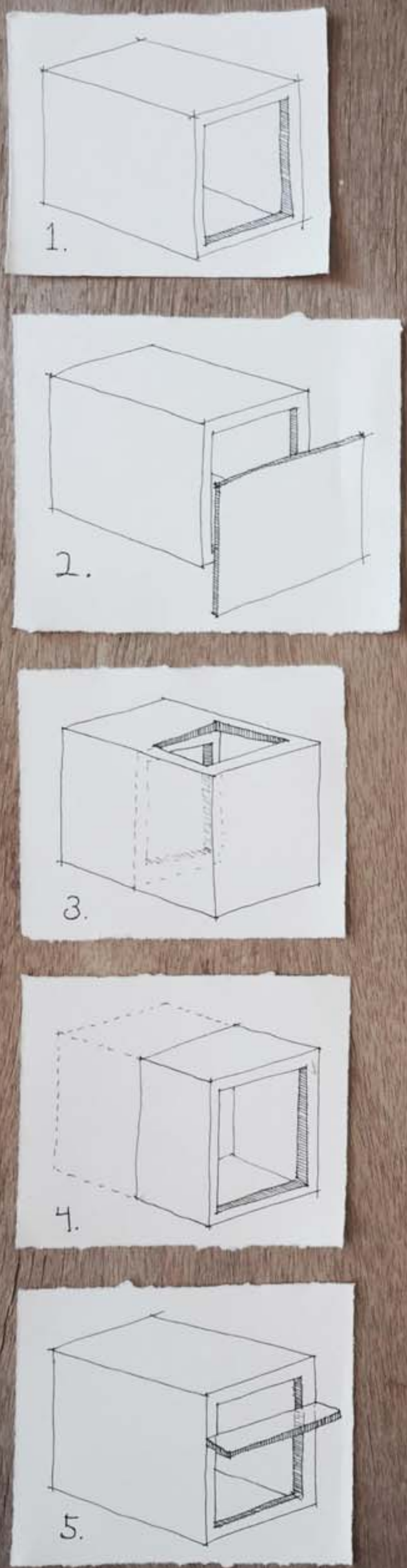

COMPUTER SIMULATIONS vs SCALE MODEL STUDIES

Daylight Factor calculated and measured in 5 simple rooms

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Norwegian Research Council	Funding support
PhD-candidate NTNU and TUW, Anna Sochocka	Measurements in the scale model
Link Arkitektur A/S	A part of Ecotect and Radiance simulations

ABSTRACT

Daylight simulations are becoming a more and more common method for documentation daylighting in buildings in Norway, typically by calculations of daylight factor. There are, however, different programs that have different interfaces, and the parameters of the programs need to be set properly to achieve a realistic result. How accurate the simulation programs are when compared to a measurement in a scale model in a daylight lab?

Daylight factor in five different models of a room were measured in the daylight laboratory at NTNU using Artificial Sky, which is the overcast sky simulator. For each model there is a white and a black version. The result from this measurement is used as benchmark. The five rooms are then modelled and daylight factor is calculated with the help of computer programs: Relux (Raytracing method), Ecotect/Desktop Radiance (export from Ecotect to Desktop Radiance and reimport of results to Ecotect) and Radiance. Results are compared and analysed.

The focus is on Relux, as this is the most prevalent lighting simulation program in Norway. For Relux, different parameter settings were compared within the “quick recommendations” of the manual. Simulations in Relux are conducted by a non-professional user who uses the Relux manuals as a guide, while simulations in Radiance and Ecotect/Desktop Radiance are conducted by an experienced user with several years of practice. All five models are tested as a white and as a black alternatives.

The different models can be shortly described as follows: Deep room (Room 1), Deep room with outside obstruction (Room 2), Room with skylight and borrowed light (Room 3), Shallow room (Room 4), Deep room with mirrored light-shelf (Room 5).

Good correlation between calculated and measured daylight factor has been found, especially for rooms with white surfaces, only small average differences were noticed; i.e. below 15%

In black rooms a larger differences in between programs and between programs and benchmark (model measurements) were found, the differences for single points exceeded 20%; We should remember that the light level in a back part of a black room is very low, i.e. DF is often lower than 1%, consequently, the difference of 20% means just 0,2% DF.

The parameter setting in calculations is very important; and the importance varies in between parameters. One of the important parameters, "inter-reflections" in Relux, "ambient bounces" in Radiance and Ecotect, should be chosen according to the room reflectance’s; about 10 inter-reflections are needed for a white room; about 3 inter reflections for a “standard” room, while 1 is enough for the black room. Another important factor is the “precalculate windows” setting that distorts the results closest to the window, and in the case of large windows, as is the case in the present study, it is recommended to turn it off.

When comparing the calculation results using different parameters in Relux, the parameter settings affect strongly the result. The difference up to -44% occurred for a single points even if the settings specified in the manual were used.

In the case where a large outside obstruction is situated in front of the window, i.e. the light reflected from an outdoor wall is the main source, the Relux program performed worst, creating up to -44% maximum difference comparing to the benchmark for a single point, and about 30% average difference (all points). Radiance and Ecotect/Desktop Radiance was also conservative with -20% average difference.

Keywords; *Daylight simulations, scale model measurements, daylight factor, reflectance measurements, artificial sky, Relux Raytracing, Radiance, Ecotect.*

CONTENTS

1 BACKGROUND

The Norwegian building regulations, TEK10, states in §13-12 Lys that rooms where people stay for prolonged periods of time shall have satisfactory supply of daylight. In the guidance to the TEK10, VTEK10, more specific recommendations are given, one of them states that said rooms shall have an average daylight factor (DF) of minimum 2%.

With an increasing need for documentation of daylight conditions in architecture according to building standards and regulations, computer based lighting simulation programs are becoming gradually more popular tools, especially for verifying and testing the daylight factor in buildings. Compared to model measurements, computer simulations are less time-consuming, and have the possibility to give more visually pleasing results, such as visualizations of the room in question, false color plan views, false color 3d views, etc.

The main goal for this study has been to test the latest versions of the most prevalent daylight simulation programs in Norway, namely Relux, Ecotect/Desktop radiance and Radiance, against measurements of scale models in the simulator of the overcast sky, Artificial Sky, in Daylight laboratory at NTNU, Faculty of Architecture and Fine Art, Light & Colour Group.

By mutual comparison of simulation results of the exact same room in different programs, and by comparison to a “benchmark” measurement done in the Daylight lab, the following questions can be answered:

I. Are results from popular ray-tracing simulation programs comparable to results from the artificial sky?
II. How much impact do the calculation parameters have?

2 METHOD

2.1 The 5 rooms

The following section contains descriptions and explanations of the rooms.

Five different rooms representing typical cases from modern architecture were chosen. All rooms were developed on the same base scale model, figure 1. The base model has been assembled by Heidi Arnesen for her PhD-project, finished in 2002 (Arnesen 2002).

To pinpoint the potential deviations, the rooms were tested in two versions. One version with a high reflectance of the interiors (white), and one with a low reflectance (black). For the high reflectance versions a white and diffuse cardboard was used to cover room surfaces; it reflects 88% of the incoming light. For the low reflectance versions a black diffuse fabric was used. The fabric reflects only about 2,5% of the incoming light.

The scale model does not represent a specific room, but can be compared to a small room in scale 1:5 or a big room in scale 1:10.

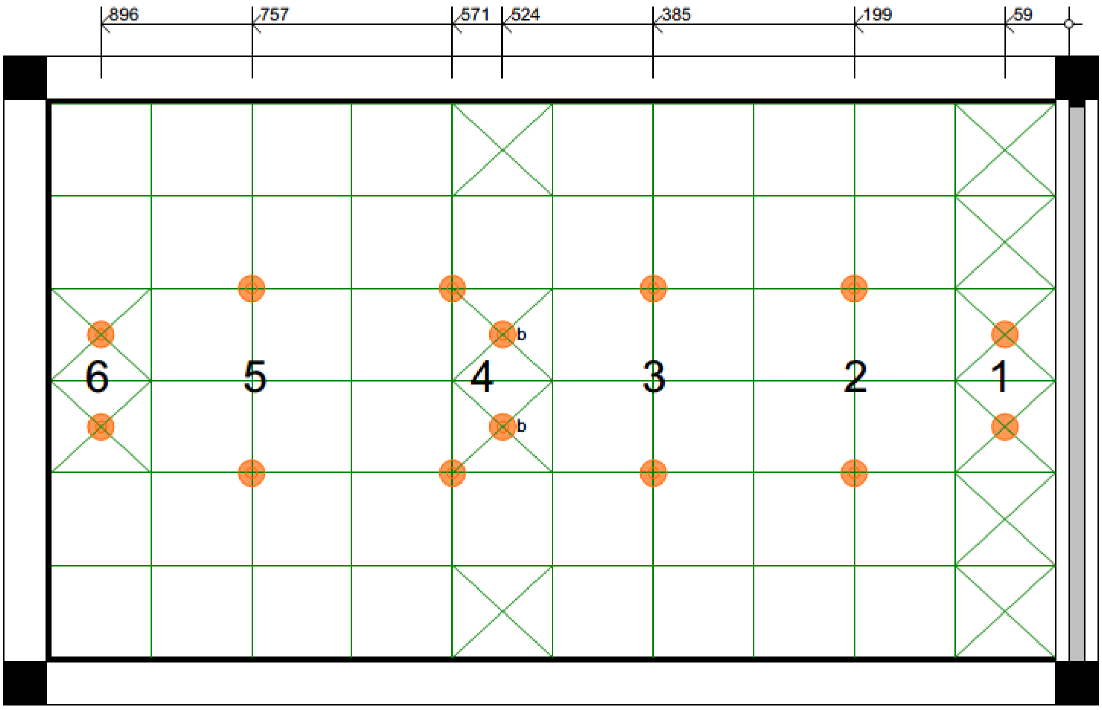
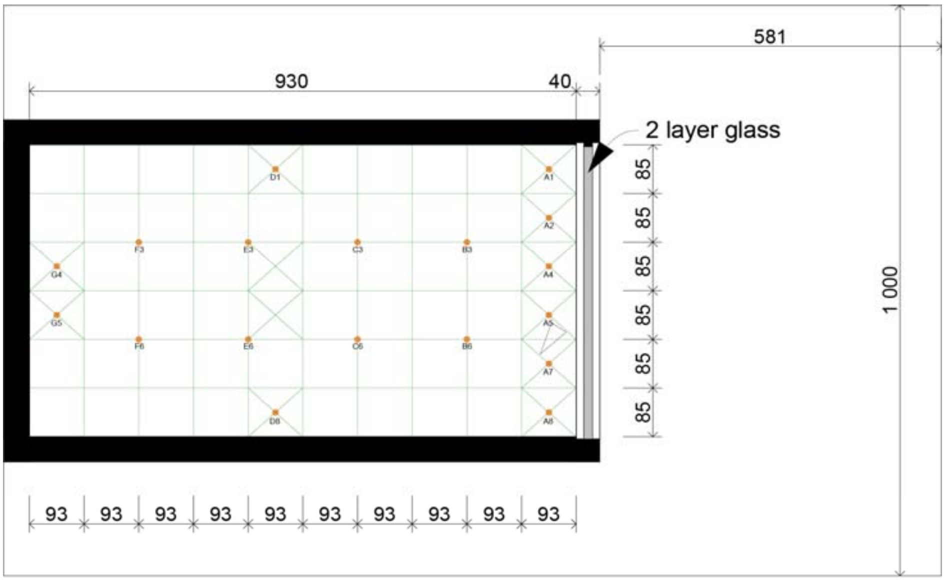


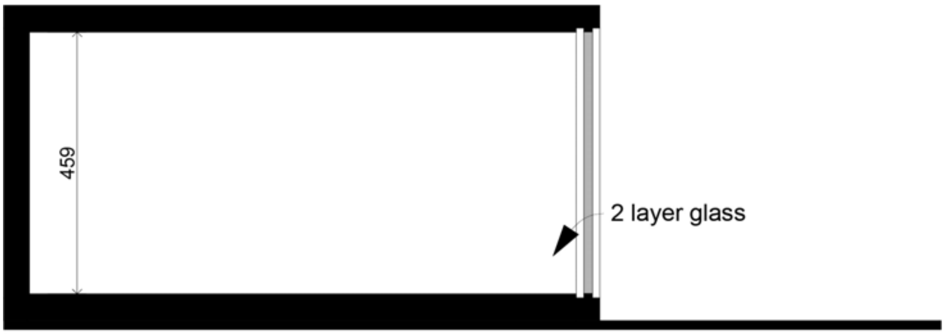
Fig 1 – The plan of the base scale room with the grid and measuring points.

Figure 1 shows a grid layout and measurement points that were used to measure daylight factor in the scale room. Exactly the same grid and the same measurement points were used in simulations.

The simulation results are presented in graphs in figures (9-49 except 29), where each value represents the average of the pair points closest to the center. The value closest to the window is called 1, and then going through 2, 3, 4 and 5 to 6. In room 4 alternative measuring points, marked 4b, are used.



Plan



Long section

Cross section

Fig 2 – Room 1: Deep room; dimensions in mm.

The Room 1 is called a deep room. It is about twice as deep as it is wide and high; and has one of the short walls replaced with a window. It could be compared to an office in scale 1:5, or a conference room in scale 1:10. The model was placed on a black painted table as ground.

