Daylight Simulation: Validation, Sky Models and Daylight Coefficients

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Daylight Simulation: Validation, Sky Models and Daylight Coefficients

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This thesis is dedicated to the memory of Professor Neil Bowman

Director of the Institute of Energy and Sustainable Development

1994 to 1999
Abstract

The application of lighting simulation techniques for daylight illuminance modelling in architectural spaces is described in this thesis. The prediction tool used for all the work described here is the Radiance lighting simulation system.

An overview of the features and capabilities of the Radiance system is presented. Daylight simulation using the Radiance system is described in some detail. The relation between physical quantities and the lighting simulation parameters is made clear in a series of progressively more complex examples. Effective use of the inter-reflection calculation is described.

The illuminance calculation is validated under real sky conditions for a full-size office space. The simulation model used sky luminance patterns that were based directly on measurements. Internal illuminance predictions are compared with measurements for 754 skies that cover a wide range of naturally occurring conditions. The processing of the sky luminance measurements for the lighting simulation is described. The accuracy of the illuminance predictions is shown to be, in the main, comparable with the accuracy of the model input data. There were a number of predictions with low accuracy. Evidence is presented to show that these result from imprecision in the model specification - such as, uncertainty of the circumsolar luminance - rather than the prediction algorithms themselves. Procedures to visualise and reduce illuminance and lighting-related data are presented.

The ability of sky models to reproduce measured sky luminance patterns for the purpose of predicting internal illuminance is investigated. Four sky models and two sky models blends are assessed. Predictions of internal illuminance using sky models/blends are compared against those using measured sky luminance patterns. The sky model blends and the Perez All-weather model are shown to perform comparably well. Illuminance predictions using measured skies however were invariably better than those using sky models/blends.

Several formulations of the daylight coefficient approach for predicting time varying illuminances are presented. Radiance is used to predict the daylight coefficients from which internal illuminances are derived. The form and magnitude of the daylight coefficients are related to the scene geometry and the discretisation scheme. Internal illuminances are derived for four daylight coefficient formulations based on the measured luminance patterns for the 754 skies. For the best of the formulations, the accuracy of the daylight coefficient derived illuminances is shown to be comparable to that using the standard Radiance calculation method.

The use of the daylight coefficient approach to both accurately and efficiently predict hourly internal daylight illuminance levels for an entire year is described. Daylight coefficients are invariant to building orientation for a fixed building configuration. This property of daylight coefficients is exploited to yield hourly internal illuminances for a full year as a function of building orientation. Visual data analysis techniques are used to display and process the massive number of derived illuminances.
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I declare that the content of the submission represents solely my own work.

Contents

Chapter 1. Introduction 1

Chapter 2. Daylight Simulation 5

2.1 Daylight: Monitoring, Sky Models, and Daylight Indoors ........................................... 7
2.1.1 Measuring Daylight.................................................................................................. 8
2.1.2 Sky Models........................................................................................................ 9
2.1.3 Daylight Indoors—The Components of Illuminance ........................................ 10
2.2 Evaluation Techniques and Accuracy .................................................................. 10
2.2.1 The Daylight Factor Approach ............................................................................ 12
2.2.2 Pictures, Numbers, and Accuracy....................................................................... 13
2.2.3 Color Specification............................................................................................. 14
2.3 Case Study I: Creating the Luminous Environment .............................................. 15
2.3.1 Example: Uniform Sky ........................................................................................ 15
2.3.2 Example: CIE Overcast Sky .............................................................................. 16
2.3.3 Example: CIE Overcast Sky Defined by Its Horizontal Illuminance .............. 18
2.3.4 The Ground “Glow”: An “Upside-Down” Sky .................................................... 19
2.3.5 Summary............................................................................................................ 20
2.4 Case Study II: Predicting Internal Illuminances ..................................................... 21
2.4.1 A Simple Space .................................................................................................. 21
2.4.2 Computing Daylight Factor Values .................................................................... 21
2.4.3 The Dayfact Script ........................................................................................... 23
2.5 Case Study III: Introducing Complexity .................................................................. 24
2.5.1 Appropriate Complexity ................................................................................... 27
2.5.2 Views from the DF Plane .................................................................................. 28
2.5.3 The Ambient Exclude/Include Options .............................................................. 28
2.6 Case Study IV: Creating Skies with Sun ................................................................. 28
2.6.1 Gensky ............................................................................................................. 29
2.6.2 Time of Day Image Sequence .......................................................................... 30
2.6.3 Gendaylit ......................................................................................................... 32
### Chapter 3. Validation I: Preparation

