described in a textual format, rather than a graphically defined model. A translator program was run in AutoCAD to identify and describe the model elements in a text format usable by RADIANCE.

After the models had been transferred into RADIANCE, the surface materials had to be defined, allowing for reflectance and desired appearance. The material descriptions were entered into another text file for easy reference and editing, as the model files consisted of up to several thousand elements. Finally another file was created to describe the sky and model surroundings.

The increased complexity of modern computer-based building performance simulation tools has not rid the design profession of its traditional problem with these tools: that they evaluate completed designs. Guidance as to how to move forward in improving a design comes only from the informed user looking backwards at how the existing design performs. Often the designer has a need for information from the simulation before they have enough firm data to be able to provide the necessary input to the simulation.

An initial run of renderings was performed to ascertain viewpoints to define the scenes to be rendered fully. These renderings also provided ideas for the scope of the tests, times of the year and durations, plus highlighted 'holes' or inaccuracies in the model and places where the material definitions required changes.

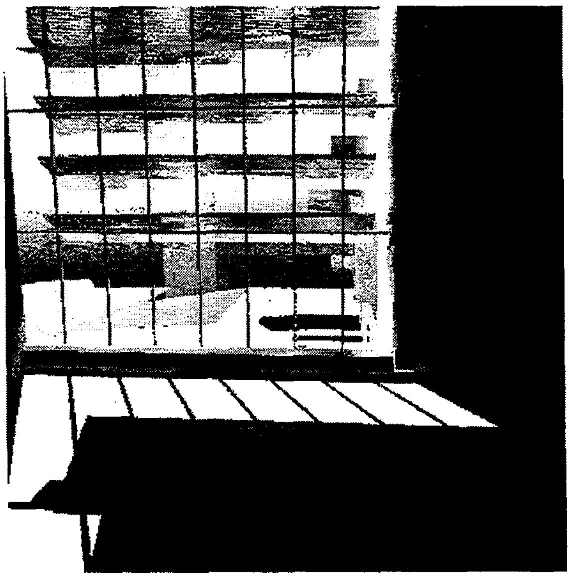

Figure 7 Museum of New Zealand, Orientation lobby, West facing glazing.

For this particular program, the realistic appearance and graphic nature of the output is extraordinarliy attractive to the design community. It is likely that it will be used more and more to provide "pictures" of interiors. However, the interpretation of quantitative information from these pictures is problematical.

For example, the architects for these projects were all nervous about being too specific about the colours or textures in their buildings. This question had not been explored in any systematic way by the design team and there was some concern that the design might be committed to this colour choice without allowing any opportunity for further exploration.

The images for the museum project clearly showed the spaces and extent of sunlight penetration. However some anomalies were noted in the in the images. In some images the spread of sunlight suggested that the light source was a very large point source rather than a parallel source of light (see Figure 7). In addition, the impact of some images was reduced by unusual surface texture effects (Figure 8).

A more serious issue is the mode of presentation of the data. The client for the museum, whilst admiring the quality of the rendered pictures, was not totally satisfied with that mode of information. It is possible that a minute by minute animation could have satisfied their needs. However, it is very difficult to compare and contrast two or three videos of design alternatives. Simple one-page diagrams are much easier to deal with in many cases, these results are produced manually not with the sophisticated simulation engine.

The luminance information obtained from Radiance pictures was more difficult to verify. A series of tests were run with a simple box model in the School of Architecture artificial sky, as a means of calibrating RADIANCE 'predictions'. A related issue that was highlighted during the project is the accuracy of the sky hemisphere description in relation to New Zealand conditions and to Wellington in particular. A lack of measured data for comparison to the RADIANCE sky description means that it is assumed currently that the definition of a North American sky can be applied to New Zealand.

The presentation of the results of daylighting simulation has the same problem of dealing with time as does thermal simulation programs: it is very difficult to define a standard situation - a "standard sky". Typically, with RADIANCE one might need to produce renderings for sunny and overcast conditions, plus some mixture of these. It is then up to the designer and the analyst to determine how frequently each condition occurs. A 'movie' of each hour of each day for a real year would be impossible to analyse, assuming the computer system to produce the movie can be found.

The most intriging difficulty with use of the Radiance output arose in presenting the pictures for the art gallery to the curatorial staff, the client. Without a visual reference point in the picture, no amount of annotation or graphical overlay could convince them of the results.