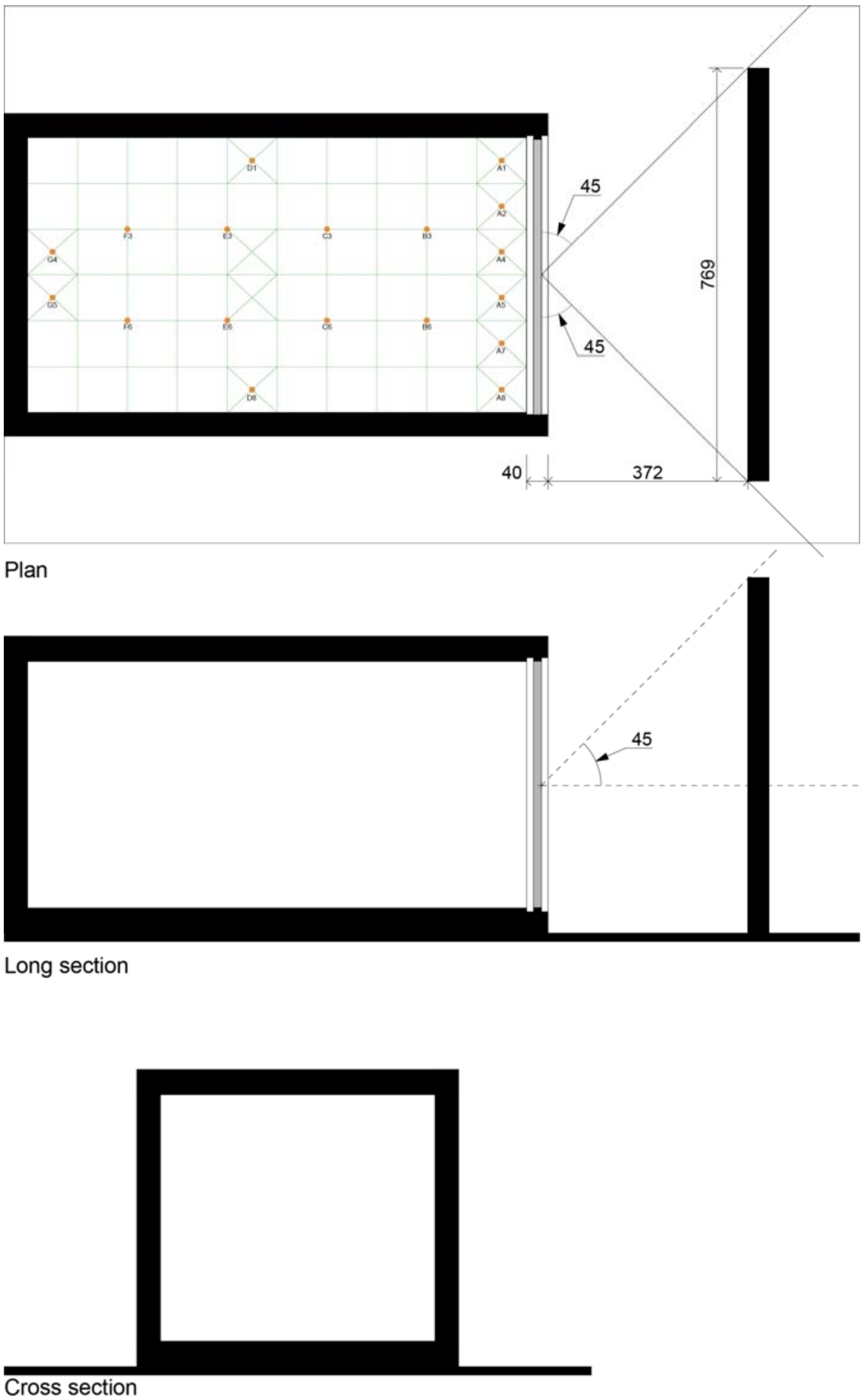


Fig 3 - Room 2: room with an outside obstruction.

Room 2 replicates a typical situation for urban situations. By adding an obstruction outside the room, the user of the simulation program is dependent on using a more advanced calculation method e.g. Precalculation of windows.

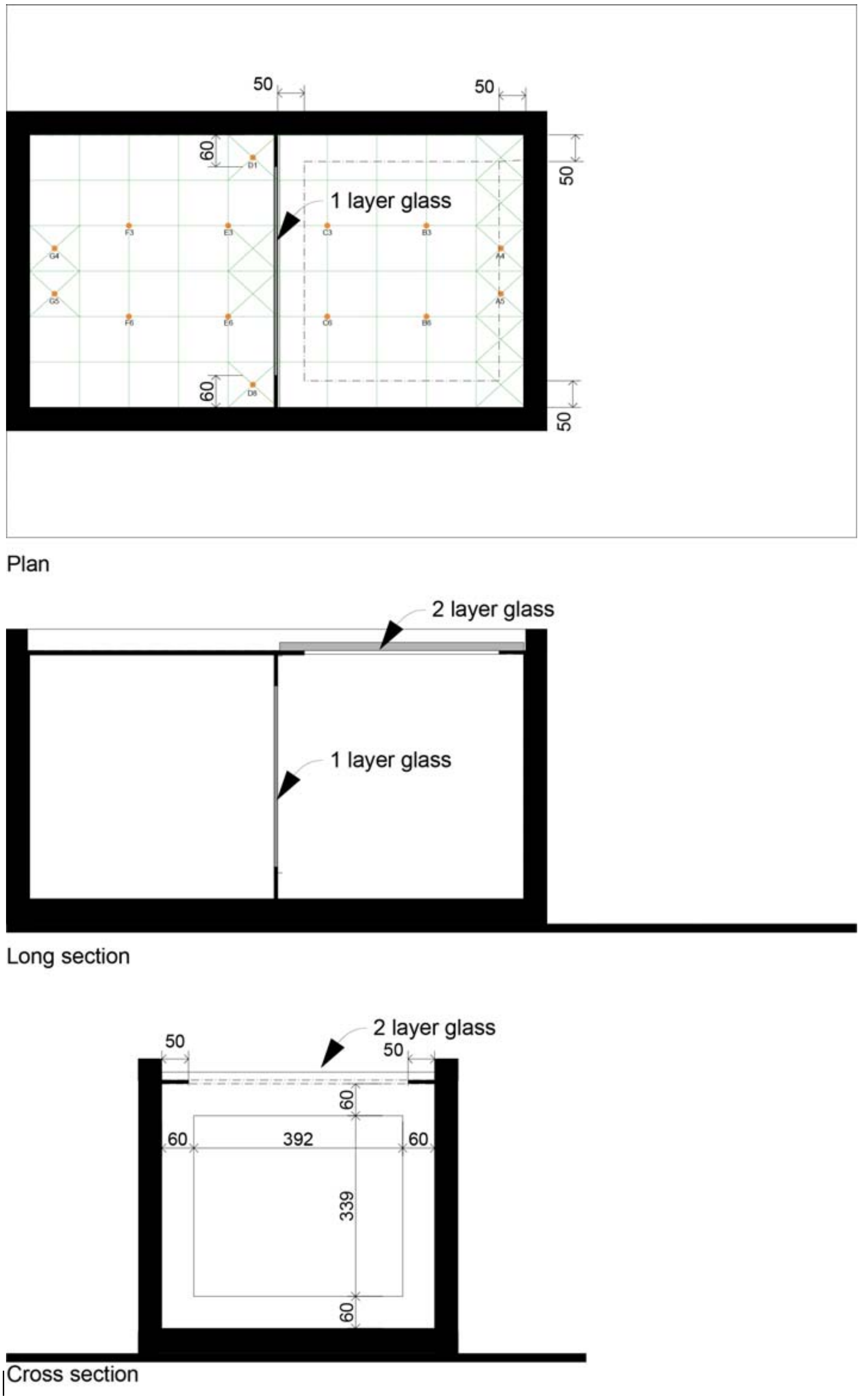


Fig 4 - Room 3: room with borrowed light and room with light from skylight.

Room3 is a combination of two rooms. One of the rooms has a skylight directly above it, while the second room ‘borrows light’ with a window towards the room with skylight. This replicates a common scenario in contemporary compact school-buildings; where rooms are often illuminated solely by the light from an adjacent glazed atrium.

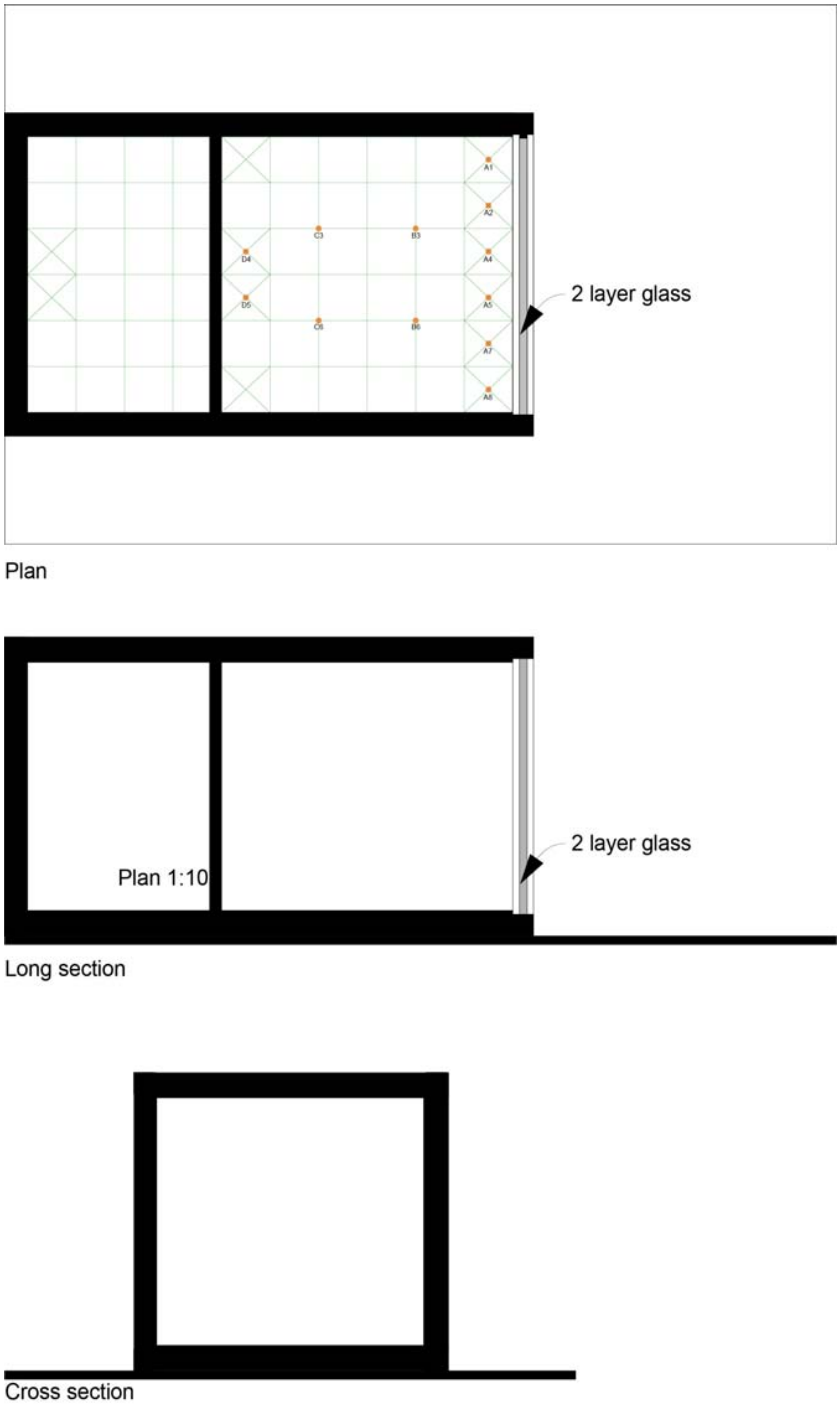


Fig 5 - Room 4 shallow room

This room is similar to room 1, but shallower.

The light shelf is considered to be one of few daylighting systems that would be suitable for Nordic conditions.

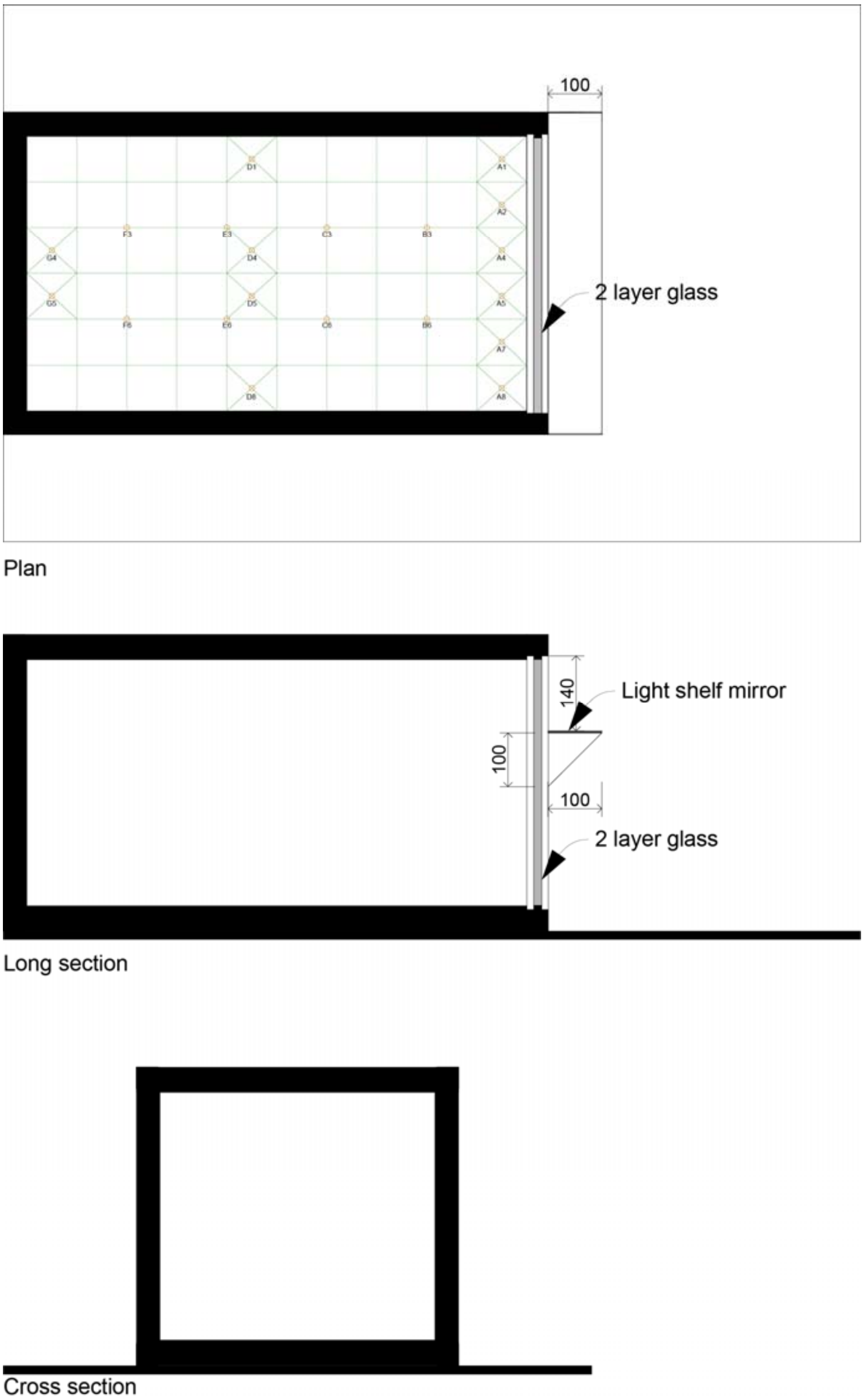


Fig 6 - Room 5, room with a light shelf.