3.1 The validation dataset
   3.1.1 Measured quantities and site details
   3.1.2 Internal conditions: illuminance measurements
   3.1.3 External conditions: monitoring the sky and sun
   3.1.4 Comparison of the validation dataset composition with the Kew TRY
   3.1.5 Scope of the validation
3.2 The lighting simulation models
   3.2.1 The office model
   3.2.2 The sun and sky models - generic form in the simulation
   3.2.3 Modelling the sky and sun
   3.2.4 The brightdata format
   3.2.5 Pre-process of the sky luminance measurements
   3.2.6 Deficiencies in the model sky representation
   3.2.7 A hypothesis concerning potentially unreliable photocell-sky combinations
3.3 The lighting simulation - preparation
   3.3.1 Simulation parameter settings and accuracy
   3.3.2 Optimization methodology
   3.3.3 Ambient calculation - progression and convergence characteristics
   3.3.4 Automation of the simulations
3.4 Conclusion

### Chapter 4. Validation II: Results and Analysis

4.1 External illuminance predictions
   4.1.1 Results and discussion
4.2 Internal illuminance predictions
   4.2.1 Individual cases
   4.2.2 All 754 skies
4.3 Error characteristics related to positional factors
   4.3.1 Sun angle relative to glazing normal
   4.3.2 Errors related to the sun angle distribution
   4.3.3 High RERs related to the “view” from the photocell location
   4.3.4 Effect of frame bar shadowing
4.4 Errors related to illuminance components
   4.4.1 Components of illuminance
   4.4.2 Errors versus fraction of illuminance component
4.4.3 Summary
4.5 Partition of the validation dataset
Chapter 5. Sky Models for Lighting Simulation 163

5.1 Introduction ........................................................................................................ 164
5.1.1 Real and model skies .......................................................................................... 165
5.1.2 Summary ............................................................................................................... 170
5.2 Radiance generator programs for sky models ................................................... 170
5.2.1 The models supported by gensky ...................................................................... 170
5.2.2 The gendaylight program ....................................................................................... 175
5.3 Evaluation I: ‘Pure’ sky models ........................................................................... 175
5.3.1 Automation of the simulations ........................................................................... 176
5.3.2 External illuminance predictions ........................................................................ 178
5.3.3 Analysis of RERs for vertical illuminance predictions ........................................ 181
5.3.4 Internal illuminance predictions......................................................................... 185
5.4 Evaluation II: Sky model blends .......................................................................... 191
5.4.1 Model sky blends: ex post facto synthesis ........................................................ 191
5.4.2 The blending functions ........................................................................................ 193
5.4.3 Illuminance predictions for sky blends .............................................................. 197
5.5 Conclusion .............................................................................................................. 207

Chapter 6. Daylight Coefficients: Formulation, Validation and Application 210

6.1 Introduction .......................................................................................................... 210
6.1.1 The daylight factor approach to annual estimates ........................................ 212
6.1.2 Annual daylight provision based on varying sky conditions ......................... 213
6.2 Daylight coefficients: Fundamentals, prediction and analysis ......................... 215
6.2.1 Fundamentals ...................................................................................................... 215
6.2.2 Overview of the discretisation schemes ........................................................... 218
6.2.3 The ‘Naive Method’ ............................................................................................ 219
6.2.4 The ‘Default Refined Method’ ........................................................................... 228
6.2.5 The ‘Finescale Refined Method’ ........................................................................ 237
6.3 Validation of DC derived illuminances .............................................................. 243
6.3.1 DC formulation for validation ........................................................................... 243
6.3.2 Variants of the daylight coefficient formulation ........................................... 246
6.3.3 Pre-process of the sky luminance measurements .......................................... 247
6.3.4 Results .................................................................................................................... 250
6.3.5 Summary ............................................................................................................... 256
Figures