A spotlight was placed in the art gallery scenes to provide a well-understood reference against which to judge the natural light. Against the unlit backdrop of the gallery spaces the daylighting created strong sources of glare, but it was difficult to appreciate the magnitude of the glare. By placing a spotlight within the scene the glare sources could be compared with a controlled artificial light (Figure 5.) producing 150 lux on a given surface.

Conclusion

We have described how the RADIANCE lighting simulation program was applied to four projects concerned with the daylighting of their interior spaces. This description shows that such simulations provide a very powerful tool to examine many lighting design options for a building and to compare and contrast them easily both visually, in terms of a simulated snapshot of the space, and numerically through various glare calculations and lighting level measures. These simulations give good feedback to the designers on their design modification and the rendered images that are created are certainly pleasing to the eye.

However, we also highlight the problems associated with ensuring the simulation is accurate for local climatic conditions. Problems are also encountered in the use of such a highly sophisticated simulation system by architects and other designers who are not experts in the field of lighting. The removal of these problems will advance further the whole field of building simulation.

To do so, without also contributing to information overload for the designer, requires better undertanding of the input data and added sophistication in the tools provided for processing the output data. Two aspects of this development are the subject of current research at Victoria University.

One research project is examining the daylighting potential of Wellington skies. The building to be

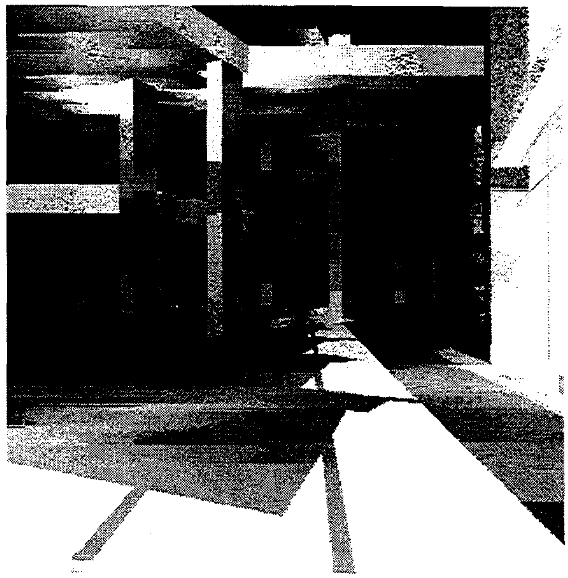

Figure 8 Museum of New Zealand, Orientation lobby, North facing glazing.

refurbished for the School was empty during the summer of 1992-3. It has been used as a natural test-bed for measurements of the daylight factor in a large scale real building. In additon, the national research laboratory Industrial Research Limited has a project to measure the luminance and spectral distribution of New Zealand skies (Bittar 1992). When this data is available, it is planned that it will be used to further "calibrate" RADIANCE for local conditions.

The second research project is the subject of another paper at this conference (Amor, Donn, Hoskings, 1993). It looks to develop an aspect of the "expert advisor" assisting the designer to input the correct data and to interpret the output data.

Tools like RADIANCE in the very near future will be able to provide building designers with a realistic picture of the implications of their design decisions on computers they have in their offices. Placing this type of tool in the hands of designers places the design information directly at the place where it will be most useful.

However, issues such as those highlighted above must be addressed in the writing of the interfaces to these simulation tools. If they are to have a significant impact on design, then these tools must have more than the conventional "user-firendly" interface.

To provide useful information for the design process, not only the input but also the output data must be processed iinto terms that are readily understood.

The designer who is to use a simulation tool like

RADIANCE requires on interface that is an expert system, an advisor not only on the input but also on the output.

References

Amor, R.W., Groves, L.J. and Donn, M.R. 1990 "Integrating Design Tools for Building Design", In ASHRAE Transactions, Vol. 96, Part 2, 501-507.

Bittar, A; 1992 private communication: FRST research project, Industrial Research Limited, Lower Hutt, NZ;

Donn, M R; 1985 Design Tools; EMPA report , Zuerich, CH

Ward, G.J. 1990 "RADIANCE: A Tool for Computing Luminance and Synthetic Images", Lighting Systems Research Group, Lawrence Berkeley Laboratories, California, USA.