The light shelf is considered to be one of few daylighting systems that would be suitable for Nordic conditions. It is meant to distribute light more evenly in the room. The top of the light-shelf is fitted with a mirror.

2.2 Preparatory measurements

To be able to replicate the lab-test in a computer program, precise measurements of reflectance and transmittance had to be made. The luminances of all materials were measured three times. Values in table 1 show the average values. To ensure stable illumination conditions, the measurements were carried out in the Artificial Sky (Matusiak, Arnesen 2005). The 99% reflectance standard and samples of the measured materials were situated horizontally at the black table at the middle of the Artificial Sky and a handheld luminance meter (Minolta LS-100) was used for luminance measurements from the standing position close to one of the mirror walls.

In addition the Kodak Grey Card was measured in the same way. The grey card was reported to have reflectance of respectively 18% and 90% for the gray and the white side.

Table 1 – Reflectance measurements.

	Specimen cd/m2	Ref. cd/m2	Reflectance %
White cardboard	1904	2140	88,08
Black textile	53,95	2124	02,51
MDF	693	2082	32,96
Wood	801	2098	37,81
Black table	151	2127	07,04
Grey side of the Card	384	2135	17,84
White side of the Card	1929	2133	89,55

Also transmittances of the two different types of windows were measured. By mounting the luminance meter on a tripod, measuring the same surface twice, once through the glass, and once directly, a value for transmittance was found.

Table 2 - Transmittance

	Through glass	Directly	Transmittance
2-layer glass	97,95	126,83	77,23%
1-layer glass	112,5	126,8	88,77%

A similar method was used for finding the reflectance of the mirror. By holding the luminance meter in the same spot, measurements were taken once directly of a diffuse surface and once via the mirror at approx. 90 degree angle. Special care was taken to ensure that the luminance meter was only rotated, and not moved.

Table 3 – Specular reflectance

	Via Mirror	Directly	Specular reflectance
Mirror	2432	2572	94,56%

2.3 The measurements in the Lab

The measurements in the lab were conducted separately and independently by two persons over the course of several days. Person one, Anna Sochocka, measured all 5 rooms in 2 variants (white and black) three times. Person two, Fredrik Martens Onarheim, measured two variants of Room 1. The average results for Room 1 were compared, see figures 7 and 8.

Both persons used the same two lux meters. The first one, a Hagner EC1, was placed on the top of the model, while the second one, a Hagner EC1-X (flat sensor with a wire) was situated inside the model at the respective measuring points. The wire was entering the model through a small hole in the back of the model.

Each person calculated the average daylight factor for pair of points situated on both sides of the room axis, the daylight factor at the middle axis of the room is presented in figure 7.

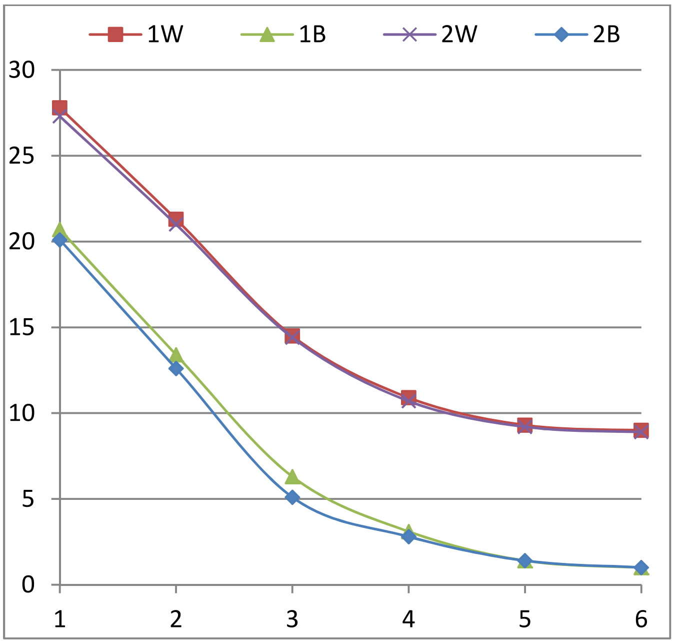


Figure 7 – Comparison of model measurements, DF at the axis of Room 1

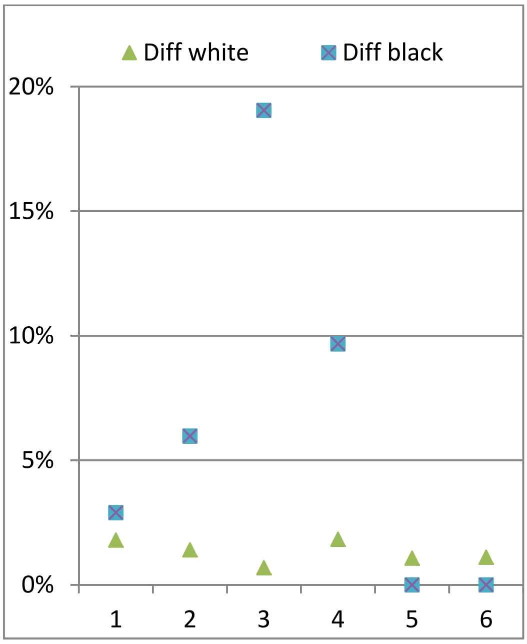


Figure 8 – The difference.

The upper curves in fig 7 represent the measurements in the white room (1W and 2W), while the lower curves represent measurements in the black room (1B and 2B). The difference, expressed as a percentage, is presented in figure 8. Measurements in the white rooms differ with less than 2% from person 1 to person 2. Measurements in the black rooms seem to be more challenging. Some of the measuring points of the black room differ more than the measuring point of the white room. This is probably due to the rough surface of the black room. A fleece-like material was used to achieve as low reflectance as possible. The measurement points were then marked by thin pieces of black paper strips. This paper, which the lux-sensor would sit on top of, may have caused the sensor to be slightly off-level, hence pointing the sensor either more or less towards the window. This is especially critical in the black room, as there is almost no light reflected off the walls, only direct light falling on the sensors obliquely from the side window. Figure 8 shows that one particular measuring point deviates from the rest (point 3). Considering how much this point deviates from the rest of the results from the same room, it is considered to be a wrong measurement, and is disregarded. The results when comparing measurements of person 1 and person 2 were otherwise so consistent (discrepancies up to 10% are acceptable in this setting) that it was decided not to repeat measurements for all rooms and variants by the second person.

The results of the model measurements are represented with a thick red line as a benchmark value(s) in all following graphs.

2.4 The measurements in Relux (version 2013.1.5.4)

Modelling in Relux

Relux was chosen as the main lighting simulation program for this project, as it is considered to be a program with easy user interface, widely available and used by many consultants for actual daylighting calculations. All modelling and measurements in Relux were done by Fredrik Martens Onarheim, NTNU.

All calculations were done as Raytracing calculations.

The different rooms were modelled as “interior” projects in Relux, using cubes to represent the elements outside of the room that would have an effect on results. This is a fairly quick and common way to model a scene for daylighting calculations.

All materials used in Relux are Raytracing materials type "plastic", with a diffuse surface of the exact reflectance that was measured in the actual model, see table 1.

The evaluation area, and “Reference plane” were edited in order to give results in the same measuring points as the ones used in the benchmark model measurements, see figure 1.

Setting parameters in Relux

By following the Relux manual “Fit for Raytracing v2011.3.0 July 2011’’, four different parameter sets were chosen: three in the normal mode, and one with the expert mode. The “Fit for Raytracing” manual states that for normal daylight calculations, picture quality should be set to average or high, and inter-reflections should be set to 4-7. This is explored in calculations R1 and R2. In the calculation R3 the Inter-reflection parameter is increased to 10 and in the R4 the expert mode was added.

R1: Picture quality average, Inter-reflections 4

R2: Picture quality high, Inter- reflections 7

R3: Picture-quality high, Inter-reflections 10

R4: Picture quality high, Inter-reflections 10, Expert mode active.

In R4, expert mode, the base illuminance is set to 0.0, the spatial resolution is set to 0.1 and precalculate windows is disabled. All this follow recommendations for expert mode settings in the ”Fit for Raytracing" manual.

For more detailed description, see the 2007 manual in combination with the 2013 manual as well as the “Fit for Raytracing” manual.

Web pages where the manuals were downloaded from:

Relux 2013 manual:	http://www.relux.biz/pdf/09_manual_reluxSuite.pdf
Relux 2007 manual:	http://www.relux.biz/pdf/09_relux2007.pdf
Relux fit for Raytracing manual:	http://www.relux.biz/pdf/09_RaytracingManual.pdf

The 2007 manual is in fact an obsolete manual, but it is a very good base for users who have never used Relux. The 2013 manual focuses on new features in Relux. The "Fit for Raytracing" manual includes advices when calculating with Raytracing.

Output from Relux

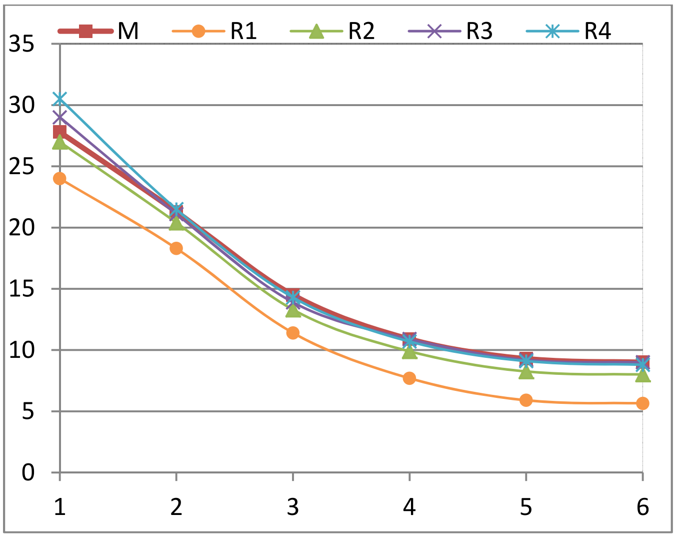
Relux can offer many different outputs. In this case, for the convenience of comparing results from different measurements, a grid was used.

3 RESULTS from Relux

The following pages shows the results of the measurements of the four different Relux calculations compared to the benchmark (scale model measurements). The graphs to the left (odd figure numbers) show the results of all measurements expressed in daylight factor in the Y axis, and measuring points (starting from the window) in the X axis. The graph to the right shows the results of the Relux calculations in comparison to the benchmark (measurements of the scale model in the Artificial Sky). In this graph the 0% line represents the benchmark measurements; the Y axis represents the difference between simulation and benchmark in percentages, while the measuring points are shown on the X-axis (starting from the window).

All benchmark model measurements are shown by a thick red line.