Chapter 1. Introduction

Chapter 2. Daylight Simulation

Figure 2-1. Basic daylight components: (a) global horizontal (sky and sun), (b) diffuse horizontal (sky only), and (c) direct normal (sun only)................................. 8

Figure 2-2. Components of daylight: (a) direct sun, (b) direct sky, (c) externally reflected, and (d) internally reflected............................................................... 11

Figure 2-3. Internal and external horizontal illuminance................................................... 12

Figure 2-4. Illuminance calculation (a) can be used to calculate daylight factors. Image generation (b) can be used to render images with detail corresponding to need................................................................. 13

Figure 2-5. The luminous “envelope” describes luminance as a function of incident direction........................................................................................................... 20

Figure 2-6. Plan view of room............................................................................................. 21

Figure 2-7. Daylight factor plots showing the effects of the -ab parameter. The top graph (a) uses fewer samples over the hemisphere, -ad 512 -as 0, than the bottom graph (b) which uses -ad 1024 -as 64. ........................................ 22

Figure 2-8. Ground plane versus ground glow ................................................................. 24

Figure 2-9. Ambient bounces and the ground plane........................................................ 25

Figure 2-10. Daylight factor curves with ground plane and obstruction. The top graph (a) shows the -aa 0.2 setting, which results in an inappropriate interpolation. The bottom graph (b) shows better results with the -aa 0.1 setting................................................................. 26

Figure 2-11. Nesting of a detailed office module in a coarsely modeled atrium building...................................................................................................................... 27

Figure 2-12. Two views from the daylight factor plane: unobstructed view (a), and view with nearby building (b). ................................................................. 28

Figure 2-13. Possible light transfers for ambient bounces equal to 0 (a), and 1 (b). .......... 34

Figure 2-14. The direct solar component (a) is not accounted for by mkillum because it is part of the Radiance direct calculation. The direct sky component (b) is accounted for by mkillum, as is the indirect solar component (c), and the indirect sky component (d)........................................ 36
Figure 3-1. Instrumentation layout and obstructions to view above horizon ............... 46
Figure 3-2. Building 9 with inset showing test offices.................................................. 47
Figure 3-3. Photographs of the BRE office rooms (a) single glazing and (b) innovative glazing .......................................................... 47
Figure 3-4. The BRE test cell .......................................................................................... 48
Figure 3-5. Krochmann PRC sky scanner positioned on the roof of the BRE lighting laboratory building and detail................................................. 50
Figure 3-6. Sky scanner measurement pattern............................................................ 51
Figure 3-7. Distribution of validation dataset samples from the year 1992...................... 53
Figure 3-8. Distribution in azimuth and altitude for validation database and entire year ................................................................................................................................................. 54
Figure 3-9. Distribution in clearness index compared to TRY ........................................ 55
Figure 3-10. Line drawing and rendering of office scene description .............................. 57
Figure 3-11. Simplified ground plane model .................................................................... 58
Figure 3-12. Sky and sun source geometry (not to scale) ................................................. 60
Figure 3-13. Hybrid deterministic/stochastic sampling of the light sources for the sun and the sky ................................................................................................................................................. 61
Figure 3-14. Application of brightdata pattern type .................................................... 63
Figure 3-15. Sky luminance data - measured and brightdata-format grids .................... 64
Figure 3-16. Comparison of the measurement pattern (a) with the brightdata format grid (b) ................................................................................................................................................. 67
Figure 3-17. Interpolation across concatenated vector ................................................... 69
Figure 3-18. Rectangular and circular patch geometry .................................................. 70
Figure 3-19. Sky 093_92_13h15...................................................................................... 72
Figure 3-20. Sky 125_92_13h15...................................................................................... 73
Figure 3-21. Sky 273_92_12h15...................................................................................... 74
Figure 3-22. Horizontal and vertical illuminances ......................................................... 75
Figure 3-23. Schematic for sky luminance versus angle ................................................. 76
Figure 3-24. Sky scanner (a) and solar tracker (b) acceptance angles (not to scale) ... 77
Figure 3-25. False colour maps and profiles of the circumsolar luminance for a measured-interpolated sky and a Perez model sky for case 188_92_13h30................................................................................................................................................. 78
Figure 3-26. Predicted sky component (daylight factor) versus number of ambient divisions ................................................................................................................................................. 83
Figure 3-27. Constant ambient value approximation....................................................... 84
Figure 3-28. Results for ambient divisions excursion...................................................... 87
Figure 3-29. Recursive progression of ambient calculation; levels 1 to 6....................... 89
Figure 3-30. Convergence characteristics of the illuminance calculation ...................... 91
Figure 3-31. Structure of the 'executive' program .......................................................... 95