Room 1 comparison between Relux parameters



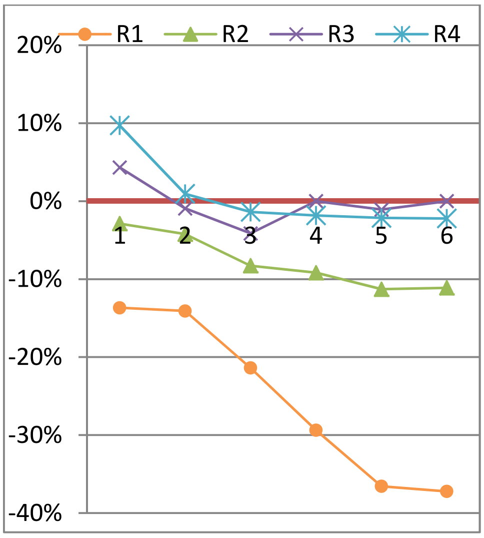
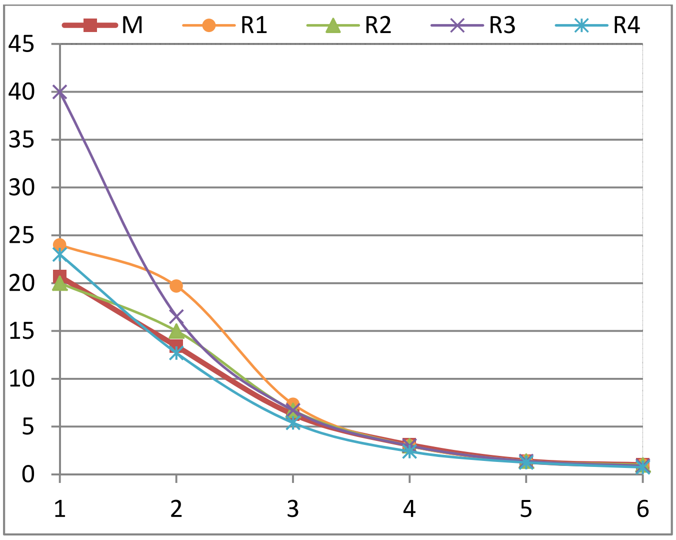


Fig 9 - Relux Room 1 white version

Fig 10- Difference

The white version of Room 1 reveals acceptable values for R2, R3 and R4, while R1 deviates with -38% at the measuring points deepest in the room.



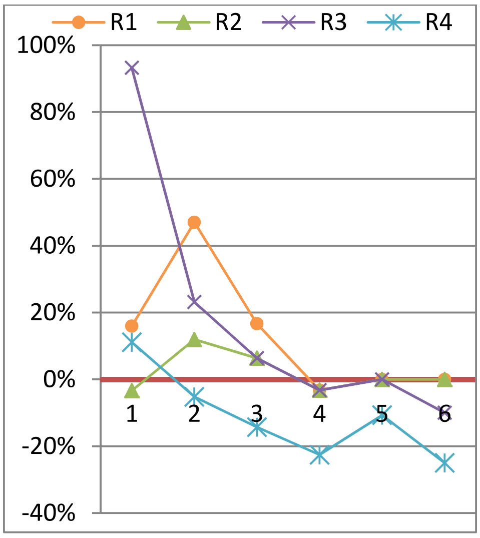
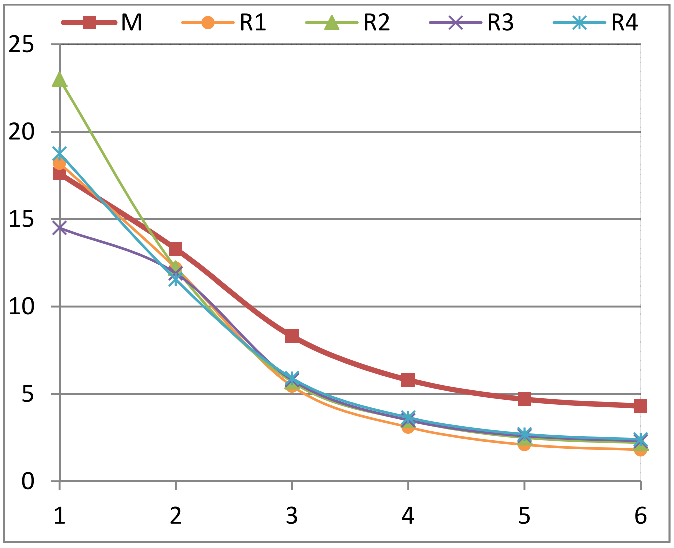


Fig 11 - Relux Room 1 black version

Fig 12 - Difference

The black version shows highly inconsistent values close to the window for R1 and R3. Further into the room, from measuring point 3 and above, the values for R1, R2, R3 are very close to the benchmark model measurement, while R4 deviates with -22% for point 6.

Room 2 comparison between Relux parameters



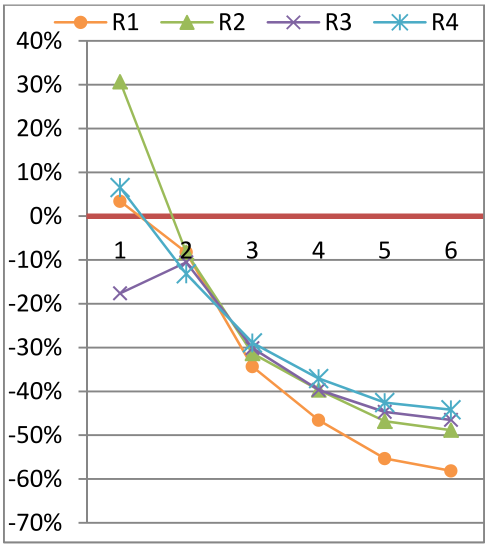
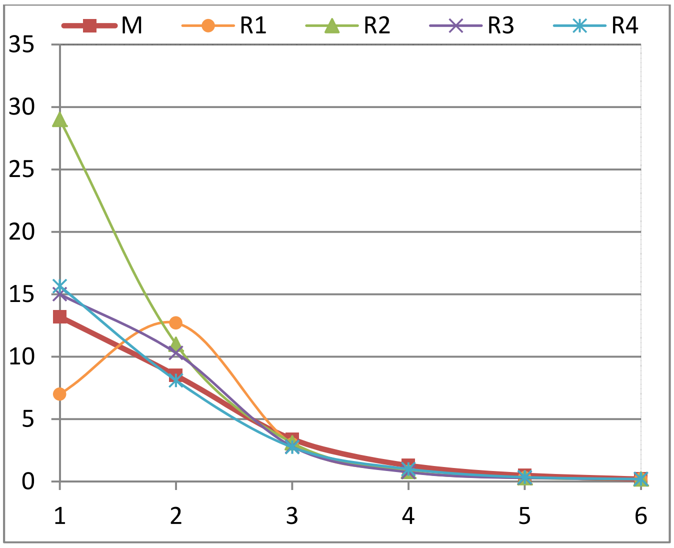


Fig 13 – Relux, Room 2 white version

Fig 14 - Difference

Results close to window are inconsistent. Other than that, the four versions of Relux parameters gives about the same result, except for R1, that deviates considerably more from the benchmark than the others. In general all versions produce surprisingly conservative results in this case when compared to the benchmark, and the difference increases the further away from the window we measure, ending up with -42 % for R4 and with -60% for R1.



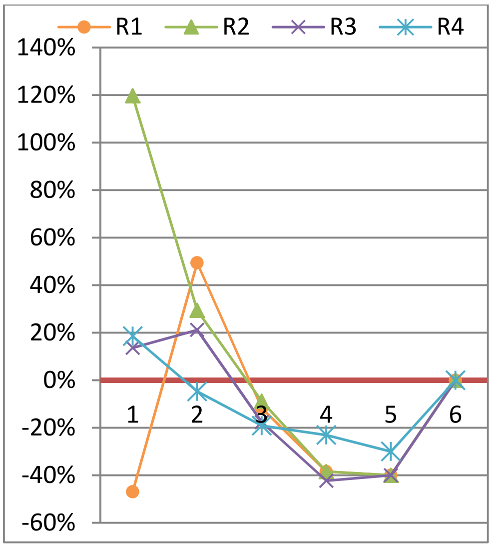
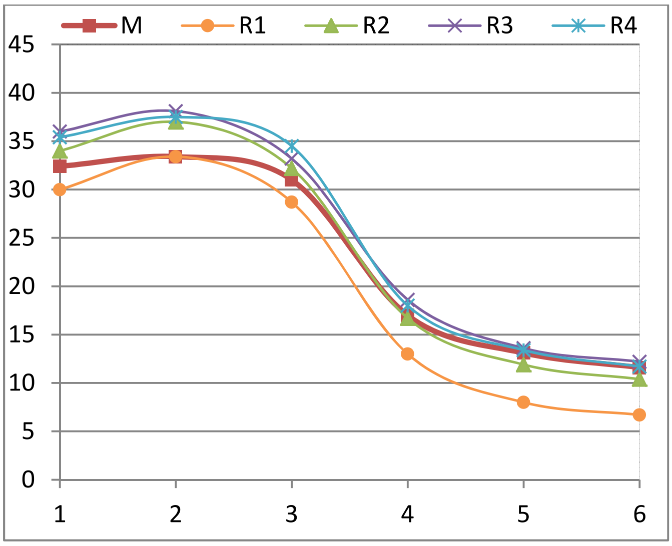


Fig 15 Relux, Room 2 black version

Fig 16 - Differene

In the black version of room 2 the results are very inconsistent by the window with R2 creating most deviations, in the long distance from the window the discrepancy up to -40% was found. R4 appeared to be the most accurate of the four.

Room 3 comparison between Relux parameters



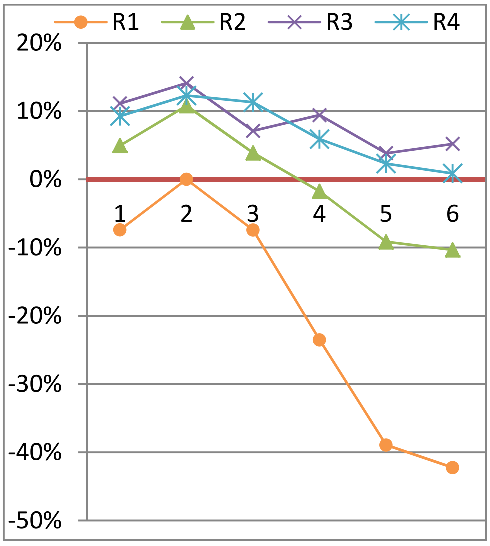
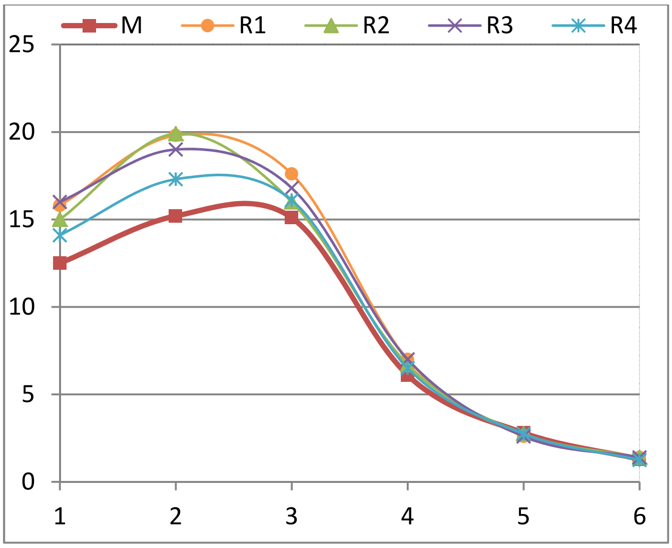


Fig 17 - Relux Room 3 white version

Fig 18 Difference

The white version of Room 3 shows slightly optimistic results for all Relux alternatives, except for R1 that has deviations down to -42%. All other Relux alternatives (besides R1) show deviations up to +-12%.



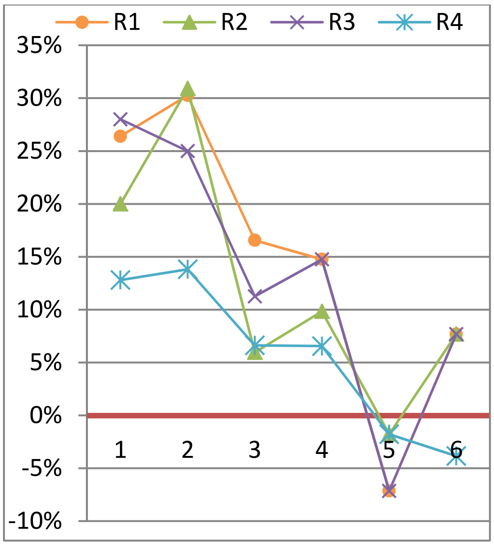
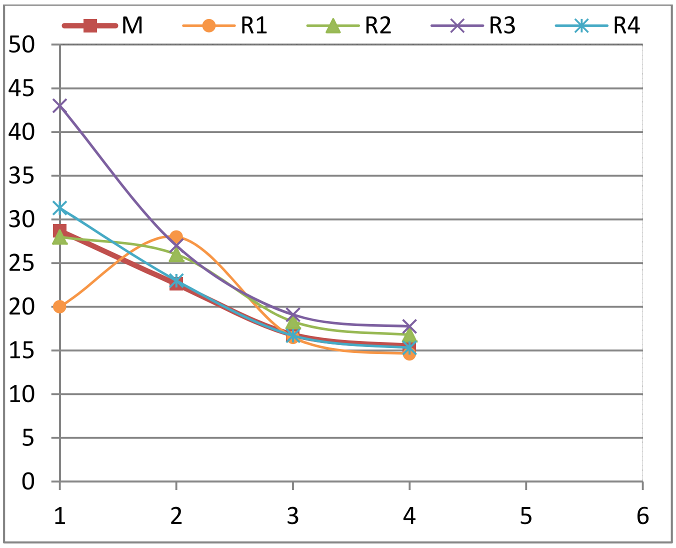


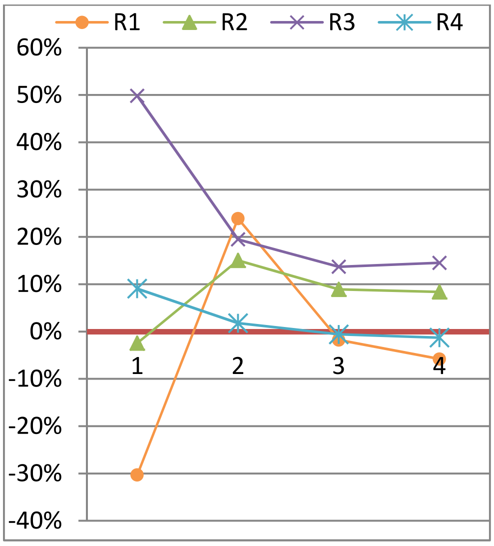
Fig 19 - Relux Room 3 black version

Fig 20 - Difference

For the black alternative the deviations are considerably higher for R1, R2 and R3, leaving R4 as the only acceptable alternative.