Chapter 3. Validation I: Preparation

Figure 2-15. A daylight simulation of an atrium designed by Foggo Architects, U.K. (Model courtesy of John Mardaljevic) .................................................................................................................. 37
Chapter 4. Validation II: Results and Analysis

Figure 4-1. Predictions for total vertical illuminances .............................................................. 98
Figure 4-2. Vertical illuminance RER time-series ............................................................... 100
Figure 4-3. Vertical illuminance RER time-series ............................................................... 101
Figure 4-4. Vertical illuminance RER time-series ............................................................... 102
Figure 4-5. Vertical illuminance RER time-series ............................................................... 103
Figure 4-6. Clear glazing - 102_92_13h00 and 121_92_14h15 ............................................. 104
Figure 4-7. Diffuse light shelf - 137_92_12h00 and mirror light shelf - 318_92_12h00 ....... 105
Figure 4-8. Rendering and luminance map for room with mirror light shelf 318_92_12h00 ................................................................. 108
Figure 4-9. Predicted vs measured illuminance scatter plot .............................................. 109
Figure 4-10. Frequency distribution in RER - all skies ....................................................... 110
Figure 4-11. Relative error versus scan number ............................................................... 111
Figure 4-12. Number (per bin) versus |RER| ..................................................................... 112
Figure 4-13. Illustration for sun incidence angle plots ...................................................... 114
Figure 4-14. Relative error versus angle between sun position and glazing normal ...... 115
Figure 4-15. Relative error versus angle between sun position and glazing normal ...... 116
Figure 4-16. MBE and RMSE as a function of binned sun position ..................................... 117
Figure 4-17. Photocell view of sun position .............................................................. 119
Figure 4-18. Key renderings for sun positions .............................................................. 119
Figure 4-19. Illustration for photocell renderings (127_92_12h00 p_cell 2) ....................... 121
Figure 4-20. Photocell 1 - day 102_92 ........................................................................... 122
Figure 4-21. Photocell 2 - day 127_92 ........................................................................... 122
Figure 4-22. Photocell 2 - day 318_92 ........................................................................... 123
Figure 4-23. Vector geometry ....................................................................................... 124
Figure 4-24. Illuminance components .......................................................................... 126
Figure 4-25. Fraction inter-reflected component by photocell ........................................ 128
Figure 4-26. Fraction sky component by photocell .................................................. 129
Figure 4-27. Mean absolute fractional error as a function of binned fractional component of illuminance .......................................................... 130
Figure 4-28. Fraction of total per bin ........................................................................... 131
Figure 4-29. Generating ray bundles to test for visibility of circumsolar disc ............... 135
Figure 4-30. RER histograms for ‘reliable’ data .............................................................. 136
Figure 4-31. RER histograms for ‘potentially unreliable’ data ........................................ 136
Figure 4-32. Partitioned dataset ................................................................................... 138
Figure 4-33. MBE and RMSE stratified by clearness index ......................................... 139
Figure 4-34. Illuminance RER time-series .................................................................... 140
Figure 4-35. Illuminance RER time-series .................................................................... 141
Figure 4-36. Illuminance RER time-series .................................................................... 142
Figure 4-37. Illuminance RER time-series .................................................................... 143
Figure 4-38. Lo-amb results ....................................................................................... 146
Figure 4-39. Photocell points reversed .......................................................................... 147
Figure 4-40. Lo-amb results with calculation points reversed ....................................... 147
Figure 4-41. Hi-amb results ....................................................................................... 149
Figure 4-42. Accuracy versus parameter resolution ..................................................... 150
Figure 4-43. Renderings of model and measured skies for day 318_92 ....................... 153
Figure 4-44. Renderings of model and measured skies for day 121_92 ....................... 154
Chapter 5. *Sky Models for Lighting Simulation*

Figure 5-1. Overcast (a) and overcast-intermediate (b) skies................................. 168
Figure 5-2. Intermediate-clear (a) and clear (b) skies.............................................. 169
Figure 5-3. Luminance profile and maps for narrow-range sky models................... 174
Figure 5-4. CIE overcast sky model......................................................................... 178
Figure 5-5. CIE clear sky model.............................................................................. 179
Figure 5-6. Intermediate sky model......................................................................... 180
Figure 5-7. Perez all-weather model....................................................................... 180
Figure 5-8. Sky models MBE and RMSE................................................................. 182
Figure 5-9. Internal illuminance: sky models MBE and RMSE............................... 186
Figure 5-10. Sky model percentiles RER comparison.............................................. 188
Figure 5-11. RER time-series for overcast (with sun) model - CS6-VIS and CS6+VIS... 189
Figure 5-12. Example composite skies................................................................... 194
Figure 5-13. Linear and power-law blending functions.......................................... 195
Figure 5-14. Plots of RMSEs for linear blends......................................................... 196
Figure 5-15. Maps of RMSEs for power-law blend................................................... 197
Figure 5-16. Clear + overcast sky composite............................................................ 198
Figure 5-17. Intermediate + overcast sky composite............................................... 198
Figure 5-18. Sky models and composites MBE and RMSE....................................... 199
Figure 5-19. Percentile sky blends......................................................................... 201
Figure 5-20. Time-series RER for clear-overcast and intermediate-overcast blends... 202
Figure 5-21. Time-series RER for clear-overcast blend and Perez.......................... 203
Figure 5-22. Time-series RER for clear-overcast blend and Perez.......................... 204
Figure 5-23. Time-series RER for clear-overcast blend and Perez.......................... 205
Figure 5-24. Time-series RER for clear-overcast blend and Perez......................... 206

Chapter 6. *Daylight Coefficients: Formulation, Validation and Application*

Figure 6-1. Global and diffuse illuminance availability (klux)........................................ 211
Figure 6-2. Cumulative diffuse illuminance............................................................... 212
Figure 6-3. Daylight coefficient basics..................................................................... 216
Figure 6-4. DC patch schemes based on scanner measurement pattern................... 219
Figure 6-5. Patch ID and building orientation......................................................... 220
Figure 6-6. The naive formulation................................................................. 221
Figure 6-7. Predicted DCs for the NM................................................................. 224
Figure 6-8. Identical DC values for the same patch positions................................. 226
Figure 6-9. Incomplete sky coverage with ‘circular’ sources.................................... 227
Figure 6-10. Sun displacement angle..................................................................... 227
Figure 6-11. ‘Aimed’ rays..................................................................................... 229
Figure 6-12. The refined formulation...................................................................... 231
Figure 6-13. Calculated daylight coefficients for the default Refined Method .............. 233
Figure 6-14. Photocell hemispherical views for scene illuminated by patch#17 .......... 235
Figure 6-15. NM and RM comparison test ................................................................. 236
Figure 6-16. Four ‘finescale’ patches for each ‘default’ patch ..................................... 238
Figure 6-17. Indirect DCMs for the finescale discretisation at p_cells 1 and 6 ........... 240
Figure 6-18. Relationship between the building configuration and the spatial pattern in the coefficient of variation for p_cell 6 .................................................. 241
Figure 6-19. The four components of illumination ...................................................... 244
Figure 6-20. Comparison of scanner measurement pattern with DC patch scheme .............................................................................................................................. 248
Figure 6-21. Sky 125_92_13h15................................................................................. 249
Figure 6-22. Error characteristics for the 4 DC variants and the standard calculation .............................................................................................................. 251
Figure 6-23. Comparison standard calculation and DC variant 4 ................................ 252
Figure 6-24. Comparison standard calculation and DC variant 4 ................................ 253
Figure 6-25. Comparison standard calculation and DC variant 4 ................................ 254
Figure 6-26. Comparison standard calculation and DC variant 4 ................................ 255
Figure 6-27. Key TRY time series maps ..................................................................... 262
Figure 6-28. Sky model mixing function ..................................................................... 263
Figure 6-29. DC derived illuminances for p_cell 3 (south glazing) ............................. 264
Figure 6-30. DC derived illuminance components ..................................................... 265
Figure 6-31. Rotation-invariant nature of the DCM .................................................... 266
Figure 6-32. ‘MAP-rose’ for p_cell3 ............................................................................. 267
Figure 6-33. ‘FRQ-rose’ for p_cell3 ............................................................................. 268
Figure 6-34. ‘CML-rose’ for p_cell3 ............................................................................. 269
Figure 6-35. ‘TI-rose’ for all photocells ......................................................................... 270
Figure 6-36. Frequency distribution of predicted TDFs as a function of glazing orientation ............................................................................................................. 271
Figure 6-37. Examination of TDF distributions for three orientations ....................... 273
Tables