Room 4 comparison between Relux parameters

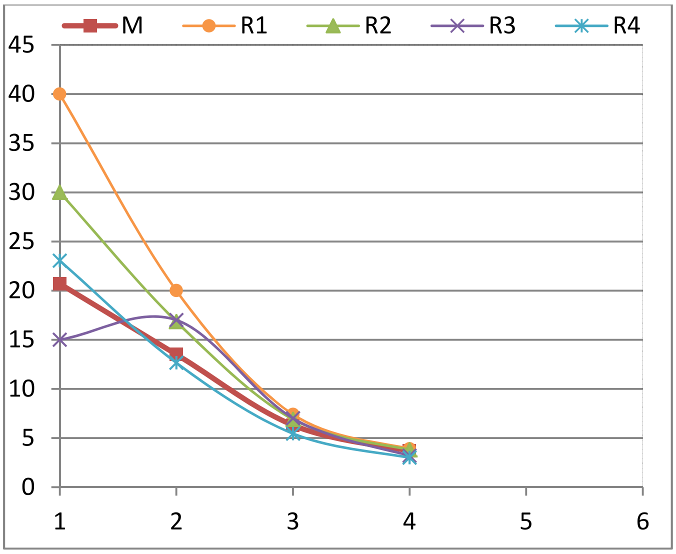




Fiog 21 - Relux Room 4 white version

Fig 22 - Difference

As in all other rooms, the results close to the window are inconsistent. When considering measuring points 2, 3 and 4, R4 shows the best results with deviations below 5%. R1 and R3 deviates with about 20% while R2 deviates with over 10%.



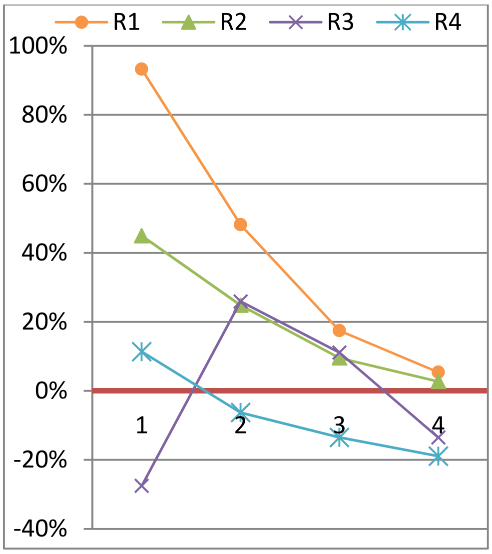
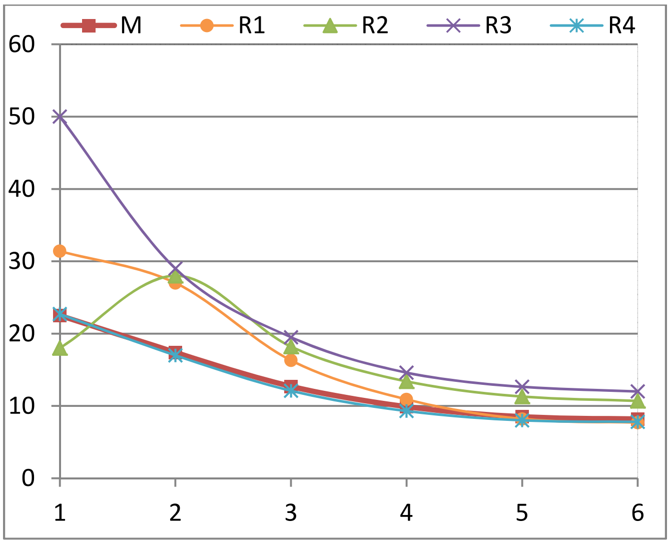


Fig 23 - Relux Room 4 black version

Fig 24 - Difference

The results for the black room are even less accurate than the ones for the white alternative, and no alternative is within the threshold of acceptable results for measuring points 2- 4.

Room 5 comparison between Relux parameters



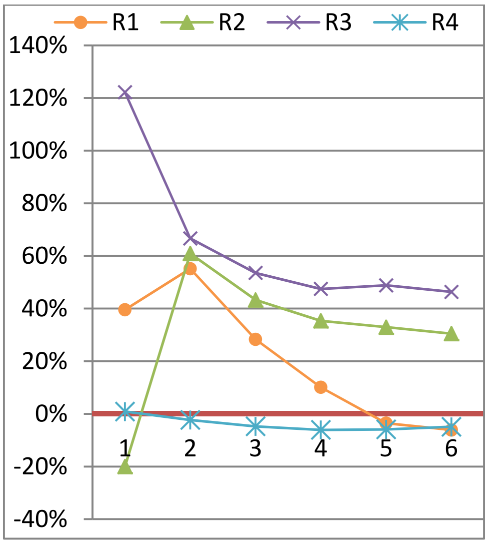
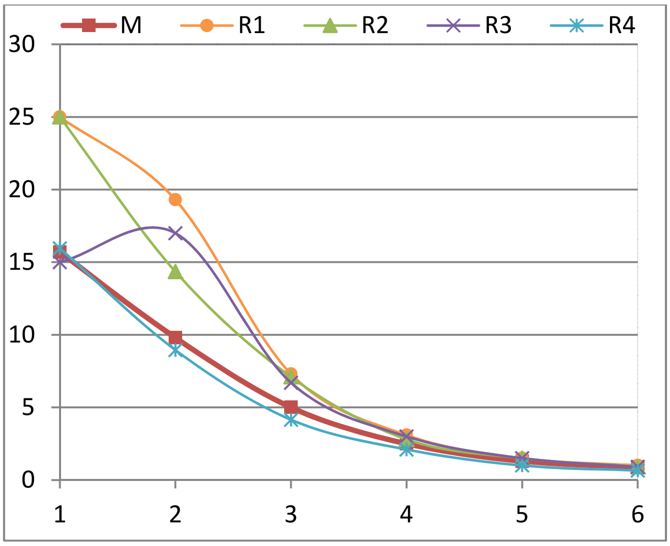


Fig 25 - Relux Room 5 white version

Fig 26 - Difference

For the white version of this room, R4 shows very precise results, with no more than a 5% difference compared to the model measurements. The other parameter settings show dewiations mostly around 40%, and are not within acceptable threshold deviations.



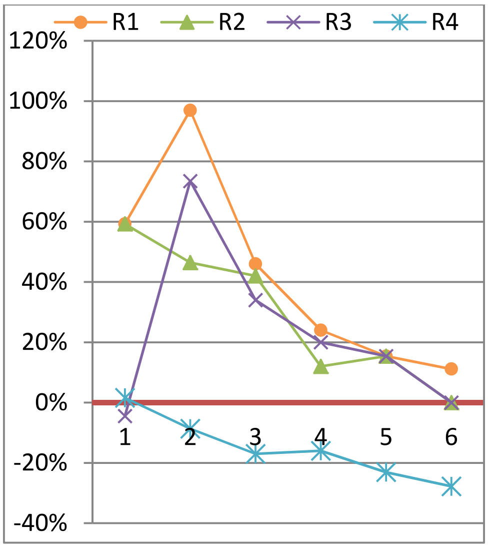


Fig 27 - Relux Room 5 black version

Fig 28 - Difference

For the black version of this room the results vary even more than for the white. Although, as with the others, results are seemingly similar deep into the room, as can be seen on the graph to the left, the deviations for the respective alternatives are +-20% at measuring points 4-6.

4 DISCUSSION of results from Relux

In general, the result in the front of the room seem to be inconsistent, as the "precalculate windows" setting distorts the results closest to the window. Only R4 has this setting turned off, as it is standard with "non-expert" settings. The window in our rooms is too large compared to the measured area to use the precalculate option in Relux. Relux states in their manual Fit for Raytracing (Relux AB 2011) that

"[…]here the precalculation would produce a very high number of virtual window light sources, resulting in extreme calculation times. So it is reasonable to deactivate the precalculatiuon in these cases. This is justified, because the big window openings guarantee that a lot of the indirect sample rays can leave the scene and thus the incoming daylight can be captured well also by the standard indirect calculation algorithm."

The figures below illustrate the difference between a calculation with and without "precalculate windows" in the case of room 1.

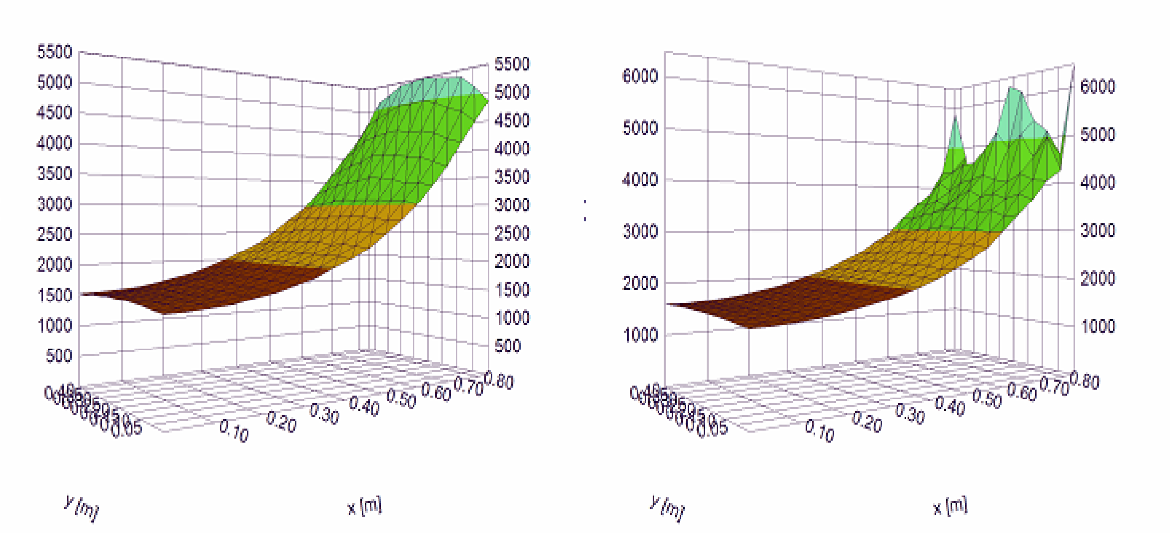


Fig 29 - The 3D mountain plot of the illuminance, left without precalculate windows activated, right with precalculate windows activated

Results in the black alternatives of the rooms are inconsistent, especially in the rear part of the rooms. The difference in for example the black alternative of Room 1, where R4 is 30% lower than the benchmark in fact represents a difference of 0,25% percent points (1%-0,75%). When daylight levels are this low, the sources of error become more evident, as rounding of decimals can result in a big deviance when calculating difference. That being said, calculating daylight values below 1% is very common, and relevant for daylight calculations in practice.

Through all rooms and all alternatives, R4 gives the most consistent results close to the window. This is likely unique for these rooms, as they have relatively large windows compared to the size of the room. In the rear part of the room R4 gives the results closest to benchmark in all white rooms, while it is hard to find the same tendency in the black rooms.

The most surprising results were found for Room 2, where even the R4 gave up to -40% difference in white version and up to -25% difference in the black room.

5 METHOD Ecotect/Desktop Radiance

Ecotect offers the possibility to perform daylight calculations in interaction with Desktop Radiance, an old version of Radiance for Windows. Desktop Radiance is an out-dated version of Radiance for Windows and has not been updated since 2002 while Radiance has undergone constant updates and improvements. However, the interaction between Ecotect and newer Radiance versions does not work seamlessly and requires interrupting the automated process and making informed changes to the .bat-script (a script automating calculations). Normal users of Ecotect are therefore forced to use the out-dated Desktop Radiance.

Ecotect generates the Radiance scene description files (.rad-files) for both the model and the sky containing materials and geometry, a Radiance input file (.rif-file) with instructions to "rad", as well as a script (.bat-file) automating the further process. Firstly, the Radiance module "rad" is called to render the Radiance scene and to produce a Radiance high dynamic range (HDR) HDR-image (.pic- resp. .hdr-file). Secondly, the Radiance module "rtrace" is called to perform daylight calculations for the measuring points in the sensor point file (.pts-file, also created by Ecotect). The result file with the RGB-values of illuminances (.dat-file) is renamed to an .ok-file and the HDR-image is opened in the Ecotect-own viewer for HDR-images. Thereafter, Ecotect offers to import the .ok-file into the "Analysis Grid" module.

Modelling in Ecotect/Desktop Radiance

All rooms and variants were modelled using the easy-to-use modelling tools in Ecotect. Materials fitting the measured reflectances were assigned to the surfaces. Sensor points were defined in the analysis grid. The export was initiated and the files described above were generated.

Parameters in Ecotect/Desktop Radiance

The simulations were performed pretending a 'normal Ecotect-user' without expert knowledge about the underlying Radiance routines has been given the task to do the simulations, letting the automated process do the job. However, the process needed to be interrupted and the sky description was replaced by a prepared .rad-file matching the ground reflectance in the lab. This was necessary to achieve comparable results. Then, the .bat-file was commenced and the automated process continued.

Parameter settings for export to Desktop Radiance are limited to the settings in the .rif-file to "rad": VARIABILITY, DETAIL, QUALITY can be set to "low", "medium", "high". In addition, the number of ambient bounces can be edited. The Ecotect export wizard proposes however a value dependent on the chosen parameters to "rad". For the simulations variability, detail, and quality were set to "high", and the ambient bounces set to 8.