Chapter 1. Introduction

Chapter 2. Daylight Simulation

Table 2-1. Minimum separation and relative computational cost for a range of -ar settings .................................................................................................................. 40

Chapter 3. Validation I: Preparation

Table 3-1. Sample from file for day 318_92.csv .................................................................. 49
Table 3-2. Global quantities file ........................................................................................... 51
Table 3-3. Sample from global quantities file s319_92.alr ................................................. 52
Table 3-4. Measured data for case 102_92_13h00............................................................ 52
Table 3-5. Code example sun/sky input file ....................................................................... 65
Table 3-6. Data file for sky 102_92_13h00 (radiance values) ............................................ 66
Table 3-7. Pattern of rectangular patches......................................................................... 70
Table 3-8. Likely luminance gradients across regions ....................................................... 78
Table 3-9. Source visibility related errors - type, circumstance and effect..................... 80
Table 3-10. ‘Basecase’ parameter values (av=0) ............................................................... 88
Table 3-11. Number of points at each level where hemispherical sampling was initiated. 90
Table 3-12. Measured quantities by vector index ............................................................... 92
Table 3-13. Vector index for first predicted quantities ....................................................... 93

Chapter 4. Validation II: Results and Analysis

Table 4-1. Ambient parameters for external illuminance predictions............................. 97
Table 4-2. Summary of sky conditions and glazing type ................................................ 104
Table 4-3. Approximate horizontal and vertical angles subtended by shadow discs at glazing mid-point................................................................. 124
Table 4-4. Ambient parameter settings (av=0) ................................................................ 145
Table 4-5. Glazing sampling probability at photocell locations normalised to 1 at p_cell 1................................................................................................................ 148
Table 4-6. Difference between measured (patch) luminances and equivalent patches from continuous sky luminances....................................................... 155

Chapter 5. Sky Models for Lighting Simulation
Table 5-1. Measured distribution and sky model specification................................. 166
Table 5-2. Sky generator program parameters.......................................................... 177
Table 5-3. Vertical illuminance: average |MBE| and RMSE ....................................... 183
Table 5-4. Internal illuminance: average |MBE| and RMSE ....................................... 187

Chapter 6. Daylight Coefficients: Formulation, Validation and Application
Table 6-1. DC Variants.............................................................................................. 247

Appendix A. Validation data
Table A-1. Scan ID................................................................................................. 292
Table A-2. Predicted quantities by vector index...................................................... 298
“Das licht! Das licht!”