In order to produce the HDR-image, "rad" requires a camera and a view. If selected in the Ecotect export wizard, the current view in Ecotect is used (often with an outdoor viewpoint). If not, arbitrary camera settings are chosen during the export (usually a perspective with narrow angle along the x-axis looking 'west'). Experience has shown that this position has influence on the result. In order to simulate a 'normal user' who is usually not aware of this issue, a camera was not consciously placed in Ecotect.

The parameters to "rtrace" calculating the sensor values are fixed and are given in the .bat-file (and could be overwritten there); they and are presented in table 4. Note: the ambient values –av increasing the general lighting levels by defaults by 1%.

Simulations in Radiance had to be run twice. Firstly, a set of fixed parameters ("flags") to "rtrace" was used assuming these as sufficient for high precision. A second run following the (correct) iterative process of developing the settings until unchanging results are achieved showed that the settings in the first run were insufficient for the white models. This was in particular true for the number of ambient bounces, set to 8 in the first run, which needed to be minimum 10. Unfortunately, the second run could not be carried out with Ecotect/Radiance because no pc with the Desktop/Radiance was accessible at that moment. **Therefore, all Ecotect/Desktop Radiance simulations are run with 8 ambient bounces only.**

Fig 30 and 31 show exemplary for Room 2 the deviations between Ecotect/Desktop Radiance with 8 ambient bounces and Radiance with 8 or 10 ambient bounces.

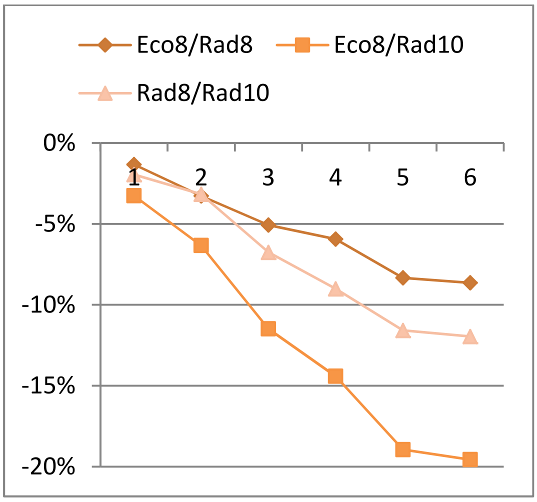


Fig 30 – Deviations for Room 2, white

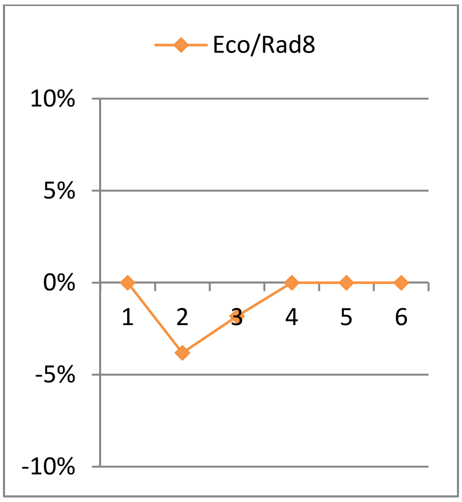


Fig 31 – Deviations for Room 2, black

Fig 30 shows error increasing for Ecotect/Radiance until of ca. 10% in point 6 compared with Radiance with –ab 8. It can be assumed that Ecotect/Desktop radiance with –ab 10 might also be 10% lower for the white rooms. In case of the black rooms Radiance and Ecotect/Desktop Radiance show no relevant difference.

6 METHOD Radiance

Radiance is a suite for analysis and visualisation of lighting. Based on UNIX philosophy it has a modular structure of many individual programs/commands allowing high flexibility at the cost of a steep learning curve. Radiance is command line-based and programs can only be commenced via a terminal. Radiance 4.2 was used for simulations.

Radiance takes the scene input (text files with descriptions of geometry, materials, light sources, including the sky) and compiles it into a binary octree. The octree is then simulated using a stochastic backward-raytracing method. Output can be images or data. HDR-images are created using "rpict", while "rtrace" is commonly used for numerical data output such as illuminance or luminance values, as is the case in this study. The output can be post-processed with third party software or with other Radiance tools e.g. "falscolor" to generate false colour-images.

Modelling in Radiance

Instead of using the text-based modelling facilities in Radiance, the geometry .rad-files from the Ecotect/Desktop Radiance simulations were reused and the material descriptions were corrected to the correct values from the measurements. In addition to the "plastic" materials, a "mirror" material was used for the top of the light shelf in Room 5.

Parameters in Radiance

Table 4 lists the parameters for both runs that had to be performed.

The influence of flags for "rtrace" was investigated in depth for the white and black model of Room 1. As simulations were conducted under overcast sky, main focus was on the "ambient" parameters for the diffuse indirect component of light. It was found during the second run that the underestimation of results in the white models was primarily linked to the –ab flag for ambient bounces as the illuminance readings of sensors deeper into the room strongly dependent on the internal reflections inside the models. Changes in other parameters showed minor, but supplementary effect.

Table 4- parameters in simulations with Ecotect/Desktop Radiance and Radiance

	Ecotect/Desktop Radiance	**Radiance**	
	1st run, black & white models	*1st run, black & white models*	*2nd run, only white models*
Ambient			
-ab	8	8	10
-ad	512	2048	2048
-as	256	1024	1024
-ar	32	500	256*
-aa	0.1	0.1	0.1*
-av	0.01 0.01 0.01	0 0 0*	0 0 0*
Direct			
-dt	0.05	0.03*	0
-dc	0.75	0.75*	0.75*
-ds	0.2	0.2*	0.1
-dr	3	3	2*
-dp	2048	2048	512*
Limiting			
-lr	12	-12	-10*
-lw	0.0005	0.0005	0.002*

* .. defaults of "rtrace" in Radiance 4.2

In black rooms the unusual high value of ambient bounces was unnecessary. As the results were already at hand, the results from the first run were used. The comparison with the determined parameters for the white models shows that some parameters are set too excessive and could have been optimised for the sake of simulation time.

At the beginning of the second run some simulations were first passed through "mkillum" (known as "window pre-calculation" in Relux) before commencing "rtrace". However, also here changes of the –ab flag were overruling the results.

7 RESULTS of Relux, Ecotect/Radiance, Radiance measurements

The following pages show the results of the daylight factor calculations done with the four different simulation programs as compared to the benchmark, that is, scale model measurements. As it was the most promising the Relux alternative, R4 is included in all following graphs to represent Relux.

Room 1 comparison between Model, Radiance, Ecotect/Desktop Radiance and Relux

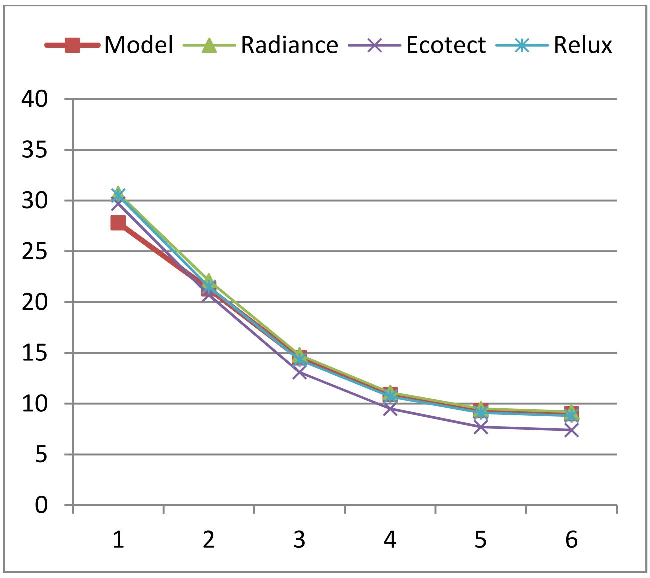


Fig 32 - Room 1 white version

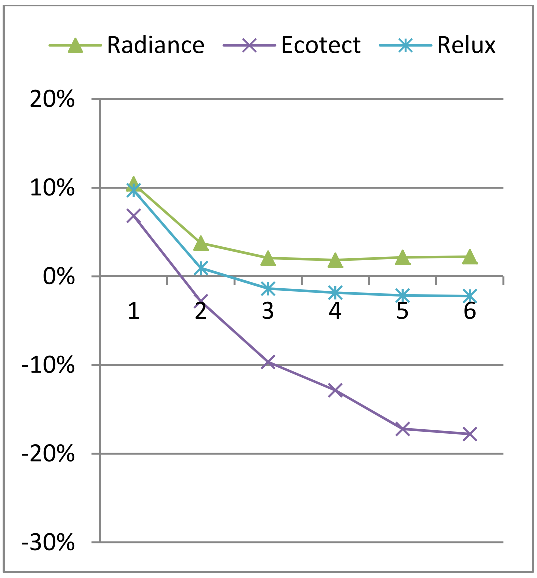


Fig 33 – Difference from benchmark

For all simulation programs, the result is up to 10% higher than the benchmark in the point 1 close to the window. From here the results of Radiance and Relux correspond closely to measurements with a deviation around 2%. Ecotect deviates with up to -18% in the back of the room.

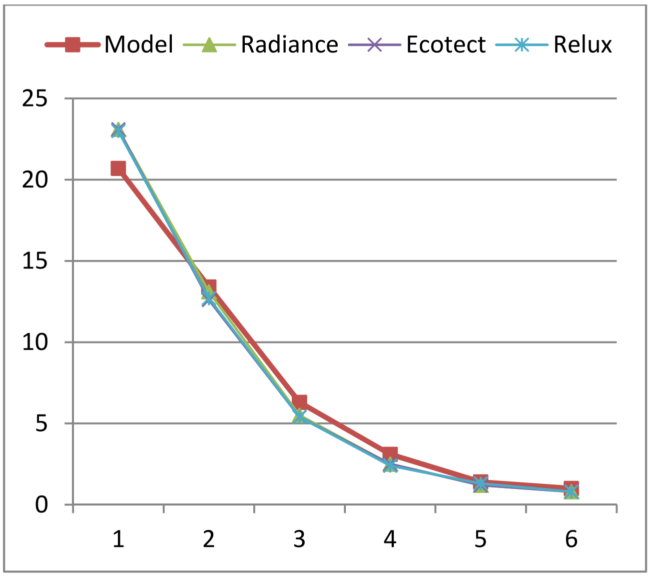


Fig 34 - Room 1 black version

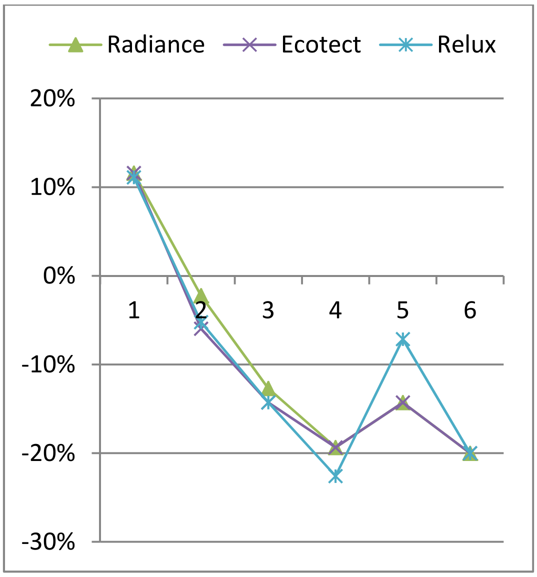


Fig 35 – Difference from benchmark

In the black version of the Room 1 all three simulation programs show converging results. Also here, the results close to the window are about 10% higher than the benchmark. From there the results become more conservative, and are 10 to 20% lower than the benchmark in the back of the room. However, it must be noted that a difference of 20% between Relux and the benchmark in points 4 and 6 represents only a difference of 0,2% DF between the scale model (1,0% DF) and Relux (0,80% DF).

Room 2 comparison between Model, Radiance, Ecotect/Desktop Radiance and Relux

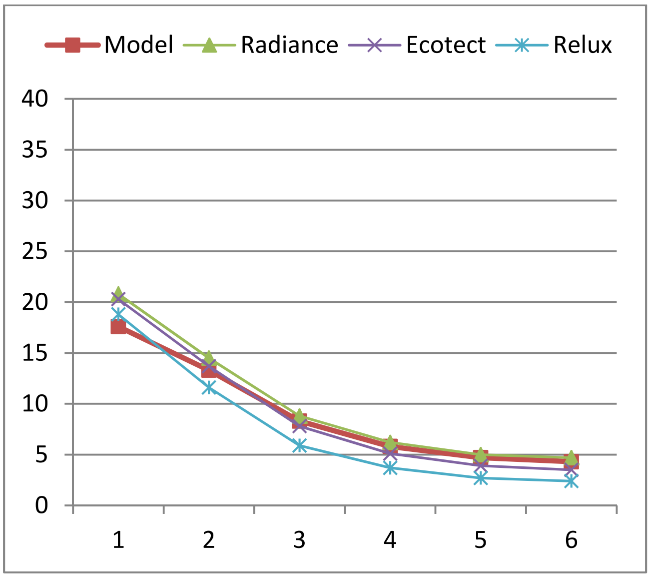


Figure 36 - Room 2 white version

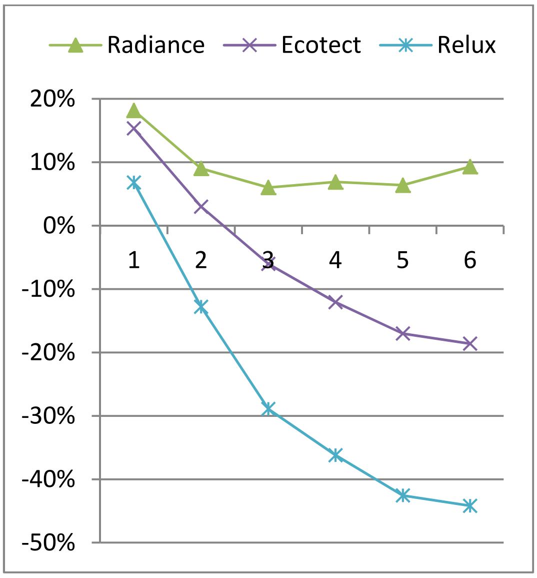


Fig 37 – Difference to benchmark

All simulations show again higher values near the glass. Opposite to Room 1, Relux produces results that deviate by up to -44% from the benchmark. Deeper into the room Radiance produces results well within the 10% error threshold, ca. 7% above the benchmark, while Ecotect deviates by up to -19%.

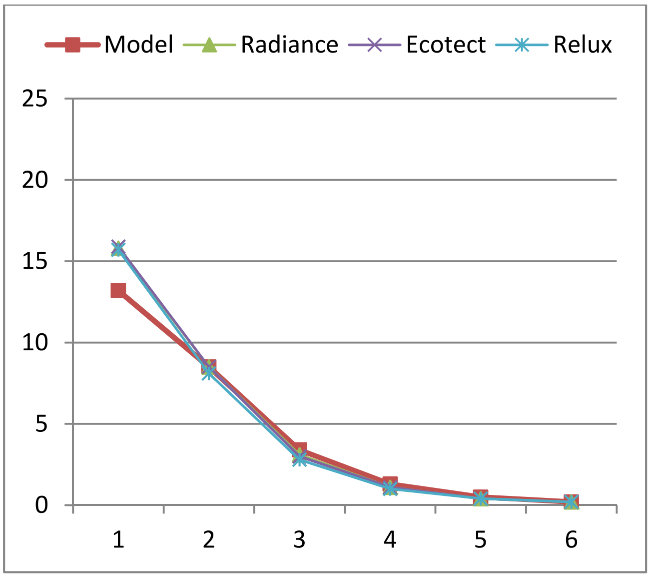


Fig 38 - Room 2 black version

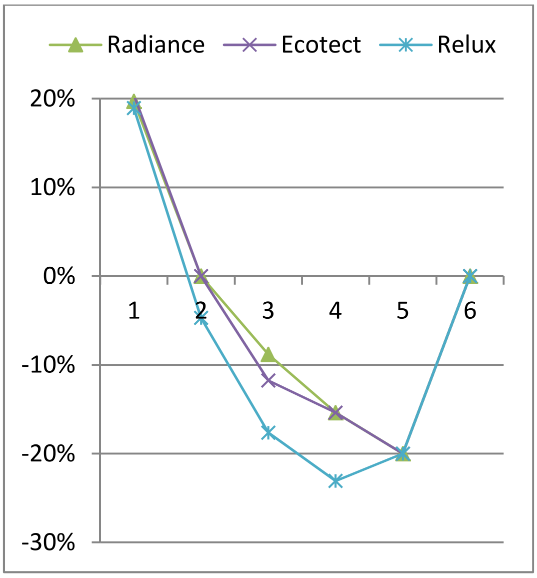


Fig 39 – Difference to benchmark

Also in the black version of Room 2, the three simulation programs follow the same trend, with Relux being somewhat more conservative than the other two. A deviation of Relux about 20% in points 3-5 represents a difference between DF=1,0% in model vs. DF=0,8% in Relux.

Room 3 comparison between Model, Radiance, Ecotect and Relux

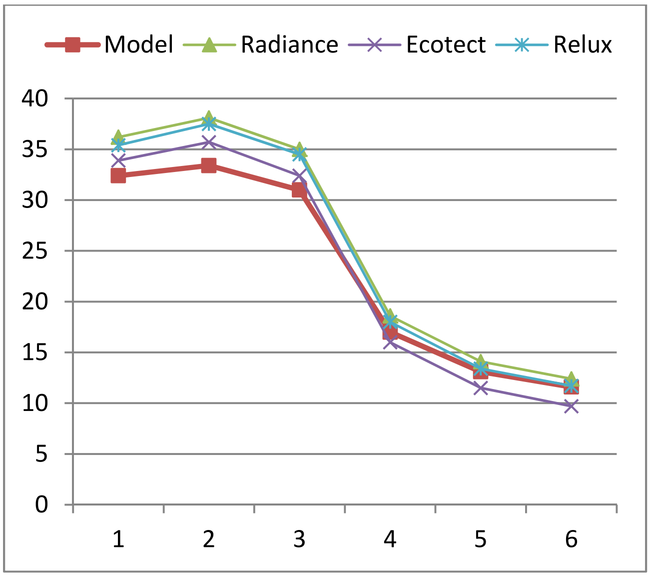


Fig 40 - Room 3 white version

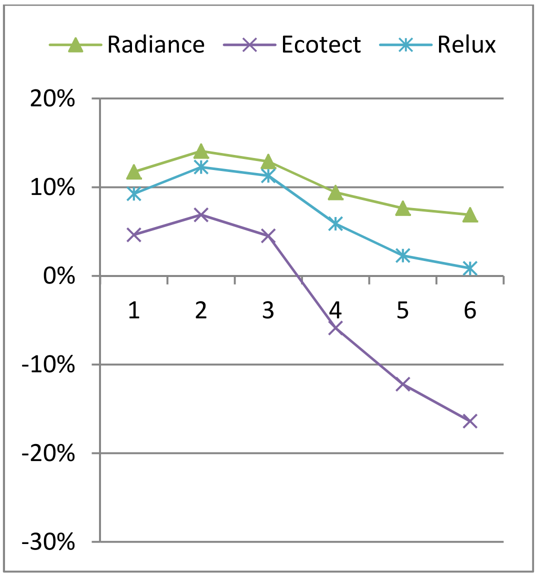


Fig 41 – Difference to benchmark

As with Room 1 and 2, Room 3 shows that results close to the window are about 10% higher than benchmark. Given that the window in this case is a skylight, more measuring points are affected by this (point 1-3). Otherwise, results are within error threshold of 10%, except for the points 5 and 6 of Ecotect.

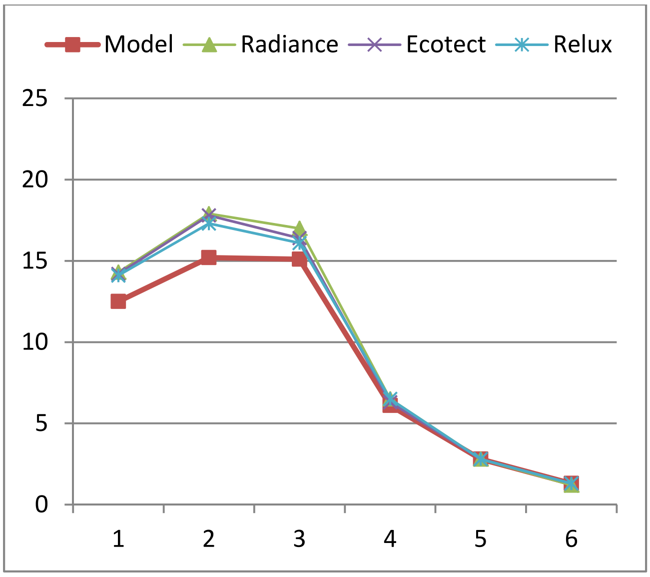


Fig 42 - Room 3 black version

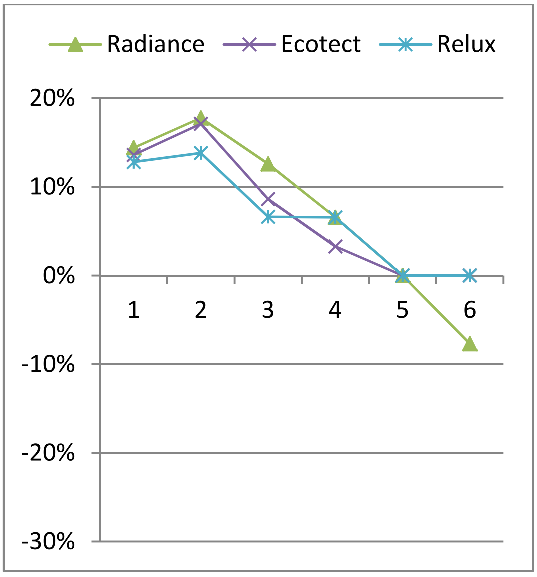


Fig 43 – Difference to benchmark

A similar tendency is found in the black version. Results from the simulation programs under the skylight are higher than the benchmark.

Room 4 comparison between Model, Radiance, Ecotect and Relux

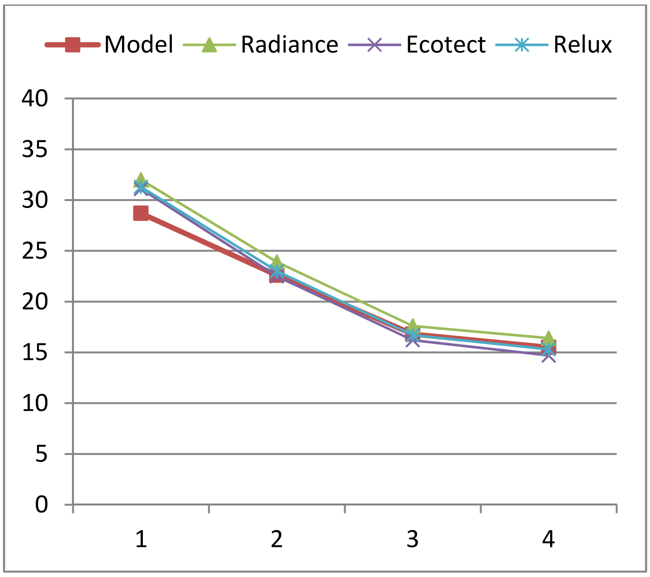


Fig 44 - Room 4 white version

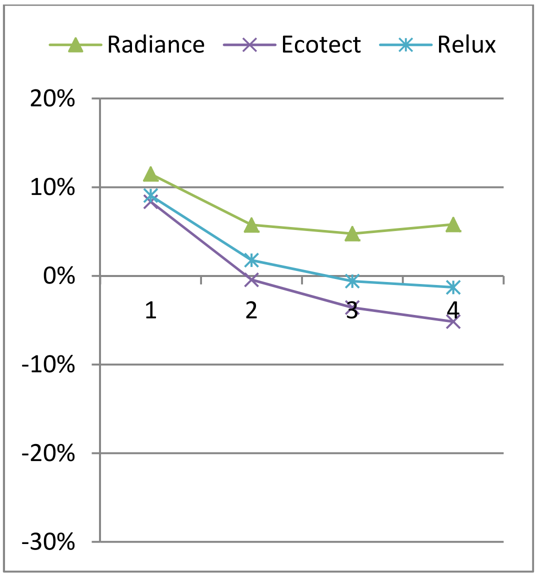


Fig 45 – Difference to benchmark

Room 4 in white version behaves similarly to the Room 1. No deviation larger than 10% was found, something that could be expected as this room is shallower than Room 1 and the strong deviations in Room 1 were found in rear part of the room.

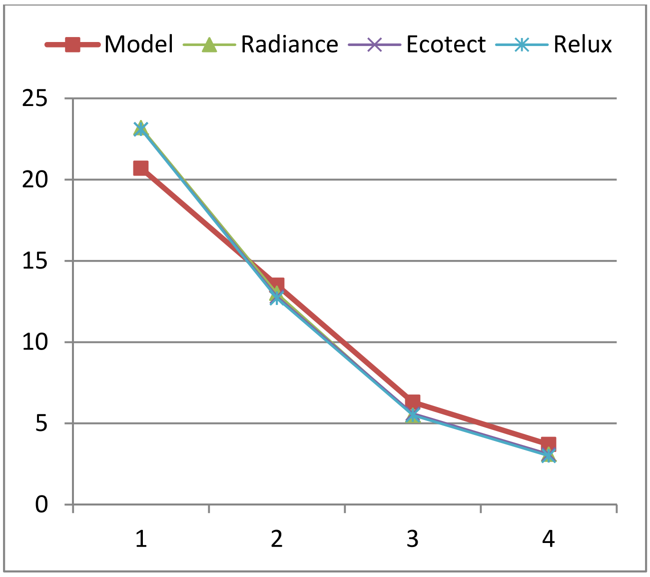


Fig 46 - Room 4 black version

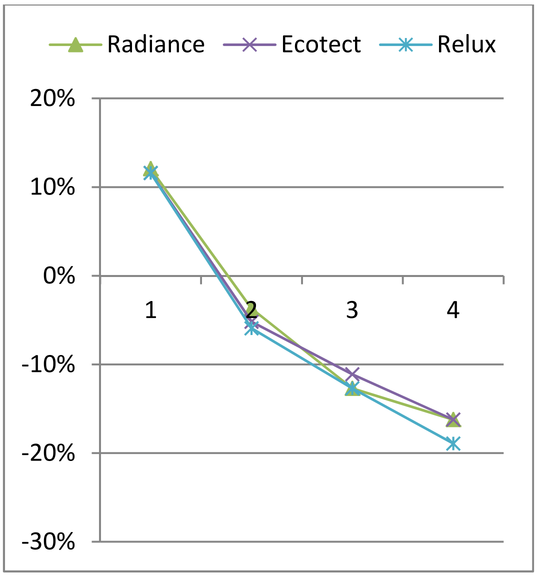


Fig 47 – Difference to benchmark

The black version of Room 4 behaves similarly to the white version, and as we can see, the deviations get larger the further from the window we measure. All simulation programs behave in a similar manner. Deviations of up to -20% can be found.