Tristan und Isolde, Act II
Richard Wagner
Chapter 1

Introduction

"I read part of it all the way through"

SAM GOLDWYN

The goal of the work described in this thesis is the accurate simulation of hourly internal daylight illuminance levels for a full year under naturally occurring meteorological conditions. The prediction tool used for all the work described in this thesis was the \textit{Radiance} lighting simulation system [Ward 98]. Chapter 2 is an introduction to daylight simulation using the \textit{Radiance} system. This chapter was originally published in the book \textit{Rendering with Radiance: the Art and Science of Lighting Visualization}.\footnote{Note that the originator of the Radiance system has been known variously as: Greg Ward, Greg Larson and Greg Ward Larson. Despite this, and several changes of employment, he has yet to escape recognition as the (effective) sole originator/creator of the Radiance system. As of late-1999, ‘Greg Ward’ is the name to use.} This chapter introduces to the reader the fundamentals of using \textit{Radiance} for exacting daylighting simulation work. The chapter covers a range of topics from daylight factor prediction for simple spaces to creating renderings of highly complex architectural designs. Throughout the chapter, a strong emphasis is placed on the relation between physical
quantities and the lighting simulation parameters. The use of the ambient calculation for inter-reflected light, generally considered to be one of the more perplexing features of the Radiance system, is carefully described. The examples given in this chapter demonstrate how the performance of the ambient calculation can be optimized by judicious examination of the scene prior to attempting any simulations. This chapter was conceived as a 'tutorial' on daylight simulation for those already familiar with, at least, the basics of the Radiance system.\textsuperscript{2} The chapters that follow are concerned with the validation of the illuminance calculation and the formulation, application and proving of techniques for daylight illuminance prediction.

The validation of the Radiance illuminance calculation under real sky conditions is described in Chapter 3 (Preparation) and Chapter 4 (Results). The validation dataset is based on simultaneous measurements of the internal illuminance in an office space and the luminance distribution of the sky.\textsuperscript{3} The internal illuminance was recorded at six locations along the length of the office, and the sky luminance was measured at 145 points evenly distributed across the hemisphere. The validation dataset contains measurements - internal and external - for 754 unique skies that cover a wide range of naturally occurring conditions: from heavily overcast, through intermediate to clear. The sky brightness patterns used in the lighting simulation were based directly on the sky luminance measurements. A hypothesis regarding potentially unreliable photocell-sky combinations in the validation dataset is advanced. Chapter 4 begins with a summary presentation of the validation results. Thereafter, the validation results are subjected to a range of investigations. These analyses are gradually refined and evidence is presented to support the hypothesis advanced in Chapter 3. On the strength of this evidence, the photocell-sky combinations in the validation dataset are partitioned into 'reliable' and 'potentially unreliable'

\textsuperscript{2} For a practical introduction to Radiance, readers are directed to Chapters 1 to 4 of the book Rendering with Radiance.
\textsuperscript{3} Validation data were supplied by the Building Research Establishment.
sets based on the visibility of the circumsolar region from the photocell location. The accuracy of the illuminance predictions for the ‘reliable’ set is taken to be the intrinsic accuracy of the illuminance calculation.

The use of sky models for lighting simulation is investigated in Chapter 5. For this, the validation exercise was repeated but now the sky luminance patterns are based on sky models. The sensitivity of internal illuminance predictions to sky model type is evaluated. In all, four different sky model formulations and two sky model blends are assessed.

An implementation of the daylight coefficient approach for \textit{Radiance} is described in Chapter 6. With the daylight coefficient approach, the internal illuminance for arbitrary sun and sky conditions can be evaluated by reusing pre-computed daylight coefficient values for a discretised sky. Five candidate daylight coefficient formulations for \textit{Radiance} are examined. One of these is found to be potentially very inaccurate and it is eliminated from further consideration. The accuracy of the remaining formulations is tested using the validation dataset. Illuminance predictions for the office space are derived from daylight coefficients using the measured sky luminance patterns for all 754 skies in the validation dataset. The accuracy of daylight coefficient derived illuminance predictions are compared against measurements and those obtained using the standard \textit{Radiance} calculation method. This chapter then shows how daylight coefficients can be used to predict the annual daylighting potential of an architectural space. A methodology for the efficient evaluation of annual daylighting potential as a function of building orientation is presented. Several possible applications for these new techniques are discussed. The thesis concludes with a list of suggestions for the practical application of the new techniques and recommendations for future work.

Familiarity with the \textit{Radiance} system is a desirable, though not essential, prerequisite for critical reading of this thesis. It is hoped that many of the
findings described here will be of interest, to a greater or lesser degree, to all those concerned with daylight prediction.