Room 5 comparison between Model, Radiance, Ecotect and Relux

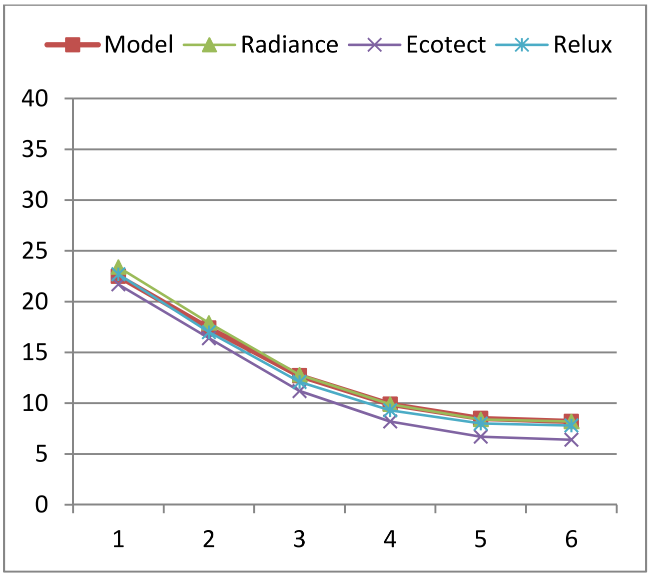


Fig 48 - Room 5 white version daylight factor

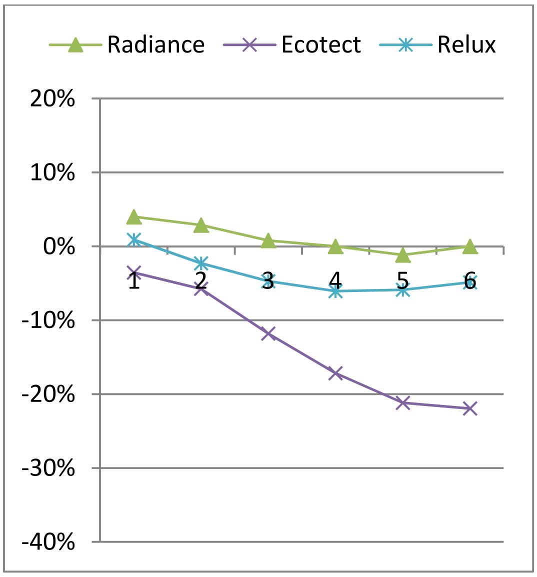


Fig 49 – Difference to benchmark

The Room 5 has exactly the same dimensions as Room 1, but a mirrored light-shelf is situated outside the window. The lower results compared to Room 1 confirm that the light shelf has no positive effect on the light level under overcast conditions. Relux and Radiance produce results very close to the measured values while Ecotect produces results exceeding -20%.

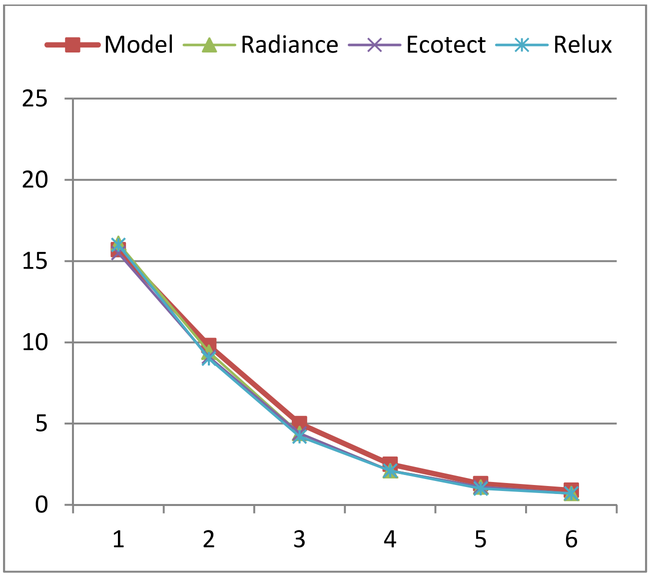


Fig 50 - Room 5 black version daylight factor

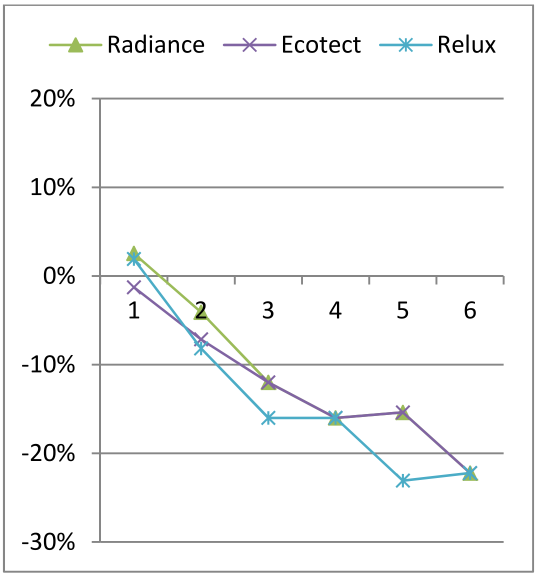


Fig 51 – Difference to benchmark

Also the black version of Room 5 performs similarly to the black version of Room 1. All programs show similar deviations to -22% in the rear part of the room.

Tables 5 and 6 summarise the deviations for the evaluated rooms.

	Relux (R4)		Radiance		Ecotect	
	White	Black	White	Black	White	B Black
Room 1	+9,7%	-22,6%	+10,4%	-20,0%	-17,8%	-20,0%
Room 2	-44,2%	-23,1%	+18,2%	-20,0%	-18,6%	+20,5%
Room 3	+12,3%	+13,8%	+14,1%	+17,8%	-16,4%	+17,1%
Room 4	+9,1%	-18,9%	+11,5%	-16,2%	+8,4%	-16,2%
Room 5	-6,1%	-23,1%	+4,0%	-22,2%	-22,0%	-22,2%

Table 5. The MAXIMUM differences between the calculated and the measured values.

All tools share the same pattern of underestimating the illuminance in black rooms. The overestimations of about +10% in all simulation tools are usually found near the glass for both the white and the black room. The highest over- and underestimation was found for Room 2 and Relux.

	Relux (R4)		Radiance		Ecotect	
	White	Black	White	Black	White	B Black
Room 1	-1,6%	-10,7%	+2,2%	-13,5%	-11,2%	-14,3%
Room 2	-32,6%	-11,2%	+8,0%	-4,4%	-9,0%	-5,9%
Room 3	+7,6%	+6,6%	+10,6%	+9,6%	-0,7%	+5,9%
Room 4	+0,6%	-9,3%	+5,8%	-8,2%	-2,0%	-8,1%
Room 5	-4,8%	-16,0%	+0,4%	-13,7%	-14,5%	-13,7%

Table 6. The MEDIAN differences between the calculated and the measured values.

Despite the glitch in Room 2, Relux shows very good agreement with the benchmark for the white cases. Radiance shows also very good agreement with often less than 5% error, however also higher overestimations. The underestimations in Ecotect/Desktop Radiance in the white models are allocated deeper into the rooms and are linked to the missing ambient bounces.

8 DISCUSSION of results model vs Relux vs Ecotect/Desktop Radiance vs Radiance

The studied rooms are designed to represent the extreme cases regarding room surface reflectance, namely black with practically none reflectance and white with very high reflectance of 88%. In normal simulations situations, the average reflectance of internal surfaces of rooms is usually around 50%.

The black version of rooms was created to test how well the respective programs calculate the 'direct component' of daylight factor that is the light from the sky. The reflectance of all opaque surfaces in black rooms was as low as it was practically possible, only 2,5%. In such a case it is reasonable to neglect the reflected light and identify the light in black rooms exclusively as the 'direct' light from the sky. The results show that all programs generate significant differences to the benchmark. The results show that the difference increases further away from the glazed façade and an underestimation of around 20% have to be expected. However, the DF-values in question are very small and the differences are often less than 0,25% DF. It should also be considered that the scale model measurements in black rooms were more challenging than in white rooms and some errors may be imbued in the measurement results as well.

In the white version of rooms the daylight factor depends on both, the 'direct' component and the 'internally reflected' component of light. The importance of those two components changes with the distance from the window. By comparing the values of daylight factor in the respective points in the white and black versions of Room 1, we find that the internally reflected component (in white room) is rather stable around 8%, while the direct component decreases dramatically from about 20% in point 1 to 1% in point 6. The result is the dramatic decreasing of daylight factor from about 28% to about 9%.

It is also interesting to look closer at the point 1 situated very close to the window. All simulations in all rooms produce results that are about 10% higher than the benchmark. In practice, the area up to 0,5m from all walls is disregarded from the calculation, and also this measuring point would be disregarded, especially if the model represents a room of small dimensions (a one-person office room). The optimistic results for Room 3 may also be the consequence of large glass area in this room.

The differences between the programs are more evident in the white rooms than in the black rooms. Considering that all the programs used in this study are based on Radiance algorithms the importance of the right choice of parameters becomes obvious.

Fig 52 illustrates the influence of the parameter called either inter-reflections, internal reflections or ambient bounces on results. For the purpose of testing when the inter-reflections stabilized in the white and black room, a measuring point in row 6 was chosen in room 1. Model X : Reflectance 88% (white model), Model Z: Reflectance 2% (black model) while Model Y is a model with reflectance 20% floor, 50% walls 70% ceiling. The Y-axis represents daylight factor, and the X-axis represents the number of inter-reflections set in the parameters of the calculation.

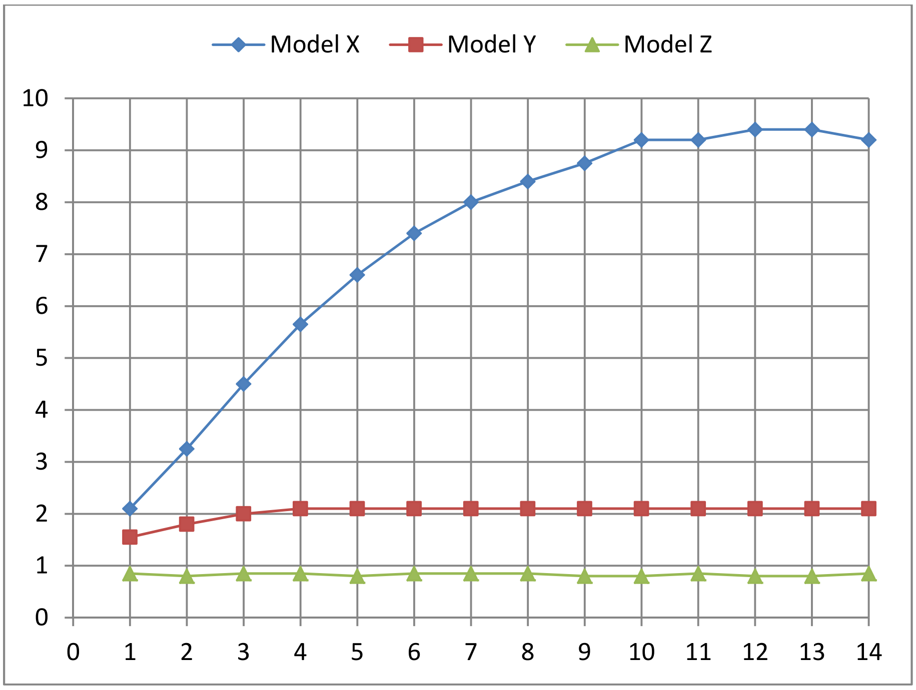


Fig 52 – Inter-reflections in different reflectance-models.

The graph shows that at least 10 inter-reflections are necessary for a white model, 3 inter reflections are sufficient for a "standard" model, while 1 is adequate for the black model. In the black room the parameter has little influence as the black wall absorbs most of the light. This means that the direct component of the sky is the main parameter, and therefore all three simulation programs behave similarly in the black room.

9 CONCLUSIONS

In white rooms without outside obstructions all the examined programs produced results very similar to each other and to the benchmark, only small differences were noticed; average differences were lot below 15%, table 6. Ecotect/Desktop Radiance delivered the largest differences in this group of rooms, something that can be explained by the lower number of inter-reflections (8 vs 10 in Radiance).

In black rooms a larger differences in between programs and between programs and benchmark were found, the maximum differences for single points exceeded 20%; but we should remember that it concern very small numbers, less than 1% DF; the difference of 20% means just 0,2%DF.

In cases where an outside obstruction is situated in front of the window, i.e. significant ‘outside reflected component’ is present, Relux program performs worst, creating even -44% maximum difference in a single point, table 5, and about 30% average difference, comparing to the benchmark. The maximum difference for Radiance and Ecotect was up to +/-20% and the average difference was below 10%.

The setting of one of the important parameters, "inter-reflections" in Relux, "ambient bounces" in Radiance, depends on the room reflectance’s; about 10 inter-reflections are needed for a white room; about 3 inter reflections for a “standard” room, while 1 is enough for the black room, figure 52. Another factor is the “precalculate windows” setting that distorts the results closest to the window, in the case of large windows, as was the case in the present study, it is recommended to turn it off.

The daylight factor calculated for a white room in Relux can differ up to -40%, depending on how the parameters are set, even within the values recommended in the manual, as we can see in the graph of Relux comparisons in Room 1, figures 9 and 10. In general, the Relux results close to the window seem to be inconsistent, as the “precalculate windows” setting distorts the results closest to the window. Only R4 has this setting turned off, as it is standard with “non-expert” settings, figure 29.

Relux, Radiance and Ecotect behave similarly in both reflectance variants, the white room and the black room, given that the parameters are set optimally when considering the room characteristics.

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